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Invited papers and selected continuing education lectures

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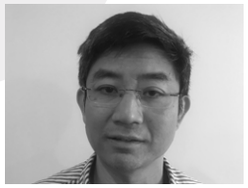

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Preface

It is with pride and gratitude that we present the 2025 edition of *Australasian Anaesthesia.*

This publication represents the collective effort, expertise, and dedication of a remarkable group of editors, authors, and contributors. To all those who have shared their time, knowledge, and insights to bring this edition to life, I extend my sincerest thanks. Your commitment to advancing our field and sharing your experiences is what makes this publication such a valuable resource for anaesthetists across Australasia and beyond.

The past two years, from 2023 to 2025, have been a challenging yet transformative time for healthcare. We have faced ongoing repercussions from the pandemic era, including system pressures, staffing shortages, and increasing demands on our workforce. In parallel, we have witnessed rapid advancements in medical technology, data integration, and patient-centred care. These challenges have tested our resilience and adaptability, but they have also underscored the incredible strength of our community. Through these trials, the field of anaesthesia has continued to evolve, demonstrating its ability to adapt, innovate, and lead.

One of the most rewarding aspects of our specialty is the diversity of experience and expertise we bring to the table. Anaesthesia is not just about technical proficiency; it is about understanding the nuances of care across a broad range of clinical contexts. Whether in operating theatres, intensive care units, pain clinics, or retrieval and disaster medicine, anaesthetists serve as both clinicians and collaborators. Each of us brings a unique perspective, and it is this breadth of knowledge and experience that enriches our practice and enables us to navigate the complexities of modern healthcare.

In recent years, our role has continued to expand beyond the operating theatre. We are increasingly becoming stewards of the entire perioperative journey, offering leadership in prehabilitation, risk stratification, and postoperative recovery. This shift has opened up exciting new areas of research, innovation, and education. It is a reminder of the dynamic nature of anaesthesia and the endless opportunities for growth within our specialty.

As I reflect on the incredible contributions to this edition, I am struck by how fortunate I am to work alongside such talented, inspiring, and generous colleagues. The commitment to excellence and the willingness to share knowledge within our community are truly humbling. It is this collective spirit that not only drives the success of this publication but also ensures the continued advancement of anaesthesia as a specialty.

The team at *Australasian Anaesthesia* is a diverse and dedicated group. Without their help, the quality and consistency of this publication would not be possible. There is a long list of names that deserve thanks, but I would like to acknowledge and welcome Greer Sutherland to our team for the 2025 edition. She's brought a wealth of knowledge and professionalism that has already led to a breadth of amazing changes.

Thank you for joining us on this journey, and I hope you find this edition as thought-provoking as I do.

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B-lines and beyond: Lung ultrasound for the perioperative clinician

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Edited by Dr Alex Yartsev

INTRODUCTION

Severe perioperative hypoxaemia, defined as a SpO_2 ≤ 85% for two minutes or longer, is a relatively common event, occurring in 3.5% of patients in one study,[1] with potential significant harm to the patient. In order to narrow the differential diagnosis of hypoxaemia and target treatment, the perioperative physician often relies on clinical suspicion, examination and chest radiography (CXR). However, clinical examination, including lung auscultation[2,3] and fluid status assessment,[4,5,6] has high inter-operator variability. CXR has limitations, including the logistics, poor sensitivity to early changes, and inter-operator interpretation at the point of care.[7] Finally, empirical management, such as increasing positive pressure ventilation or diuresis, may pose potential harm to patients.

Initially, lung ultrasound (LUS) was thought to be infeasible due to air in the lungs obstructing the passage of ultrasonic waves. However, in the 1990s, Dr Daniel A Lichtenstein uncovered multiple artefacts consistently associated with specific conditions, the interpretation of which forms the basis of LUS today. This led to the development of the original point-of-care LUS protocol: "Bedside Lung Ultrasound in Emergency (BLUE)".[8]

LUS utilises a rapid, easily accessible point-of-care tool to aid in perioperative decision-making. LUS can assist in the evaluation of pneumothorax, pneumonia, pulmonary oedema, atelectasis, and other common causes of severe perioperative hypoxaemia or any perioperative respiratory distress. Newer protocols, such as eFAST[9] and RUSH,[10] have been widely embraced in intensive care and emergency departments to approach ultrasound scanning systematically, with resultant high inter-operator agreement and reproducibility. Small studies show LUS changes physicians' management plans,[11,12] reduces IV fluid administration, and improves mortality.[13] However, LUS has experienced limited exposure in the perioperative environment due to a lack of formal training, variable expertise and operator dependence,[14] inconsistent access to ultrasound machines, perceived limited utility, and operational constraints. Therefore, this article aims to familiarise clinicians with the basis of LUS physics, findings and interpretation, through a recommended protocol.

LUS VERSUS CONVENTIONAL RADIOGRAPHY: CHEST X-RAY (CXR) AND COMPUTED TOMOGRAPHY (CT)

All three imaging modalities (LUS, CT and CXR) provide valuable information regarding lung fields and pathologic conditions. LUS and CXR are both available as point-of-care modalities, eliminating the need for patient transport; the technologies are widely accessible, and images are retrieved easily. However, LUS and CT differ significantly. Table 1 highlights the advantages and disadvantages of LUS compared with the other modalities.

Table 1. Advantages and disadvantages of LUS compared with CXR and CT

Advantages	Disadvantages
Widely available – does not rely on radiographer availability after-hours.	Operator typically a medical practitioner, increasing cognitive and temporal load.
Inexpensive – existing ultrasound almost universally available in Australia and New Zealand due to other indications (echocardiography, vascular access, regional anaesthesia).	Training and experience required beyond already expected proficiencies with radiograph interpretation.
Avoids ionising radiation – no risk to staff, negligible clinical thermal risk to foetus.[15]	Potentially wide degree of operator dependency.[16,17]
Reduces occupational health and safety risk in positioning obese patients for CXR or transfer for CT.	Limited by various obstructions to the probe and patient positioning, especially breast and cardiothoracic surgery, dressings, etc.
Reduces risk to patient stability caused by transfer to CT scanner (a less clinically controlled environment).	Longer scan duration versus CXR (8-12 minutes versus < 30 seconds).
Faster to start scanning versus CXR, and overall versus CT, by avoiding booking, transfer, potential wait, and scan duration.	Less accurate versus CT (the gold or reference standard in many comparative sensitivity and specificity studies).
More accurate versus CXR for pneumothorax sensitivity (79% vs 40%),[18] pleural effusions (80-100% vs 24-100%),[19] and earlier identification of pulmonary oedema.	70% maximal coverage of lung in ultrasound contributing to reduced sensitivity as cannot rule out pathology.

PHYSICS AND EXPLANATION OF ARTEFACTS

A solid understanding of the physics behind LUS artefacts is crucial for accurate interpretation and recognition of underlying pathology. The conversion of ultrasound beams into an image by the processor assumes that: (a) sound travels at a constant speed in a straight line, (b) sound reflects once per tissue interface, (c) the interface is perpendicular to the beam, (d) sound returns directly to the transducer, and (e) the beam's attenuation is uniform and linear. When this expected pathway is disrupted, artefacts appear on the image.

Ultrasound beams are reflected whenever two tissues of differing acoustic impedance abut each other, forming an interface. The pleural interface (pleura to air in the lung) and the lung parenchyma-air interface cause virtually all beams to be reflected, creating artefacts in imaging that are interpreted (in other words, the lung itself is not imaged). Abnormalities within the pleura, interstitium, or alveoli produce unique, reproducible artefacts,[20] the most common of which are reverberation artefacts.

Reverberation artefacts occur when an ultrasound pulse encounters two closely spaced, parallel reflective surfaces. Instead of returning immediately, the pulse becomes trapped between them, bouncing back and forth before eventually reaching the transducer in delayed intervals. This repeated reflection produces a characteristic reverberation artefact on the ultrasound image.

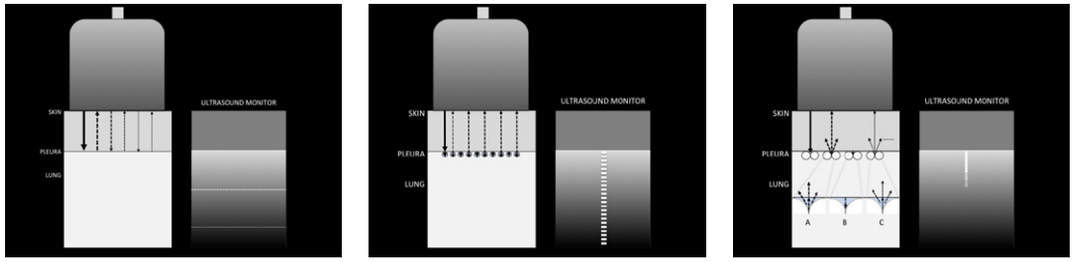
The different types of artefacts are described below and displayed in Figure 1.

A-lines are a form of long-path reverberation artefact. "Long-path" refers to a distance between the two reflective surfaces which is discernible to the human eye. Most of the ultrasound beam hits the highly reflective pleural surface, returning back to the probe – a true representation of where the pleura is located. However, some of the beam then continues to bounce between the probe and the pleura, forming subsequent horizontal lines or A-lines. They exhibit fade due to attenuation of the ultrasound beam with each reflection, diminishing with increasing depth.

B-lines are a form of short-path reverberation artefact, where the distance is less than half an ultrasound pulse length. The beam reaches a fluid-filled alveolus within secondary lobules, which are clusters of up to 30 acini, bound by interstitial fibrous septa. The beam bounces between the highly reflective superficial and deep fluid surfaces, and with each return, a small amount of pulse is sent back to the transducer. Due to the short distance, surface reflectiveness, and the fact that the surfaces are perpendicular to the beam, little to no attenuation occurs, and thus, B-lines do not fade.

Comet-tail artefacts are also short-path reverberation artefacts, but occur where ultrasound encounters highly reflective, closely spaced surfaces – such as calcium, cholesterol crystals, or metal – that are too small to be distinguished as separate structures. Unlike B-lines, comet-tail artefacts weaken with each reverberation, resulting in a bright, vertical streak that rapidly fades. This occurs because the beam either reflects off non-parallel reflective surfaces, causing scattering, or is absorbed by the tissues involved, both of which reduce the fraction of the beam that returns to the transducer. Confusingly, B-lines were previously called comet-tail artefacts, and even described as such in the BLUE protocol.

Figure 1. Graphical depictions of reverberation artefacts



A-Lines B-Lines Comet-Tail

Reproduced with kind permission from LITFL[21,22,23]

PRACTICAL ASPECTS

Patient positioning

- Supine: most likely position intraoperatively. Ideally, arms out to improve access.
- Semi-recumbent: useful if patients are unable to lie flat, or there is a need to assess for an apical pneumothorax.
- Lateral and prone: useful for assessing a larger surface area of the lung.

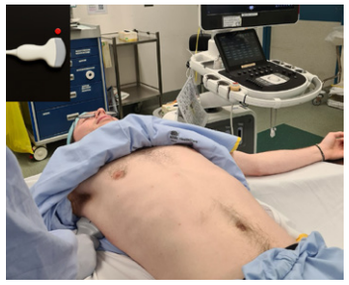
Probe selection and orientation

- Low frequency or curvilinear probe: all-purpose use.
- High frequency or linear probe: for interrogating the pleura.
- Phased array probe: particularly useful when performing concurrent echocardiography. However, the smaller footprint can challenge rib visualisation.
- The curvilinear probe is better than the phased array probe for interpretation, particularly for novices and pleural-based pathologies.[24]
- Always scan in a longitudinal (rather than transverse) orientation, with convention dictating the left of the screen to be cephalad (head to left) – see Figures 2 and 3. This allows easy identification of the pleura between the two ribs.
- NB: The benefit of transverse orientation in regular scan is that more artefacts can be seen in a single respiratory cycle; however, this technique requires advanced operator skill and risks mistaking A-lines for the pleural surface.

Knobology

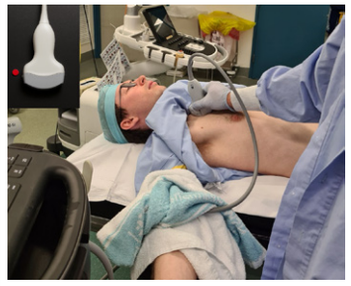
- Presets: use the "lung" preset if available. The "abdominal" preset is useful for assessing consolidation and effusions, but may diminish visualisation of A-lines, B-lines and pleural sliding. This is represented in Figure 4.
- Depth: set to 15–20 cm for lung imaging, but reduce depth for assessing pleura, or use the zoom function.
- Gain: adjust to maximise contrast and visualisation of the pleural line and B-lines (if present).
- Duration: scan each scanning zone for one respiratory cycle, or 5–6 seconds.
- Turn off focal zones: if you need one, position it at the pleural line.
    - Dial near and far field gain to the same brightness using time gain compensation (TGC); otherwise, the machine will dim distal B-lines.
- Advanced: turn off tissue harmonic imaging (THI) and spatial compounding – this will maximise artefacts generated.

Figure 2. Probe position over PLAPS point



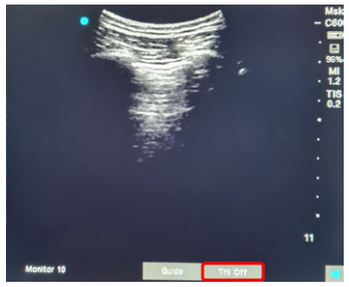
Best achieved with the patient's arms out. Probe marker towards the head. PLAPS = posterior lateral alveolar and/or pleural syndrome

Figure 3. Longitudinal/ parasagittal probe position, scanning over the anterior chest



Probe marker towards the head

Figure 4. Ultrasound with "MSK" preset used



Head to left. MSK preset used. THI off. A-lines demonstrated (SonoSite SII, FUJIFILM Sonosite, Inc. Bothell, WA, USA)

LUNG SIGNS: DEFINITIONS AND DESCRIPTIONS

We have attempted to collate the various nomenclature here to avoid confusion between contemporary and historical terminology; these are presented in Table 2. The term "profile" refers to a characteristic image acquired in the original BLUE protocol. Images representing many of the artefact lines that are utilised in scanning protocols are presented in Figure 5.

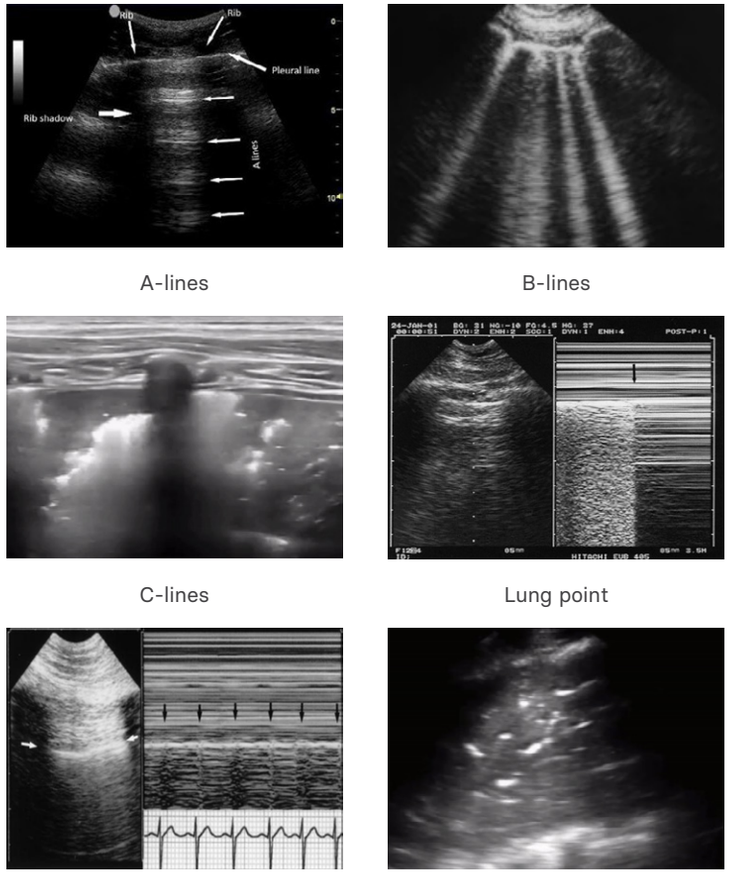
Table 2. Commonly used lung signs

Finding	Features	Interpretation
A-line *Other names: horizontal reverberation artefact, air artefact lines, repetitive pleural artefacts*	Horizontal, hyperechoic Each reverberation fades	Presence of air Does not distinguish between alveolar and pleural air (i.e. present in both well-aerated lung and in pneumothorax)
A profile	Lung sliding present	
A' profile	No lung sliding present	A profile without lung sliding
B-line *Other names: comet-tail artefact, ultrasound lung comets*	Hydroaeric comet-tail artefact Arises from pleural line Hyperechoic Well-defined Spreading up indefinitely (spread to edge of screen without fading) Erasing A-lines Moves with lung sliding when lung sliding present	Associated with Kerley B-lines Focal B-lines can be normal or associated with: - Pneumonia/pneumonitis - Atelectasis - Pulmonary contusion, infarction or neoplasia - Pleural disease Multiple diffuse bilateral B-lines are associated with: - Pulmonary oedema - Interstitial pneumonia or pneumonitis - Diffuse parenchymal lung disease/ pulmonary fibrosis

B pattern *Other names: B profile, B+ lines, lung rockets* B7 lines (septal rockets) B3 lines (ground-glass rockets) Confluent/coalescent B-lines (white lung)[25]	Three or more B-lines in an intercostal space B7: a distance of 6.0-7.0 mm between two B-lines B3: a distance ≤ 3.0 mm between two B-lines Confluent: when numerous B-lines are in close proximity, they become confluent (qualitative description and no clear definition as to what constitutes this)	It was initially thought that B3/B7 lines could distinguish between interstitial (B7) and alveolar (B3) oedema, but growing evidence demonstrates B-line morphology is influenced by many technical factors[26] B7 is associated with thickened interlobular septi on CT, B3 with ground glass opacity on CT The degree of B-line fusion is related to lung water content and degree of pulmonary oedema, but not interstitial versus alveolar involvement
B profile	B pattern that is anterior, bilateral, disseminated and associated with lung sliding	Associated with haemodynamic pulmonary oedema
B' profile	B profile without lung sliding	Associated with pneumonia or ARDS
A/B Profile	A profile in one lung, B profile in other lung (at upper and lower BLUE points)	Pneumonia in the lung with B-profile
C-line *Other names: fractal line, pleural shredding, shred line*	The term "C-line" is not standardised Referred to as hypoechoic subpleural focal areas (irregular, jagged appearance of pleural line); or, Comet-tail artefact originating from fractal line	Represent condensed lung tissue, typically seen in conditions like atelectasis or pneumonia[27] Seen with small pleural consolidations at the edge of consolidated and normal, aerated lung
C profile	Consolidation on upper or lower BLUE points	Represents pneumonia
Lung point	The point where visceral pleural separates from parietal pleura	Specific for pneumothorax Absence does not rule out pneumothorax
Lung pulse	Cardiogenic oscillations seen on pleural interface Easier to detect using M-mode and identifying T-lines	Indicates parietal and visceral pleura in opposition Presence excludes pneumothorax
Air bronchograms	Hyperechoic, branching or punctate structures seen within consolidated lung Bronchograms that move with respiration are dynamic	Static: suggestive of atelectasis or complete airway obstruction; however, can be seen in pneumonia[28] Dynamic: suggestive of pneumonia Colour doppler also helpful to distinguish between atelectasis and pneumonia: - Atelectasis: likely absent due to hypoxic pulmonary vasoconstriction (HPV) - Pneumonia: likely present due to impaired HPV[20]

Terminology including "false B-lines" named I-lines, E-lines, and Z-lines, and alveolar-interstitial syndrome, are beyond the scope of this article

Figure 5. Artefact lines used in scanning protocols



Ultrasound images of A-lines, B-lines, C-lines/shred sign, lung point, lung pulse (arrow: T-lines), air bronchograms. Images reproduced from Rao (2022),[29] Lichtenstein (2014),[30] Ross & Joffe (2017),[31] and Lichtenstein et al. (2003)[32]

INDICATIONS

Preoperative

- Assess patients with chest pain, tachypnoea, dyspnoea.
- Identify patients at risk of postoperative pulmonary complications (PPCs).
- Identify the cause of preoperative hypoxaemia (e.g. large bilateral pleural effusions).
- Identify pneumothorax and the risk of initiating positive pressure ventilation.
- Identify pleural adhesions before thoracic surgery.[33]

Intraoperative

- Differentiate the causes of intraoperative hypoxaemia.
- Identify iatrogenic injury (e.g. capnothorax).
- Screen for pneumothorax after central venous catheter (CVC) insertion.

- Monitoring lung recruitment and ventilation strategies.
- Assessing haemodynamic status: aids in diagnosing pulmonary congestion and guiding fluid management in unstable patients.
- Peri-arrest assessment to rule out pneumothorax.

Postoperative

- Identify the cause of hypoxia, hypotension, dyspnoea, and chest pain.
- Identify the risk of postoperative deterioration to plan disposition.

LIMITATIONS

LUS accuracy significantly depends on operator characteristics, such as ideal image acquisition technique and replicable conditions for serial examinations to allow comparison. Image acquisition can be further limited by patient and intraoperative barriers to the probe (such as in breast and cardiothoracic surgery); an inability to abduct arms for positioning at the posterior axillary line, which gives access to the posterior lateral alveolar and/or pleural syndrome (PLAPS) views (see Figure 3); and the presence of dressings or subcutaneous emphysema. Finally, there are risks of thermal and mechanical bioeffects, particularly to a foetus, premature neonate or infant, though these have never proven harmful in humans.[15]

PERFORMANCE, LEARNING AND RELIABILITY

LUS has a more accessible learning curve compared to echocardiography due to simpler anatomy and fewer standardised windows. Image acquisition is generally straightforward; however, interpreting artefacts and distinguishing subtle findings presents a steeper learning challenge.

Studies have demonstrated high inter-observer agreement,[34] reflecting strong reliability when performed by trained clinicians. In the perioperative setting, LUS is readily accessible, with probes and machines already in everyday use.

Practical training should include a combination of theoretical instruction, practical hands-on sessions under supervision, and case-based reviews of common pleuro-pulmonary pathologies.[15] Notably, LUS training can be extended beyond physicians, with applications for allied health professionals such as physiotherapists and paramedics. There is also growing advocacy for integrating LUS training into medical school curricula, positioning it as a modern extension of the physical examination, with diagnostic accuracy surpassing that of the stethoscope.

ANZCA's *Guideline on training and practice of perioperative diagnostic point-of-care ultrasound (POCUS) 2025* recommends formal education through didactic content or obtaining a specialist certification. This includes 20 supervised studies, 20 additional unsupervised studies with supervisor review, and the review of 10 pre-recorded cases.[35]

Evidence from a study based in a low-resource setting demonstrated that practical competence could be achieved after just five supervised scans; however, proficiency required an additional five independent scans.[36] Importantly, ongoing competence was not assessed in this cohort. In contrast, another study recommended 20–25 supervised scans to develop basic interpretive skills in LUS,[37] likely reflecting the complexity of ICU patient presentations compared to those in the emergency department or perioperative settings. This disparity underscores the need to tailor training recommendations according to clinical context.

While LUS adds to the clinician's workload, the time required to perform a comprehensive lung aeration assessment is relatively modest – approximately 8 minutes for experienced users and 10 minutes for trainees,[38] and less than 3 minutes for the BLUE protocol.[8]

ALGORITHM IN THE PERIOPERATIVE SETTING

Due to the clinical urgency of severe hypoxaemia, LUS in the perioperative setting must balance speed and accuracy. After reviewing existing protocols, we recommend following Kruisselbrink's I-AIM protocol as a framework, but scanning three key zones bilaterally as described in the BLUE protocol, using a well-established common language familiar to anaesthetists and other critical care clinicians. Various protocols

describe anywhere from 6 to 28 zones to scan to increase accuracy and information gathering; this can be attempted if time permits for a more comprehensive assessment.

With any protocol, LUS should answer the following questions:

- **Is there lung sliding?** If not, is there a lung point?
- **Are B-lines present?** How many and where?
- **Is the pleural line irregular?**
- **Is there hepatisation of the lung?**
- **Is there free thoracic fluid?** What are the size and fluid characteristics?

Three key scanning zones

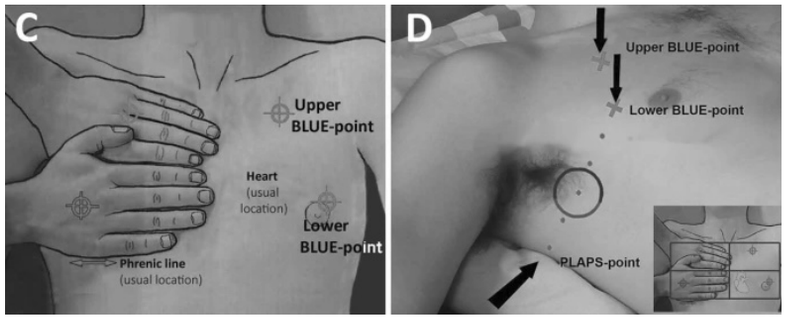
The hand placement method described in the original BLUE protocol may be ergonomically difficult to apply intraoperatively due to variable patient body sizes and positioning constraints.[8,39] Instead, identifying landmarks based on intercostal spaces and anatomical lines may be a more practical approach. These are summarised below and presented in Figure 6.

1. Anterior (upper BLUE point)
- **Location:** 2nd intercostal space, mid-clavicular line (most anterior chest in supine position).
- **Findings:** Lung sliding, A-lines (normal aeration), B-lines (interstitial syndrome, pulmonary oedema).

2. Lateral (lower BLUE point)
- **Location:** 4th intercostal space, anterior axillary line.
- **Findings:** Lung sliding, A-lines, B-lines (suggesting alveolar-interstitial syndrome), effusions.

3. PLAPS (posterolateral alveolar and/or pleural syndrome) point
- **Location:** Horizontal continuation of the lower BLUE point, as posterior as possible towards the posterior axillary line.
- **Findings:** B-lines, consolidation (pneumonia, atelectasis), pleural effusions.

Figure 6. BLUE protocol scanning zones



Reproduced from Bar et al. (2022)[40]

Kruisselbrink's protocol

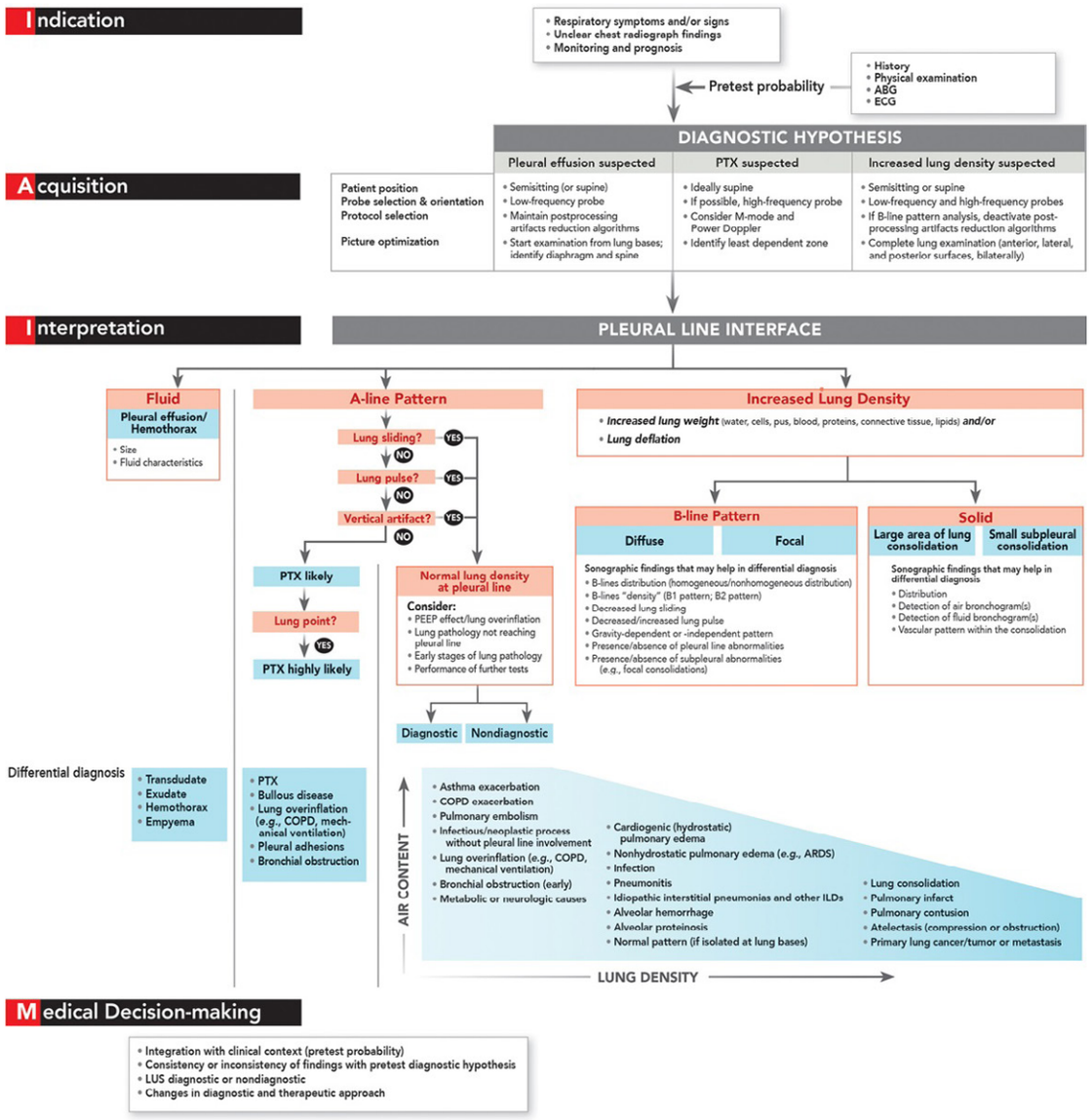
Kruisselbrink's LUS protocol provides an excellent framework to follow, applying the broad "Indication, Acquisition, Interpretation, and Medical decision-making" (I-AIM) cognitive scaffold for trainees learning LUS.[41] It also considers a wider range of differentials, particularly in the perioperative and intensive care settings.

Indication and acquisition steps optimise scanning for the suspected pathology. Interpretation provides a simple breakdown of findings to narrow the differential diagnoses. Medical decision-making emphasises placing the interpretations into context, including determining if the scan is diagnostic. This is important as differential diagnoses can produce overlapping ultrasound artefacts.

Limitations of this protocol include a lack of practitioner familiarity, a lack of disease-specific ultrasound profiles or defined pathological findings, and no guidance over acquisition technique, which may reduce consistency.

If time and relevancy permit, additions could include a comprehensive LUS assessment viewing the posterior zones, incorporating echocardiography to improve diagnostic certainty, particularly for pulmonary embolism and acute pulmonary oedema, and assessing diaphragmatic motion for phrenic nerve palsy. Kruisselbrink's protocol is graphically presented in Figure 7, and a guide for helpful interpretation of clinically relevant findings is presented in Table 3.

Figure 7. I-AIM framework for lung ultrasound



Reproduced from Kruisselbrink et al. (2017)[41]

Table 3. Key LUS findings and interpretation of the most common intraoperative causes of severe perioperative hypoxaemia

Diagnosis	LUS features		Interpretation
	Present	Absent	
Fluid			
Pleural effusion	Sinusoid sign (respiratory variation reducing parietal and visceral pleura distance on M-mode) Quad sign Spine sign Jellyfish sign	A- or B-lines over fluid zone Curtain sign	Found in dependent zones, unless complex effusion Consider drainage or diuresis Qualitative - Transudates – anechoic, non-septated fluid, homogenous - Exudates – complex, echogenic, septated fluid, debris, organised clots, pleural thickening more likely Quantitative - Formulas (such as the Balik formula) have been proposed to estimate effusion volumes - Lack validation and are unreliable for complex or exudative effusions - Routine use is not advised
A-line pattern			
Normal lung or Bronchospasm	A-lines Lung sliding B-lines (two or fewer)	B-lines (more than two) Consolidation Lung point Lung pulse	Normal LUS helps exclude parenchymal or intrapulmonary causes
Endobronchial intubation	Bilateral A-lines Lung pulse in non-ventilated lung	B-lines (early stage only) and lung sliding in non-ventilated lung Lung point	Resolves with re-positioning of ETT
Pneumothorax	A-lines Lung point	Lung sliding B-lines Lung pulse	Lack of lung sliding highly sensitive Lung point highly specific
Mucus plugging	Lung sliding A-lines Scattered B-lines Small subpleural consolidation	Lung point	Rule out other causes (e.g. pneumothorax) May need suction or bronchoscopy

Pulmonary embolus	A-lines Lung sliding May see peripheral, wedge-shaped subpleural consolidation	B-lines Lung pulse Lung point	Normal B-line pattern excludes APO/ARDS Use TTE Can follow BLUE protocol to look for lower limb DVT
Increased lung density pattern			
Atelectasis	Focal B-lines or hepatisation Static air bronchograms Lung sliding (normal or reduced) Lung pulse	Lung point A-lines	Improves with recruitment/PEEP
Pulmonary oedema	Bilateral diffuse B-lines Lung sliding	Lung pulse Lung point	Cardiogenic = bilateral, symmetric, diffuse B-lines
Pneumonia	Lung sliding (although B' profile possible but rare) Localised, asymmetric B-lines Pleural shred/fractal line Dynamic air bronchogram Hepatisation (lung sign)	A-lines in affected area Lung point Lung pulse unlikely	Localised, dependent Evolves over time with serial LUS

EXAMPLE SCENARIOS – BASED ON ACTUAL CASE REPORTS

Case 1

Case sourced from Han et al. (2020)[42]

A 73-year-old female with acute gallstone cholecystitis was planned for emergency laparoscopic cholecystectomy. She had a background of coronary artery disease with previous PCI, hypertension and type 2 diabetes. Her pre-induction vital signs were BP 170/100 mmHg, HR 90, SpO2 96% on room air. She had an uneventful induction of anaesthesia and tracheal intubation, with good bilateral air entry on auscultation and peak airway pressures of 14 cmH_2O.

Following an ultrasound-guided TAP block, surgery commenced, and pneumoperitoneum was established with intra-abdominal pressures less than 14 cmH_2O and peak airway pressures of 20 cmH_2O. After 15 minutes, the position was changed to reverse Trendelenburg with a left tilt to facilitate the surgery. At this time, the peak airway pressure jumped to 28 cmH_2O, and the $ETCO_2$ also rose to 55, along with a fall in SpO2 to 88% despite increasing the FiO_2 to 0.9. Other haemodynamic parameters were normal. Left lung auscultation was normal, with no air entry to the right. A right mainstem bronchus intubation was suspected; however, it was quickly ruled out using a bronchoscope, which demonstrated the ETT tip above the carina and no mucus plugging in the right lung. LUS was then performed, demonstrating lung sliding present on the left but absent on the right chest (an example of this is presented in Figures 8 and 9). The

surgeon then inspected the diaphragm in detail and discovered a 1 cm defect in the right hemidiaphragm. The right lung atelectasis caused by the capnothorax was slowly resolved with PEEP and recruitment, and the diaphragmatic defect was sutured by the surgeon.

Figure 8. Right lung demonstrating stratosphere sign, indicating lack of lung sliding

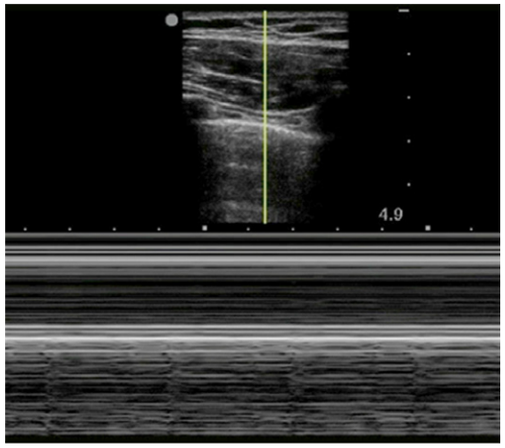
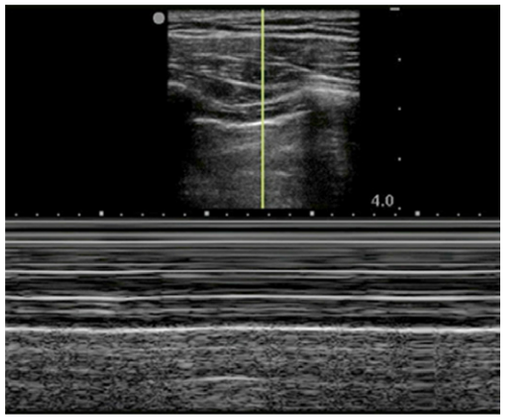


Figure 9. Left lung demonstrating sandy beach sign, indicating normal lung sliding



Case 2

Case sourced from Zhang et al. (2021)[43]

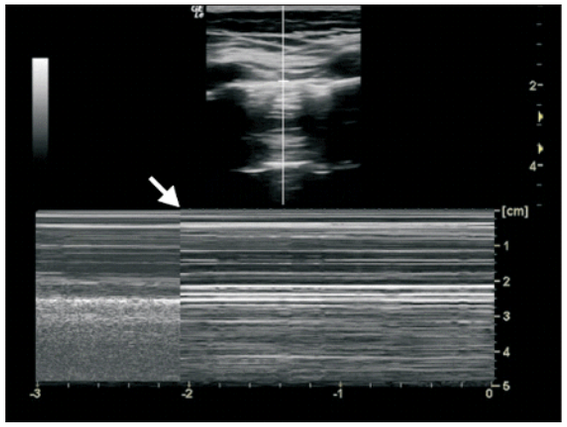
A 53-year-old male was admitted following a fall. An eFAST scan was performed in the emergency department, which demonstrated splenic rupture with intra-abdominal fluid. This was associated with progressive anaemia but no cardiac or thoracic abnormalities on ultrasound. A preoperative CT scan did not demonstrate a haemothorax or pneumothorax. Vital signs prior to induction were BP 126/82 mmHg, HR 75, SpO_2 95% on room air.

Following induction of anaesthesia and tracheal intubation, positive airway pressure was applied, noting a peak airway pressure of 14 cmH2O at this time. Breath sounds were difficult to auscultate bilaterally due to a thick chest wall. Two minutes after intubation, the patient became progressively more difficult to ventilate, with a peak airway pressure reaching 50 cmH_2O and a SpO_2 nadir of 70%.

A rapid LUS was performed, which demonstrated a lack of pleural sliding in the left upper and lower BLUE points. The lung point (see Figure 10) was visualised with lateral sliding of the probe, confirming the diagnosis and boundary of the pneumothorax. A chest drain was inserted with ultrasound guidance,

resulting in immediate improvement of oxygen saturations and airway pressures. The time interval between initial suspicion of a pneumothorax until insertion of the chest drain was less than 3 minutes.

Figure 10. Example of lung point seen on M-mode



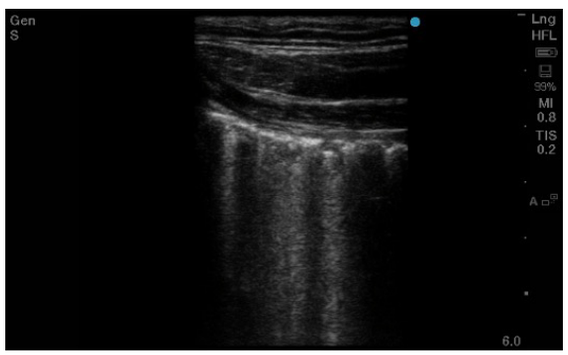
Lung point indicated by white arrow. Image sourced from Song (2018)[14]

Case 3

Case sourced from Dai et al. (2024)[44]

A 55-year-old female was planned for an elective hysteroscopic myomectomy to resect a submucosal uterine leiomyoma. She had a background of untreated hypertension and smoking. Her preoperative physical examination, ECG and CXR were all unremarkable. Her pre-induction vital signs were BP 175/98, HR 75 and SpO_2 96% on room air. General anaesthesia was induced, an LMA was placed and the patient was positioned in lithotomy. Positive pressure ventilation was commenced in VCV mode, with saturations of 99-100% on FiO_2 0.4. The surgical uterine dilation was 0.9% saline, with uterine dilation pressure of 100 mmHg. Thirty minutes into the operation, a gradual drop in SpO_2 and $ETCO_2$ was observed. LUS demonstrated diffuse B-lines (see Figure 11) in both lungs and a diagnosis of operative hysteroscopy intravascular absorption (OHIA) syndrome was made. Saturations improved following diuresis with IV frusemide and after thorough surgical haemostasis, the operation was concluded. The patient emerged well without an oxygen requirement and the B-lines were largely resolved on repeat LUS in the post-anaesthesia care unit.

Figure 11. Example of B-lines

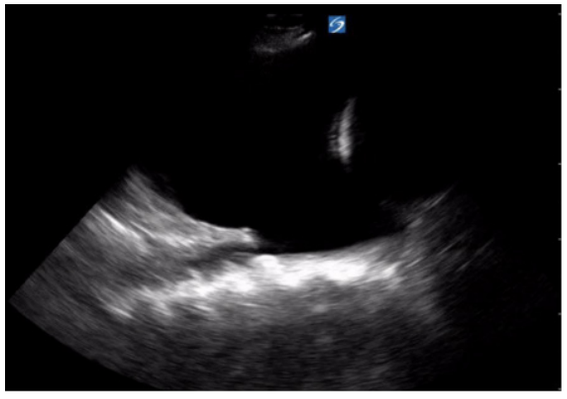


Case 4

Case sourced from Leech et al. (2015)[45]

A 56-year-old male was admitted to ICU with hypoxia secondary to left lung pneumonia. He was having issues with worsening hypoxia, and mucus plugging was suspected due to secretion retention and a left hemithorax white-out on chest radiograph. This was managed by the physiotherapist with airway clearance techniques, patient positioning and nasopharyngeal suctioning. While this improved secretion removal, the patient continued to experience ongoing high work of breathing and increasing oxygen requirements. The physiotherapist then performed a LUS, which revealed a large pleural effusion, which was subsequently drained by the medical team. Over 1500 mL was drained, which dramatically improved the patient's work of breathing and oxygen requirements, avoiding further escalation of treatment such as intubation and mechanical ventilation. An example of what this would look like on curvilinear ultrasound is presented in Figure 12.

Figure 12. Example of a large pleural effusion with spine sign



FUTURE DIRECTION

LUS is an increasingly valuable tool for perioperative physicians, offering rapid, non-invasive assessment of respiratory pathology and complementing clinical examination, auscultation, and other bedside monitoring. Like basic echocardiography, we anticipate that LUS will become a standard skill in the perioperative setting, aiding real-time clinical decision-making when interpreted within the broader clinical context and pre-test probability. However, it is essential to remember that ultrasound findings are part of the diagnostic puzzle, and patient management should always prioritise the clinical picture rather than isolated imaging results.

Despite its utility, LUS does present an additional workload and time commitment, particularly for those early in their learning curve. Currently, there is variability in training standards and credentialling, which underscores the need for formal, competency-based education pathways. Future directions should focus on the development of standardised training programs, assessment tools, and simulation-based learning platforms to ensure widespread proficiency. As the technology continues to evolve and become more accessible, further research will help define its role across different clinical settings, optimise scanning protocols, and refine its integration into routine perioperative care.

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Counting the waves – an introduction to the EEG and how processed EEG devices generate their values

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Edited by Dr Marli Smit

INTRODUCTION

This article reviews the basis of the electroencephalogram (EEG), and the principles of operation of commercial processed EEG devices. The goal is to provide an intuitive understanding of how these devices work and to clarify the technical jargon.

As with any clinical device, knowing how these monitors function is crucial, not just to appreciate what they measure, but also to recognise when they might be misleading. A clear grasp of their underlying principles helps to avoid incorrect assumptions that could impact clinical decisions, and supports a more critical appraisal of both research findings and manufacturer claims.

Rationale

Since the brain is the primary target of general anaesthetic agents, monitoring the EEG is an appealing concept. Individual dose requirements vary significantly, and balancing drug administration against surgical stimulation and patient illness is challenging. A reliable monitor of anaesthetic effect on the brain could help guide dosing, much as adjusting the vasopressor dose can be used to maintain a target blood pressure. The hope is that this could help reduce under-dosing, thereby minimising the risk of intraoperative awareness, while also minimising the deleterious effects of excess hypnotic drug administration.

Terminology

The term "depth of anaesthesia" monitor is both imprecise and misleading, contributing to confusion in both clinical practice and research.[1] It conflates the EEG effects of anaesthesia with broader systemic changes, and implies that these devices are reliable measures of effects beyond the brain. Expecting a monitor of the brain to provide a definitive measure of a multifaceted, body-wide phenomenon such as surgical anaesthesia is not just implausible, it is conceptually flawed. For such a measure to accurately reflect the state of other organ systems, a fixed relationship between them would be required. This is clearly not the case, as drugs affect different systems independently. At best, cortical electrical activity may reflect aspects of consciousness, but it cannot account for anaesthesia as a whole.

A comparison of propofol and sevoflurane illustrates this point. A propofol dose sufficient to induce 50% burst suppression (e.g. effect-site: 8–10 µg/mL) results in a Bispectral Index (BIS) in the low 20s. Achieving the same with sevoflurane requires concentrations exceeding 1.5 minimum alveolar concentration (MAC). Yet despite similar EEG patterns, the systemic effects differ markedly.

In both cases the patient is unconscious, yet with propofol alone, attempts at intubation will trigger movement and a pronounced adrenergic response, leading to hypertension and tachycardia. Surgery will not be possible due to continual reflex movements. In contrast, with 1.5 MAC sevoflurane there is profound

muscle relaxation, no movement on incision, and because it is MAC-BAR, there will be minimal change in heart rate and blood pressure. The BIS index may be the same, but the overall state of anaesthesia is markedly different.

These devices, therefore, do not measure anaesthesia *as such*; they primarily reflect the brain's surface electrical activity. For this reason, we will use the term "processed EEG" devices. This avoids overstating their capabilities while accurately describing their function: they process the EEG and generate index values.

Accidental awareness

The primary goal of general anaesthesia is to prevent conscious experience during surgery. Yet despite having highly effective drugs to achieve this, inadequate anaesthesia remains a real risk, with an incidence an order of magnitude higher than death from anaesthetic causes.[2,3] Its causes are multifactorial, and no single intervention will prevent it. Monitoring the EEG for signs of unconsciousness can play an important role as part of a wider strategy, but relying solely on a processed index would require it to be 100% reliable, which no index currently is.[4,5]

THE SCALP EEG AND HOW IT CHANGES WITH ANAESTHESIA

The scalp EEG = brain EEG + EMG + EOG

The "EEG" in routine practice refers to signals recorded from scalp electrodes, measuring voltage changes over time. Although "scalp EEG" would be more precise, the term "scalp" is omitted for convenience – since invasive intracortical recordings are seldom used outside research or special clinical settings. This omission can foster the misconception that "the EEG" reflects only brain activity. In reality, scalp electrodes also pick up signals from muscles (electromyogram, EMG) and eye movements (electrooculogram, EOG). This is especially relevant when considering the function of processed EEG monitors.

It might be assumed that cortical EEG signals arise directly from the depolarisation of individual neurons. However, because individual neurons are neither perfectly aligned nor synchronised, their electrical activity largely cancels out even a few millimetres away.

Instead, the EEG arises primarily from the summation of inhibitory and excitatory post-synaptic potentials. In particular regions of the cortex, large groups of neurons are arranged in columns that are innervated by ascending pyramidal axons. This columnar geometry means that the post-synaptic potentials add together in both time and space rather than cancel each other out. It is these post-synaptic potentials and their associated extracellular currents in the top few millimetres of the cortex that form the EEG (Figure 1).[6]

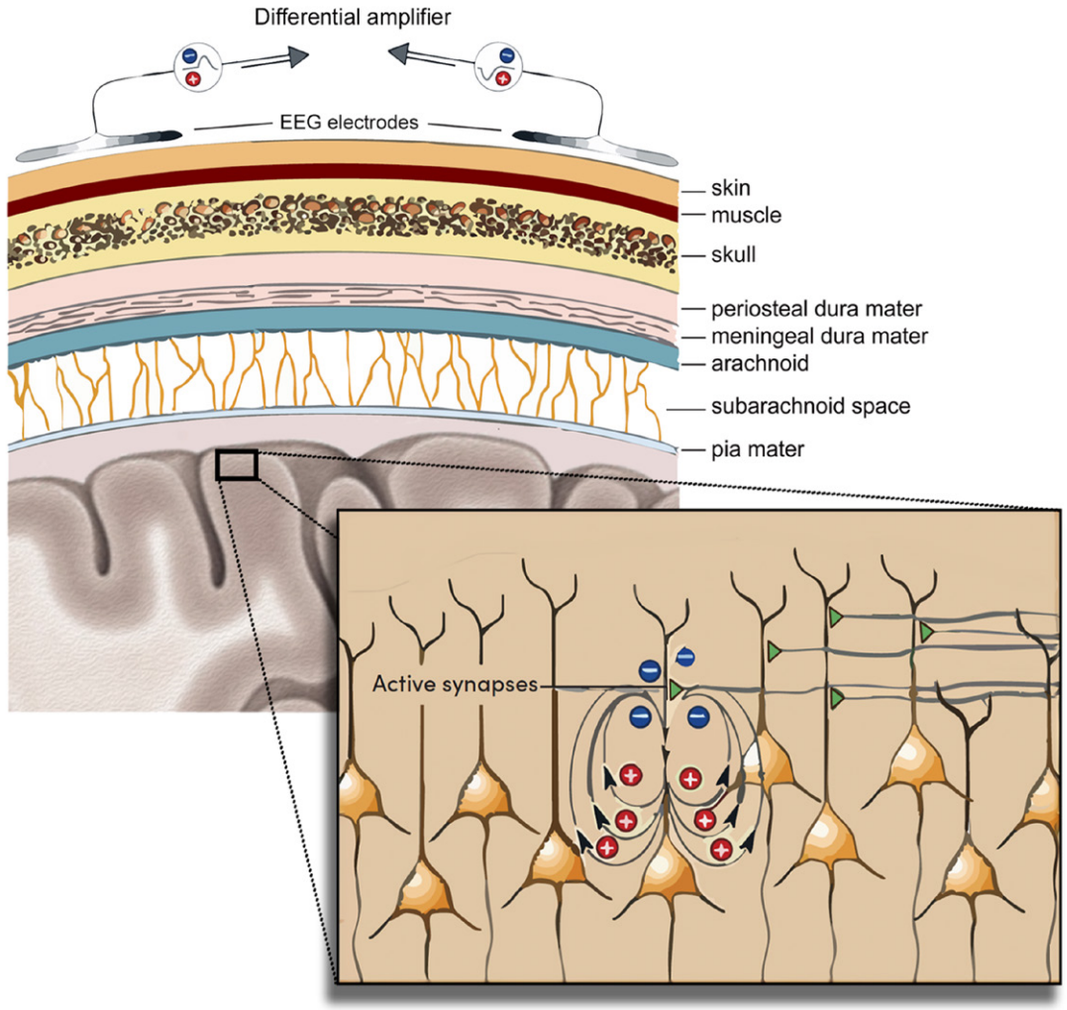
The signal that a single electrode detects arises from a few square centimetres of the top few millimetres of the surface of the brain. Deeper structures such as the thalamus and limbic system which are essential for consciousness, emotion, and the subjective experience of pain, do not produce measurable signals at the scalp directly, but they play a crucial role in shaping cortical EEG rhythms.[7]

Even when lying still with closed eyes, there is ongoing muscle tone which produces electrical activity (EMG). Although these muscles are small, they lie directly beneath the electrodes, so the signal from resting muscle can greatly exceed that of the brain, especially when the individual is awake.[8,9]

Features of the awake EEG

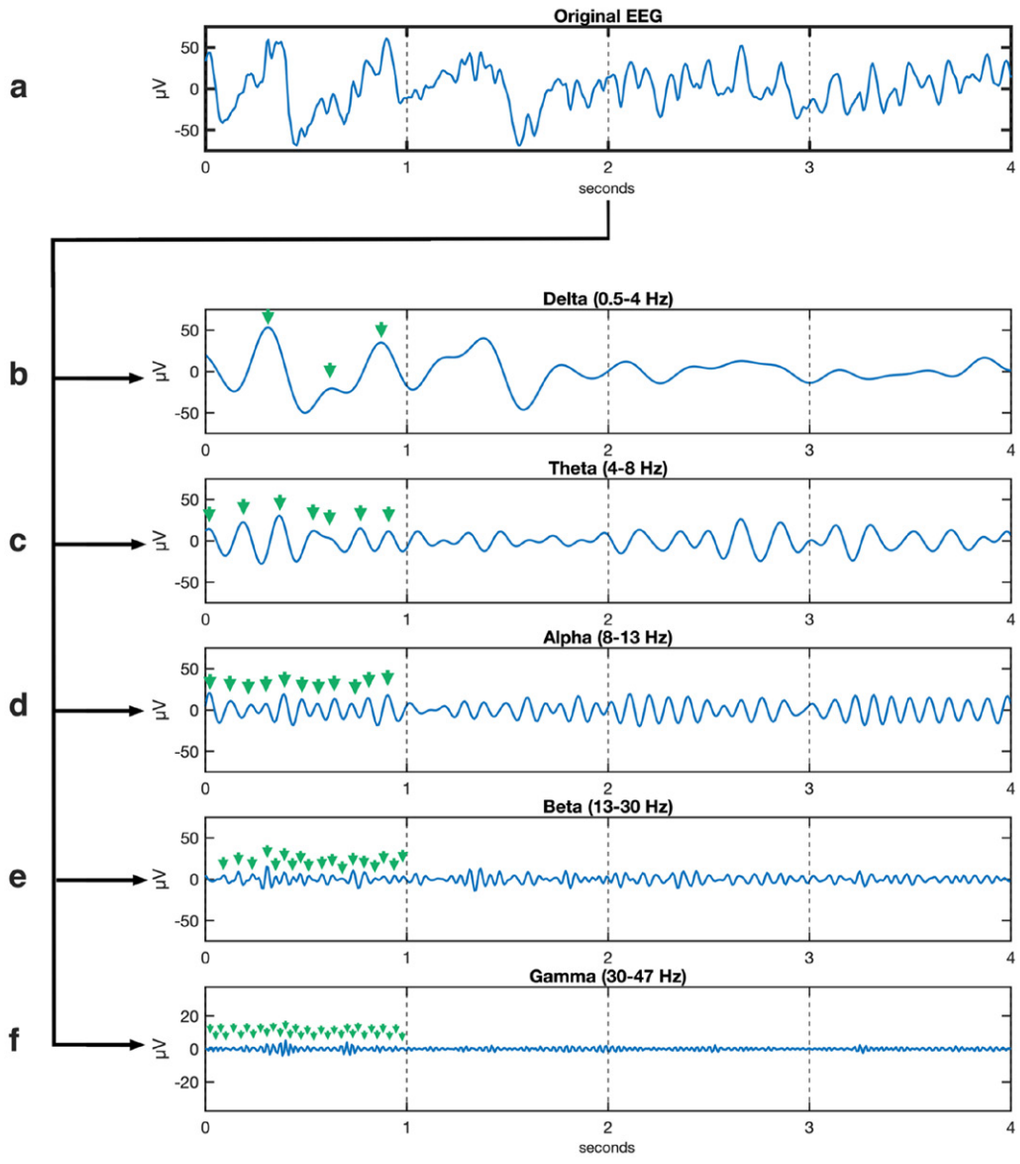
Traditionally, EEG activity has been classified into frequency bands based on empirical observations: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–80 Hz). Figure 2 illustrates how a typical EEG can be viewed via these frequency bands, which highlight the contribution of different components. These bands do not represent specific underlying physiology, but they are useful to describe broad changes in the EEG.

Figure 1. The origin of the electroencephalogram (EEG)



Summed post-synaptic potentials from cortical pyramidal cells generate extracellular currents, that are synchronised across large populations of neurons arranged in columns. The summed potentials extend through the cortical layers and are detectable at the scalp. The tissues between the cortex and the skin attenuate the amplitude and spatially blur the signal, while muscle tissue contributes additional electrical activity. Most EEG systems use at least three scalp electrodes (active, reference, and ground) for a single channel. A differential amplifier subtracts the reference signal from the active electrode, reducing shared noise ("common-mode rejection"). Figure adapted from Siuly et al. (2016).[6]

Figure 2. The raw EEG and its traditional frequency bands



a) Four seconds of raw EEG during sevoflurane anaesthesia; b–f) The same EEG filtered into conventional frequency bands. The x-axis represents time (seconds) and the y-axis voltage (μV).

The EEG always includes a mixture of frequency components, which can be seen more easily by filtering the EEG into bands of similar frequencies (b-f). Adding the filtered traces (b–f) together would reconstruct the original EEG (a).

Green arrows mark the wave peaks during the first second.

Note the large amplitude of the delta waves (up to ~60 μV), while alpha and beta are ~10–20 μV. Gamma waves are even smaller and are shown on a different scale. This is typical of the EEG – the lower frequencies have the highest amplitude, often described as greater "power." The gamma component is particularly small in this example because the patient is anaesthetised.

The Fourier transform takes this process a step further. Rather than filtering the waveform into just five frequency bands, it represents the original EEG as a sum of a large number of sine waves at frequency intervals of 0.5 or 1 Hz, each with a unique amplitude and phase (timing). See Figure 4.

In an awake individual, the EEG has a low amplitude (10–20 μV), with visible high-frequency components from muscle, which can give the waveform a "fuzzy" appearance.

When the eyes are closed, alpha waves become more prominent, a pattern referred to as the "posterior dominant rhythm" because it is maximal over the occipital cortex. Eye blinks produce large (100 μV), low-frequency deflections, which may appear as delta or theta waves. These arise from the potential difference between the cornea and retina as the eyeball rotates during blinking. Most of the high-frequency activity (>20 Hz) in the awake EEG arises from resting muscle tone.[8]

EEG changes due to anaesthesia

There are characteristic changes that occur in the EEG when anaesthetic drugs such as propofol or volatile agents are administered, and it is these changes that processed EEG devices rely on to generate their values (Figure 3). The following is a simplified account of typical changes, which omits many subtleties, drug-specific effects, and inter-individual variation. Still, it is sufficient to enable a basic understanding of how these devices work. There are several excellent review articles which offer a more detailed coverage.[4,10-12]

Broadly speaking, when propofol or volatile agents are administered, there is an increase in the power of low-frequency waves (<30 Hz) and a relative decrease in the power at higher frequencies. Most of the decrease in the higher frequencies is from loss of muscle tone, which occurs even without the use of muscle relaxants.

Once unconscious, a characteristic feature at lower hypnotic drug doses is the "spindle": a 1–2 second period of 8–14 Hz activity, which increases and then decreases in amplitude, giving it a distinctive shape. Spindles are associated with thalamic hyperpolarisation and are similar to those seen in natural sleep.

With a greater hypnotic dose, large "slow waves" become prominent (20–100 μV, 0.5–4 Hz). These are often accompanied by smaller alpha waves, giving rise to the classic "alpha-delta" description of the anaesthetised EEG. A notable feature is "phase-amplitude coupling", in which small alpha-band oscillations can be seen superimposed on the peaks or troughs of larger slow waves.[13] Painful stimuli may induce one or more of several EEG changes: increased beta activity, loss of alpha waves ("alpha dropout"), or even increased delta waves ("delta arousal"). These changes can be reversed by the administration of opioids.[14,15]

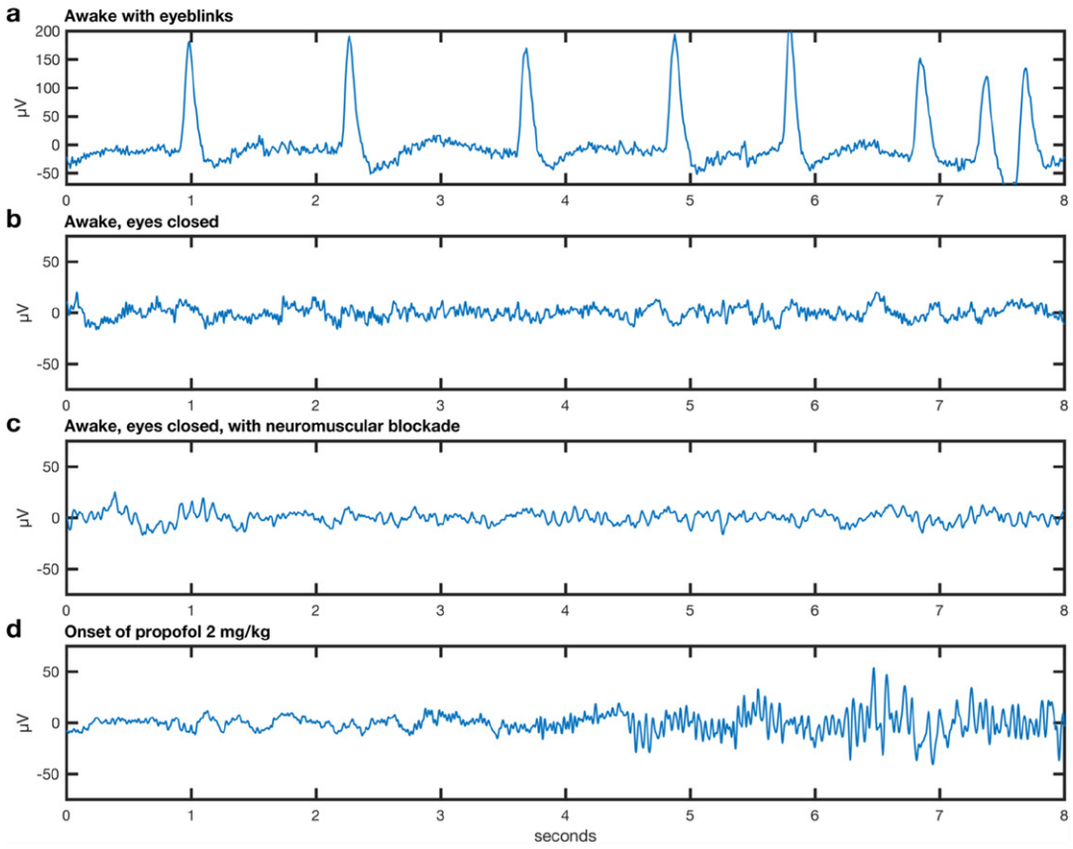
At even higher doses, "burst suppression" is induced. This is a pattern of brief periods of electrical silence ('suppression'), punctuated by large-amplitude "bursts" of EEG activity. Burst suppression does not occur during normal sleep. It can be quantified as the "suppression ratio" – the percentage of time that the EEG is suppressed over the preceding 30 or 60 seconds. When given as a sole agent in young adults, burst suppression starts to appear at propofol levels of ~5 mcg/mL and sevoflurane of ~1.5 MAC. In the elderly, or when used with other agents, it can occur at much lower concentrations. There is usually a profound reduction in brain metabolic activity when burst suppression is induced by anaesthesia, but it is not typically a desirable EEG state except in specific clinical circumstances.[4]

The relationship between these EEG changes and the level of consciousness is not precise, and the extent to which specific features appear varies between patients. EEG changes can be related to the dose of the drug ("drug-related"), or to the state of consciousness of the patient ("state-related"). Some elderly patients do not generate large slow waves, but transition to burst suppression with just a slight increase in drug dose.[16–18] Emergence from anaesthesia is not the opposite of induction, and can display a number of different patterns.[19]

Finally, this sequence of EEG changes occurs only with specific drugs. Agents such as ketamine and nitrous oxide produce different EEG patterns for the same level of responsiveness.[4,11] Ketamine can increase beta and gamma power, and reduce alpha power. In high doses, it can cause large delta waves.[4,20] Nitrous oxide has varied effects depending on dose, often increasing beta and gamma power or reducing alpha power. Large slow waves may appear during wash-in and even wash-out.[4,21,22] Neither agent causes burst suppression when given alone. Because processed EEG devices are not designed to track the sequence of EEG changes that these drugs induce, their values can be misleading when nitrous oxide or ketamine are used.

These drug-specific differences illustrate a fundamental limitation: the indices correspond to changes in cortical electrical activity, rather than a true physiological endpoint such as "level of consciousness."

Figure 3. The effect of anaesthetic drugs on the EEG

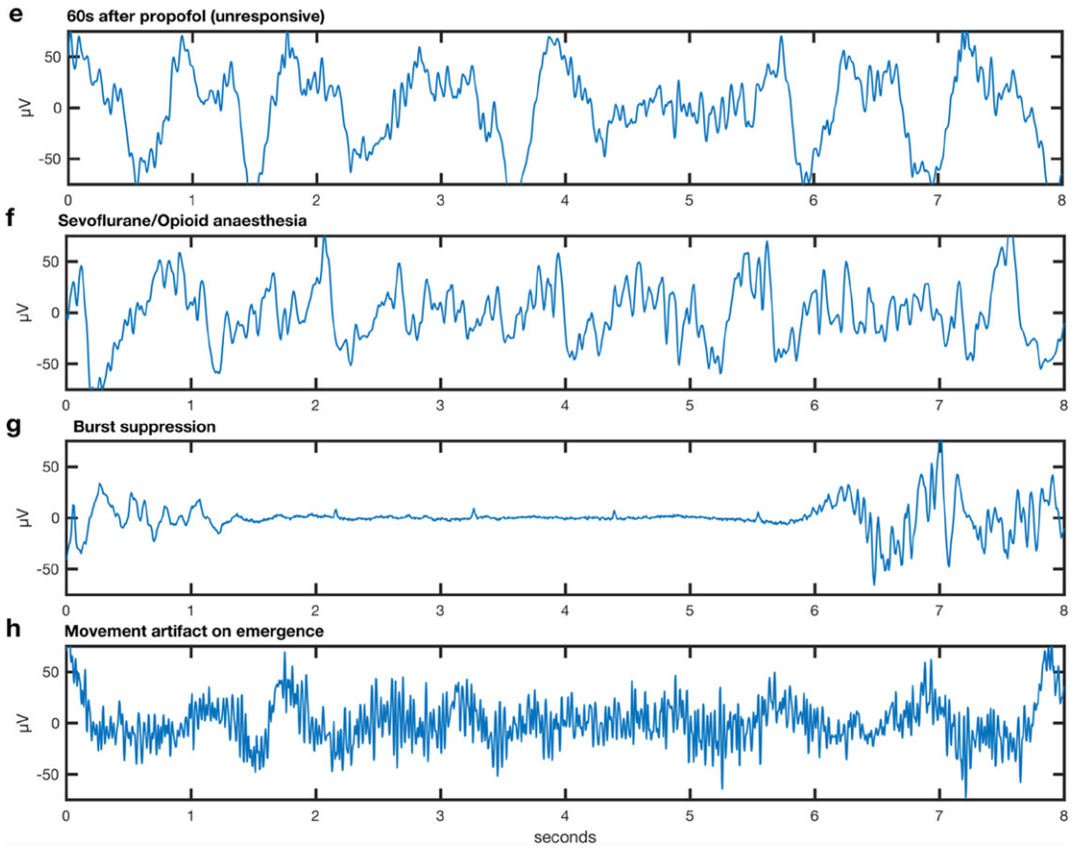


a) Awake patient with eyeblinks. The large eyeblink deflections frequently exceed the 100 μV display range. Between blinks the awake EEG resembles Panel B.

b) Awake patient with eyes closed. The typical high-frequency, low-amplitude pattern in an awake individual. The trace appears "fuzzy" due to high-frequency gamma waves from muscle activity oscillating too rapidly to resolve.

c) Awake patient with neuromuscular blockade. The fuzziness from the gamma waves of EMG is absent, but the EEG is otherwise unchanged. Alpha waves are seen at second one and four.

d) Ten seconds after a bolus of 2 mg/kg propofol. At the third second, the moment of propofol onset, there is a sudden increase in alpha and beta activity; this increased beta activity is a transient phenomenon and can occur with sedation-level doses as well.



e) Sixty seconds after propofol. The EEG has "slowed" and now contains large delta waves with some superimposed alpha. Other frequencies are still present, but they can be difficult to see without a spectrogram.

f) Established sevoflurane/opioid anaesthesia. This shows the typical large amplitude alpha-delta pattern of anaesthesia.

g) Burst suppression. Four seconds show "suppressed" EEG, followed by a "burst" giving a "suppression ratio" of 50%. Small QRS complexes (ECG artefact) are visible during the suppressed period. QRS complexes are usually obscured by EEG activity and are most apparent during suppression. It is more commonly seen in patients with left ventricular hypertrophy, thick necks, and with left-sided electrode placement.

h) Muscle artefact from patient grimacing during emergence. Many vertical spikes are seen, typical of muscle twitches.

EEGs are eight seconds' duration, and were recorded with frontal bipolar electrodes from a BIS monitor. For more detailed discussion of the nuances of EEG changes during anaesthesia, see the excellent review articles by Sleigh,[4] Hight,[11] or Purdon.[22]

HOW PROCESSED EEG DEVICES GENERATE THEIR INDEX VALUES

This section describes the key principles of index generation, while avoiding undue technical detail. The goal is to establish a conceptual framework for understanding how the index values are generated rather than offer an exhaustive discussion of every device. We will concentrate on the BIS algorithm, because that is the most well-described and it serves as an excellent guide to understanding the principles of operation of other devices. The physical components of typical devices is summarised in Table 1.

Preliminary analysis

The very first step is to convert the tiny voltages detected at the scalp into numbers that can be analysed. This process, called analogue-to-digital conversion, also includes filtering to remove frequencies outside the range of interest (typically below ~0.5 Hz and above ~128 Hz). The signal is sampled about 256 times per second to create a stream of numbers suitable for automated computer analysis. The analysis itself begins by mathematically processing the raw EEG to determine its frequency composition. This is sometimes referred to as "converting the EEG waveform from the 'time domain' (how voltage changes over time) to the 'frequency domain' (how much of each frequency is present during a particular period)."

Epochs and artefact

The EEG is analysed stepwise, breaking it into small, overlapping segments called "epochs", usually around two seconds long. Epochs which contain unwanted signals, such as from diathermy, vibration, patient movement, or eye blinks, are classified as "artefact" and are discarded.

Accurate artefact detection – separating noise from meaningful data – is crucial, but not all interference is easily recognised. Signals that mimic EEG or which lack typical artefact signatures can evade detection, and because the device calculates its index from power ratios across multiple frequency bands, artefact at key frequencies can significantly distort results. This is why electrical noise from an operating table transformer or the fluttering of a forced-air warmer can alter index values.[24,25] Displaying the EEG waveform is therefore essential, to verify that the monitor is analysing a valid signal (Table 2). Manufacturers' default screen settings vary greatly, so it is important to check that the waveform is being presented with a familiar scale and sweep time.

The Fourier transform

In the previous section, we saw how the raw EEG can be divided into traditional frequency bands. The Fourier transform takes this a step further by representing the EEG during each epoch by a set of sine waves of different frequencies, typically spaced every 0.5 to 1 Hz. In addition to the frequency, each sine wave has an amplitude (size), and a phase (timing relative to other waves). If all of these sine waves were added together, the original waveform would be reconstructed.

A key concept is the "power" of each wave, which quantifies how much of that frequency is present in the EEG. Mathematically, power is proportional to the square of the wave's amplitude – twice the amplitude means four times the power. This is similar to ocean waves: a wave that is 10 times higher carries 100 times more energy. In EEG terms, when slow waves are large, we say there is a high level of "slow wave power." This is sometimes referred to as "slowing" of the EEG, but the EEG has not really "slowed down", it just has more low frequency waves and less high frequency waves.

To improve accuracy, results from a single two-second epoch are usually averaged over the preceding 20-30 seconds. The power at each frequency can now be plotted as a graph – the power spectrum – which shows how important each frequency is in shaping the original EEG (Figure 4b). By adding up the power of all the sine waves in a certain frequency range, the "total power" within that frequency band (the "band power") can be calculated. These bandpowers are the basis of most automated EEG analysis.

While few devices display the power spectrum, some newer models use this information to generate a "spectrogram". A sequence of spectra is plotted over time, with power represented usually by colour, but occasionally by height. In this form, it becomes easy to visualise how power in different frequency bands changes throughout the anaesthetic.[4] The spectrogram reveals patterns of brain activity that are lost when the EEG is reduced to a single numerical index. Spectrograms can vary significantly in appearance between manufacturers and between patients, partly due to technical differences in how power is mapped to colour, and partly due to individual differences in EEG power and electrical conduction (Figure 4d).

Index calculation

The design of a useful processed index requires selecting features in the power spectrum that change with anaesthetic drug dosing in a way that aligns with changes in responsiveness. In a sense, the index is an estimate of how far the current EEG is along the sequence of waveforms: from the awake pattern, through slow waves, to burst-suppression (Figure 3).

All currently available monitors follow a similar approach: they calculate power within various frequency bands, derive ratios to quantify changes in the power spectrum, and then combine and scale these values to produce a final index.

The final scaling to a 0–100 range is based on calibration studies in which EEG recordings are aligned with patient responsiveness. Like any population-based model, the monitor only approximates the population average, and its accuracy depends on the quality of the validation studies and the specific drugs tested.

Importantly, the calibration studies from awake to loss of consciousness have typically been done without using neuromuscular blocking drugs.[5,26,27] This has obvious implications for whether these devices might reliably be used in paralysed patients.

Unlike physiological monitors such as pulse oximeters, which follow a clear chain from a physical principle, through signal processing, to a number with a clear meaning, processed EEG indices are not direct measures of a defined physical quantity. Rather, they are real-time implementations of statistical models, which evaluate a set of summary descriptors of the EEG power spectrum and then combine them in a way that was found, experimentally, to best fit the original training population.

How the Bispectral Index (BIS) is calculated

BIS is the best-described of the processed EEG indices mainly because of Connor's reverse-engineering of the algorithm.[28,29] Examining its calculation provides insight into the type of analysis these devices use to generate their values.

The core components

Having digitised the electrode voltages, and discarded epochs which contain unwanted noise, analysis begins by calculating the power spectrum average over the last 30-60 seconds (Figure 4). From this it derives three band-power ratios.

Beta Ratio: the logarithm of power in the 30–47 Hz band relative to the 11–20 Hz band. The name is slightly misleading, it is really gamma (>30 Hz) relative to low beta (11–20 Hz), but we retain the conventional term. When awake, most of the power >30Hz is from muscle, and because muscle tone decreases with sedation and anaesthesia, power in the gamma range falls. At the same time, 11–20 Hz power rises, so the fall is even greater in relative terms. The Beta Ratio therefore decreases during sedation and induction of anaesthesia.

Normalised Gamma: the logarithm of power in the 40–47 Hz band relative to total EEG power (0.5–47 Hz). This is gamma power as a proportion of total EEG power. Like the Beta Ratio, it decreases with induction, because 40–47 Hz activity decreases and slower activity increases. However, unlike Beta Ratio, it is also affected by delta and theta power. Increases in these will reduce the Normalised Gamma because they add to the denominator. Therefore, Normalised Gamma is more responsive than the Beta Ratio during stages of anaesthesia when slow waves are prominent.

Delta Ratio: the logarithm of power in the 0.5–4 Hz band relative to the 11–20 Hz band. This is the mirror image of the Beta Ratio: instead of quantifying the proportional fall in higher activity, it quantifies the proportional rise in slow activity. Delta Ratio is used to determine how the two previously mentioned ratios are combined.

Rescaling and compression

The raw band-power ratios have values around -60 to 0 dB. To align them with the BIS scale, the algorithm applies non-linear transformations. These not only rescale the values, but compress them in some regions while expanding them in others. The Beta Ratio is remapped to approximately 55-104, and the Normalised Gamma Ratio to about 20-105.

The rescaled ratios are then merged into a single "provisional" index. When the Beta Ratio is lower than the Normalised Gamma, the Beta Ratio is used. When the Normalised Gamma is lower, then Delta Ratio determines how the two measures are combined. If delta power is high, Normalised Gamma predominates; otherwise the Beta Ratio has greater influence. The combined value is then compressed to fit the 0-100 scale.

The effect of burst suppression

The final modification comes from burst suppression. BIS calculates the "suppression ratio" (SR): the percentage of time the EEG is suppressed during the preceding 63 seconds. When SR is between 10-50%, the provisional index is decreased slightly, producing values between 20-40. When SR exceeds 50%, the EEG band-power ratios no longer have any effect, and the index is determined solely by the equation:

BIS = 50 – (SR/2)

This generates a BIS of zero when the EEG is fully suppressed.[40,41]

The full BIS algorithm is more elaborate than the simplified account given here, but this description illustrates the main principles. The full algorithm calculates more than ten different band-power ratios and incorporates several time-dependent processes when blending them. In some cases, features from the preceding four minutes are used to decide which ratio to apply, while segments from up to 20 minutes earlier alter the threshold for burst suppression detection.

Relation of bandpowers to consciousness

It is clear from the above that BIS is far from a simple or transparent calculation. Rather than having a clear logic, the index is assembled from a sequence of physiologically-unmotivated adjustments of EEG band-power ratios.

At which point, it is reasonable to ask: *"What do all these ratios have to do with consciousness?"* A fair answer might be, *"In a direct sense, not much."* They are not derived from any model of the brain, or of consciousness, but are *proxies* – summaries of EEG changes that are seen experimentally during anaesthesia.

It is important to appreciate that a bandpower measure like Beta Ratio is not *in itself* a measure of consciousness. It can track the drug effect of propofol and sevoflurane only because these drugs change both consciousness and Beta Ratio at the same time. Neuromuscular blockade has no effect on consciousness but it does reduce Beta Ratio, showing that Beta Ratio is not a direct measure of cognitive state. This distinction is subtle but central, and it underlies the assumptions on which EEG indices are built.

The method used to blend the band-power ratios was chosen by selecting whichever gave the greatest apparent accuracy for the drugs and patients in the original development population. BIS is therefore best understood not as a mechanistic or personalised measure of cognitive state, but as a group-level "best fit."

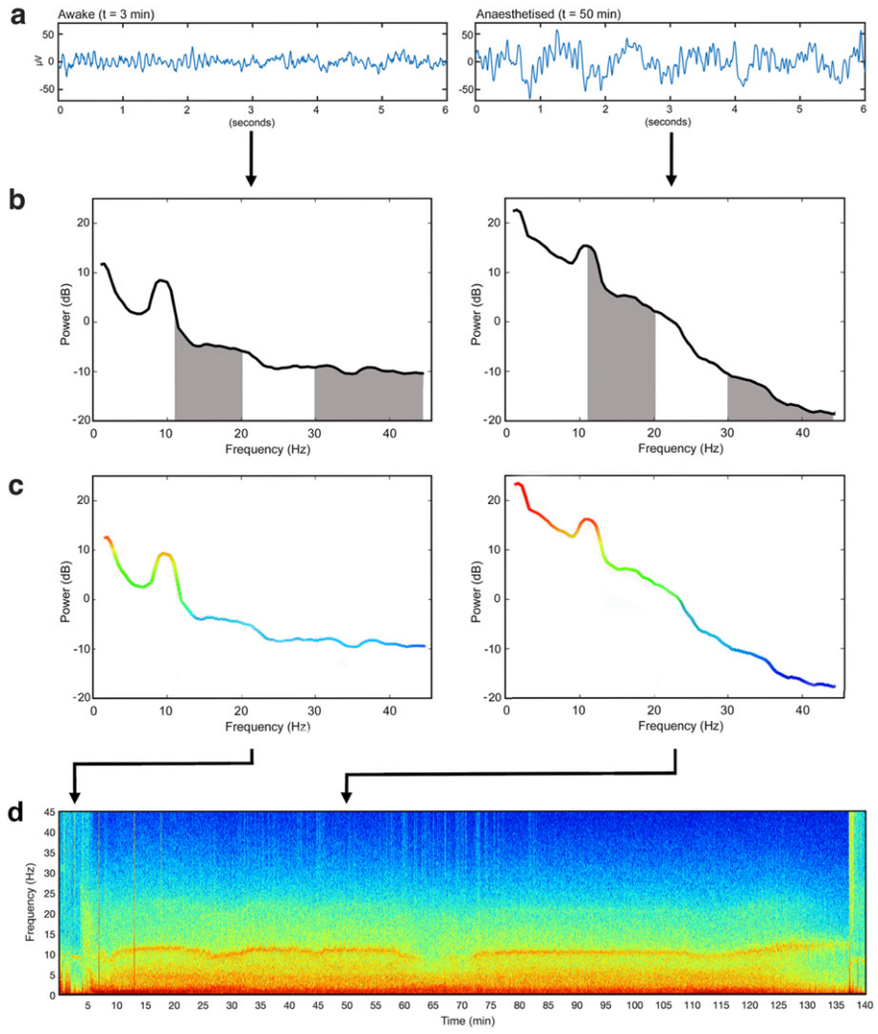
The limitation is not only statistical but also anatomical. Indices like BIS are derived entirely from frontal EEG, yet it is doubtful that consciousness resides in the frontal cortex. What these devices are really doing is evaluating is a set of drug-induced EEG changes in one brain region, under the assumption that these map in a reasonable way onto the neural processes that matter for awareness. That assumption may hold in broad terms, but it is indirect, drug-dependent, and incomplete.

The apparent precision of the final index, carefully sculpted to a 0–100 scale, conceals the blending of different measures, the statistical basis of its design, and the anatomical limitation. Recognising this is key to interpreting BIS intelligently and resisting the misplaced confidence that its scale can invite. The same logic applies to other processed EEG indices, which differ in detail but share the same empirical foundations and the same vulnerabilities.

Where is the "bispectral analysis"?

A follow-up question may arise: why has "bispectral analysis," from which the BIS index takes its name, not been discussed? Early studies suggested there was little advantage in computing the bispectrum,[31] and the recent reverse-engineering revealed that as soon as BIS calculates the Fourier transform, it discards the phase information required for bispectral analysis. It appears that there is no bispectral analysis in the "bispectral index" monitor.[32]

Figure 4. The BetaRatio before and after induction of anaesthesia



a) Two segments of EEG from before induction, and during sevoflurane anaesthesia; b) Power spectra at these two points, calculated over 20 seconds. Shaded areas indicate the frequencies used to calculate the BetaRatio; c) The power spectrum coloured to indicate power; d) The colour spectrogram for the entire anaesthetic, with the two timepoints indicated.

Before induction (a, left), the raw EEG is low amplitude with alpha waves. During anaesthesia (a, right), it has larger amplitude with prominent delta and alpha waves. The power spectrum (b) shows these changes more clearly, and demonstrates increased power at all frequencies below ~30 Hz, and decreased power above. The alpha rhythm is visible as a peak in the power spectrum, at ~9 Hz when awake, and 11 Hz during anaesthesia.

The shaded areas demonstrate how the BetaRatio will change due to anaesthesia. During anaesthesia, there is less power in the upper band, and more in the lower band, and so the BetaRatio decreases.

Panel c) shows the spectrum with colour used to indicate power. Blue is low power, red is high power, and yellow and green intermediate. The final spectrogram d) uses the data from a large number of successive power spectra remapped to colour, with time on the x-axis, and frequency on the y-axis. Anaesthesia was induced at minute 4. The increased delta and alpha power are shown by the red bands. Note the loss of alpha oscillations at minute 62. This "alpha dropout" occurred just before the patient became tachycardic and hypertensive. Opioids were administered, and a few minutes later the alpha rhythm returned.

Other processed indices: Entropy, Conox, SedLine

Other devices operate on similar principles, in that they evaluate the power in different frequency bands, then combine them and scale the results. While manufacturers emphasise unique features in their descriptions, these differences largely reflect variations in how the band-powers are combined, rather than being fundamentally distinct analytical methods.

For example, the GE Entropy monitor uses “spectral entropy” rather than “power” in different frequency bands, to generate two related indices: State Entropy (SE) and Response Entropy (RE), using frequency ranges of 0.8–32 Hz and 0.8–47 Hz respectively.[33,34] Despite common misconceptions, "spectral entropy" does not measure the “randomness” of the EEG but rather how evenly power is distributed across frequencies. Essentially, it is another way to quantify shifts in the power spectrum.[35,36] The developers proposed that RE would be more sensitive to EMG, while SE remained unaffected but in practice EMG affects both indices.[9,37]

The Conox monitor analyses power in six frequency bands across a similar range (1–44 Hz) and combines the results to generate an index of the "state of consciousness" (qCON) and a second index (qNOX) intended to indicate the "likelihood of response" to nociceptive stimuli.[26]

SedLine, originally marketed in 2001 by Physiometrix as the Patient State Index (PSI), and now integrated into Masimo’s Root device, takes a similar approach. It uses bifrontal electrodes and primarily relies on band-power analysis, although it claims to also evaluate the degree of EEG similarity on either side of the head.[38,39]

In all devices, burst suppression is calculated over the preceding 30-60 seconds, and, similarly to BIS, is used to decrease the index further towards zero.[33,40,41]

Table 3 lists features of devices available in Australia and New Zealand.

Spectral edge frequency (SEF95)

The SEF95 is an indication of the upper “edge” of the spectrum, defined as the frequency below which 95% of the total EEG power lies. Awake values are typically 20–25 Hz, and decrease during anaesthesia to ~8–14 Hz.[42] The SEF95 provides only a glimpse of the raw EEG data, and is sensitive to artefacts such as eye blinks or movement. It predates modern processed EEG devices, and while there has been a mild resurgence of interest in recent years, this appears to be driven primarily by marketing.[4,29,69]

Other displayed variables – EMG, SQI

Each manufacturer estimates EMG slightly differently, but the general principle is to assess the power in higher frequencies where EEG activity is minimal. BIS calculates EMG from power in the 70–110 Hz range over the preceding 10 seconds, displaying it as a bar graphic – an appropriate approach given the imprecise nature of the data. Conox evaluates power in the 30–42 Hz range over 30–60 seconds, displaying it on a 0–100 scale.[43] SedLine does not describe its method but it also displays EMG on a 0–100 scale. EMG values between devices are, therefore, not comparable.

Some monitors display a "Signal Quality Index" (SQI) or an "Artefact Index", which reflects a combination of electrode impedance and the proportion of artefact-affected epochs over the last ~60 seconds. While these values do not indicate the reliability of the index itself, most monitors stop displaying values when SQI falls below a certain threshold.[43,44]

LIMITATIONS OF COMMERCIAL PROCESSED EEG INDICES

There is no doubt that these indices generally decrease during induction of anaesthesia, and come back up again at emergence, but an appreciation of the role of any monitor requires an understanding of its weaknesses and when it may be misleading.

The problem of EMG

The electrical signal from muscle (primarily the forehead muscles) spans a broad frequency range, from below 1 Hz to over 200 Hz. This completely overlaps the EEG signal, making separation difficult. EMG is

particularly prominent in frontal electrodes. In an awake individual, more than 90% of the power over 30 Hz originates from muscle rather than brain.[8,9]

EMG activity decreases in a dose-dependent manner in response to anaesthesia, even in the absence of neuromuscular blockade. During balanced anaesthesia, it is typically minimal or absent. As a result, EMG serves as a reasonable, although indirect, marker of anaesthetic effect. Processed EEG devices appear to rely on this relationship and incorporate EMG into their algorithms by using frequency bands in which muscle activity predominates.[5,26,27,33]

This introduces an obvious limitation: such systems will be prone to failure when neuromuscular blocking agents are used. This is why BIS and Entropy values drop to low levels in awake individuals given neuromuscular blocking drugs, despite the EEG clearly indicating they are awake.[9,45,46] The same effect has now also been demonstrated with Conox.[47] Other devices which rely on frequency bands in which EMG is predominant are likely to share this limitation.

The irony here is striking: the very situation in which processed EEG indices could be most useful – detecting awareness in the muscle-relaxed patient – is precisely where they may be least reliable. Of course, by the time the patient is fully awake, the horse has bolted. Ideally, an EEG monitor would identify inadequate anaesthesia early enough to alert the anaesthetist before that point is reached.

The problem of precision

Processed EEG monitors use a 0–100 scale, implying a high level of precision. However, studies consistently show wide variation in index values at the same level of patient responsiveness, with substantial overlap between responsive and unresponsive states.[5,48–52] The original BIS calibration study demonstrated some patients were non-responsive to voice at BIS 75, while others were still responsive at 51.[5]

This is not simply a reflection of the inter-patient drug variability that anaesthetists encounter daily. These indices purportedly represent a physiological endpoint, ostensibly helping to manage pharmacodynamic variability. Yet, if they were truly measuring a physiological state, we wouldn’t expect index values from different levels of consciousness to overlap. By analogy, it would be as if a blood pressure monitor showed significantly different readings in different patients despite their actual blood pressure being the same.

Another issue is the internal inconsistency of these devices. Identical BIS or Entropy monitors used simultaneously on the one patient can produce substantially different index values.[53,54] Entropy monitors have even been shown to generate different values when repeatedly presented with the exact same EEG.[9] If two identical monitors can differ by more than 10 or 20 points in the same patient, clearly a 0-100 scale grossly misrepresents the device’s accuracy, and suggests that the scale itself may owe more to marketing considerations than physiological reality.

Finally, different devices produce discordant results. When EEG recordings indicating inadequate anaesthesia were replayed to five different devices, clinically significant disagreements occurred in 70% of cases.[55] It seems perverse that the anaesthetic dose that a patient receives could ultimately depend on which monitor that particular hospital has purchased, a decision shaped partly by financial and marketing considerations, rather than by patient physiology.

The problem of the reference range

BIS values between 40 and 60 are often regarded as a definitive range for ensuring unconsciousness. However, not only is there a lack of strong evidence to support this range, but there is good evidence against it.

In the original BIS calibration study, approximately 15% of participants receiving low-dose infusions of propofol, midazolam, or isoflurane, were still responsive to voice at BIS values between 50 and 60.[5,56] The authors themselves stated that “BIS levels less than 50 indicate that a patient is *probably* unconscious.” This has been confirmed independently.[57]

Given that some conscious patients had BIS values below 60 in the very study used to calibrate the algorithm, it was inevitable that this would also occur in surgical patients, and indeed, it did. A few years later, the B-Aware study reported a patient who experienced awareness with recall, despite a BIS value that never rose above 55. This prompted the authors to suggest that 55 might be a safer upper limit than 60.[58] Several large trials and case reports also documented intraoperative awareness with BIS values below 60.[59]

The B-Unaware trial reported three cases, and the BAG-RECALL trial reported five.[60,61]

Although it may be true that most patients with adequate anaesthesia have a BIS between 40 and 60, it does not follow that a BIS between 40 and 60 means they are adequately anaesthetised. "All dogs have four legs. This has four legs, therefore..."

Other manufacturers have published little or no data to support their suggested reference ranges. None have claimed to calibrate their indices in paralysed patients. As a result, we do not know how reliable these ranges are in different anaesthetic scenarios – particularly those involving neuromuscular blockade. We are left with devices that are widely used, but poorly validated, and regulated to standards far below those applied to the drugs they are meant to guide.

The problem of generalisability

Most commercial processed EEG monitoring indices were calibrated using studies conducted on young, healthy volunteers, meaning their performance is largely unvalidated in older or medically complex patients.[62] In clinical settings, variability in anaesthetic regimens, pre-existing medical conditions, fluctuating surgical stimulation, and physiological perturbations further challenge their reliability.

A particularly vulnerable population is the elderly, where reducing anaesthetic dose may be desirable to minimise side effects on other organ systems. Ageing is associated with a number of neurophysiological changes, yet processed EEG algorithms do not account for age. This can lead to higher index values despite older patients being more sensitive to anaesthetic drugs.[16,18]

The problem of lacking a sound neurobiological foundation

The lack of a solid neurobiological foundation is possibly the root cause of many deficiencies in processed EEG devices. Consciousness itself is poorly understood, as are the mechanisms by which anaesthetics induce unconsciousness.[63,64] This is why devices rely on broad spectral changes and use frequency bands in which muscle activity predominates.

A fundamental challenge is that EEG changes can arise both directly from the drug itself ("drug-related" changes) and from the altered level of consciousness that the drug produces ("state-related" changes). Should an index primarily reflect drug-related changes (and so predict dose), or should it track state-related changes (predicting level of consciousness)? Some studies seem to assume that both can be achieved simultaneously, which overlooks pharmacodynamic variability. A stronger neurobiological foundation may help disentangle these influences, but even with greater understanding, they may remain intertwined.[65] Addressing this issue is essential for improving the reliability and clinical utility of EEG-derived indices.

THE ROLE OF PROCESSED EEG MONITORING: ENHANCING SAFETY WHILE RECOGNISING LIMITATIONS

The question is, are these devices so inaccurate that they should not be used at all? While their lack of reliability is a legitimate concern, they still serve an important role when used appropriately.

Broadly speaking, processed EEG monitors can be used in two distinct ways: as an alarm to identify potential problems or as a guide to dose titration. These two approaches have very different implications for clinical decision-making.

As an alarm

In this approach, anaesthesia is conducted using established dosing regimens that include a safety margin to account for patient variability. If the index shows an unexplained trend or falls outside expected limits, this should prompt checks of drug delivery systems and equipment, with values verified by looking at the raw EEG or its spectral display. Used in this way, processed EEG can provide an additional layer of safety, notwithstanding its inaccuracies.

The history of anaesthesia has demonstrated the benefits of engineering human error out of the system and introducing fail-safes and alarms wherever possible. Total intravenous anaesthesia, however, bypasses many of these safeguards, and processed EEG monitoring can help restore some of that protection, despite its limitations.[2,66–68] Even an alarm that works only part of the time may be preferable to no alarm at all.

As a guide to dose titration

Reducing anaesthetic doses to low levels based solely on processed index values is not a safe approach. The inaccuracies discussed earlier mean that at the same index value, some patients may be anaesthetised while others are not, even at BIS values less than 60. That said, very low index values are often a result of burst suppression, suggesting that the dose could be safely reduced. Again, examining the raw EEG or the spectrogram will help distinguish between situations in which the index is accurate or misleading.

Diagnosing the index

In both cases, it is important to display the raw EEG, to determine whether the signal is suitable for automated analysis, or has been distorted by artefact. Just as cardiovascular monitoring is not based solely on a numerical heart rate, and end-tidal CO_2 is not interpreted without examining the waveform, anaesthetic management should not rely purely on a processed index derived from an obscure algorithm.

CONCLUSION

Processed EEG monitors have made brain monitoring a routine part of anaesthetic practice. However, their index values oversimplify the complex interplay between patient physiology, anaesthetic regimen, and the risk of awareness.

Their indices are generated by calculating a series of band-power ratios from the digitised EEG, and then combining and scaling the result to fit a 0–100 range. They are not measuring the level of consciousness directly, but rather how closely a patient's EEG matches the average patterns in the original training set. They are essentially statistical constructs, calibrated to their development population, and so although they may correlate with responsiveness at a group level, they can be misleading in individual patients.

Reference ranges lack supporting evidence, and no device has been calibrated for use in paralysed patients. Finally, the indices are vulnerable to artefact and other technical or physiological interference.

For all these reasons, processed EEG monitors should not be used as the primary guide to anaesthetic dosing. In their current form, they are most useful when interpreted alongside a sound understanding of the raw EEG waveform and spectrogram. Anaesthetists should be familiar with the typical EEG effects of commonly used agents and remain aware of the limitations of processed indices.

APPENDICES

Table 1. Physical components of processed EEG devices

Component	Function	Comments
Electrodes	Electrodes convert electrical potentials on the skin into electronic currents within the device, enabling measurement and analysis of underlying ionic currents.	Most processed EEG devices use single or dual-channel frontal arrays with metal/gel electrodes. Low electrode-skin impedance is critical, ensured by design features like Ag/AgCl electrodes, conductive gels, or "tine pads" that slightly penetrate the stratum corneum to reduce impedance. Proper application, including skin preparation, pressure and consistent technique will minimise the impedance.
Amplifiers	Differential amplifiers in processed EEG devices magnify very small voltages (10-50 μV) for processing.	Differential amplifiers magnify the voltage difference between two electrodes while suppressing signals common to both, a process known as "common mode rejection". This selective amplification helps reduce interference from external electrical sources, such as those present in an operating theatre.
Computing device	The computing device performs analogue-to-digital conversion (ADC) of the waveform, digital filtering, artefact rejection and further processing and analysis. Some devices allow uploading of the EEG and processed indices for later analysis.	An analogue-to-digital converter (ADC) converts the continuous EEG signal to discrete digital values many times per second, enabling further digital processing. Digital filtering and artefact rejection help reduce effects of noise. However, excessive filtering can unintentionally remove physiologically relevant frequencies, potentially distorting the EEG.
Monitor	Display the various outputs of the system, allowing users to evaluate the patient data.	Most processed EEG systems display a combination of the following: raw EEG, processed indices, and a colour spectrogram.

Information sourced from Rampil (1998)[29]

Table 2. External factors affecting processed EEG values

Source of interference	Appearance in EEG waveform	Effect on processed index	Mechanism of effect
Physiological			
Blink artefact	High amplitude (~100-200 μV) deflections with each blink.	Contributes to low frequency band power (delta or theta bands).	Cornea is electropositive relative to the retina. As the eye blinks, the globe turns slightly upwards, resulting in deflections in the EEG waveform.
Muscle activity (most commonly frontalis/ temporalis muscles)	High-frequency and relatively high-amplitude activity (amplitude correlates with strength of muscle contraction). May appear as a "fuzzy" waveform, or as short vertical "spikes."	Contributes to higher frequency band power (typically beta and gamma). Index likely to be elevated when present, and reduced when absent.	High frequencies are used by devices to generate high index values. Therefore increased muscle tone during anaesthesia can increase index values. Conversely, loss of EMG can cause falsely low index values.
ECG artefact	Small QRS-like complexes, occurring regularly with the heart beat.	May increase or decrease processed index values, depending on the size and relative contribution to different frequency bands.	More pronounced in patients with LVH, and thick necks, which enable conduction of the ECG voltage.
Ventilation	Rhythmic, very slow gentle waves synchronised with ventilation pattern; often difficult to appreciate on the raw waveform unless viewing at a lower reading speed.	Contributes to lower frequency band power, theoretically may lower index value.	Overlap between frequency components of ventilation with low frequency bands.
Non-physiological (external)			
Electrode "pop"	Sharp steep, high-amplitude upstroke followed by downslope before return to baseline.	Often triggers artefact rejection as amplitude range typically exceeds that of the system.	Mechanical movement of electrodes and/ or associated cables produce distortions in scalp-electrode impedance.
Electrical interference (e.g. operating table transformer)	Bizarre-appearing waveform.	Can cause high or low index values.	Induced currents can generate frequencies in the signal that alter the frequency ratios but do not trigger artefact-rejection algorithms.
Forced-air warmer	High-frequency activity.	Inappropriately high BIS values although a low-frequency flutter may cause low values.	Mechanical vibrations of processed EEG system cables caused by air circulation.
Power supply	High-frequency (50 Hz) and continuous activity makes waveform appear "fuzzy". Most systems have a specific filter to remove this from the waveform.	Power spectra affected by a large spike at 50 Hz.	Poor electrical shielding, poor electrode contact, or lack of appropriate filtering.
Surgical diathermy	High-frequency, high-amplitude interference rendering the underlying EEG wave difficult to discern.	Increased BIS value during electrocautery if not excluded by artefact rejection.	Large amplitude contamination of EEG signal, from induced current and muscle stimulation. Usually results in rejection of epochs, but low levels may not trigger artefact-rejection.

Information sourced from Bennett et al. (2007)10 and Rampil (1998)[29]

Table 3. Summary details of processed EEG devices available in Australia and New Zealand

Monitor	Data and display features	Index ranges, manufacturer recommended target range*
Bispectral index	Raw EEG BIS EMG Suppression ratio Signal quality index Colour Spectrogram, SEF95	 0-100, Target 40-60 Bar graphic 0-100 0-100 Recent models only
Conox	Raw EEG qCON index qNOX index EMG Signal quality index Suppression ratio	 0-99, Target 40-60 0-99 0-100 0-100 0-100
Entropy	Raw EEG State Entropy Response Entropy Suppression ratio	 0-91, Target 40-60 0-100 0-100
SedLine	Raw EEG Patient state index (PSI) Artefact Suppression ratio Colour Spectrogram SEF95	 0-100, Target 25-50 0-100 0-100 0-30

*Numerical range associated with a “general anaesthetic” hypnotic state

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Pulse oximetry – understanding the device and the sources of error

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INTRODUCTION

The first pulse oximeter was invented in 1974 by Takuo Aoyagi. In the 50 years since, it has become an indispensable monitor in anaesthesia practice and represents one of the most significant contributions to the safety of modern anaesthesia.

Monitoring patient oxygenation is an essential part of anaesthesia. Historically, this took the form of visual inspection of the patient's skin colour. However, "Is my patient pink or blue?" is a very blunt instrument for assessing oxygenation.

The ability to quantify oxygenation was improved by the development of the blood gas analyser in 1957 allowing clinicians to formally measure arterial oxygen saturation (SaO_2). SaO_2 is the fraction of total haemoglobin that is oxygenated in an arterial blood sample. Despite providing a much more precise measure of oxygenation, the delay between sampling and results limited its utility in continuous assessment of patient oxygenation.

The pulse oximeter is a device that enables non-invasive, continuous measurement of peripheral oxygen saturation, known as SpO_2. Its key advantage is that it provides a beat-to-beat measure of oxygenation, which, in most circumstances, accurately reflects the SaO_2 value.

Pulse oximeters provide additional useful data for the anaesthetist, displaying heart rate, a plethysmography trace and a perfusion index. However, this article focuses on explaining how the pulse oximeter determines oxygen saturation and explores common sources of error.

THE DEVICE

Physical components

The basic principle of pulse oximetry is that each cardiac cycle causes a transient increase in arterial blood volume within the tissue. If light is passed through this tissue bed, light absorption will increase as the volume of blood within the tissues increases.[1]

In order to measure the change in light absorption, each pulse oximeter contains at least two light emitting diodes (LEDs) and a photodetector. There are two broad physical arrangements of these components: transmittance and reflectance. In transmittance devices such as the familiar finger probe, the LEDs and photodetector are positioned on opposite sides of the device. Light emitted from each LED passes through the finger, and the photodetector measures the transmitted light.[2]

Reflectance-type oximeters are arranged so that the LED and photodetector are adjacent. Contrary to their name, emitted light is not reflected off a surface to the receiver but instead diffuses through the tissue bed.[3] These are usually applied to the forehead in situations where an adequate reading is unable to be obtained peripherally.

The photodetector measures the received light intensity, which creates a plot of light intensity (y-axis) against time (x-axis). Transmitted light intensity is mathematically converted to light absorption.[4]

By analysing light absorption at multiple wavelengths, pulse oximeters estimate the concentration of the different haemoglobin species in arterial blood. By estimating the relative proportions of oxyhaemoglobin (oxyHb) and deoxyhaemoglobin (deoxyHb) present, SpO_2 can be determined.

SpO_2 is the fraction of haemoglobin that is oxygenated as measured by a pulse oximeter. Mathematically, SpO_2 is defined as oxyHb divided by the sum of oxyHb and deoxyHb.

SpO_2 may sometimes differ from SaO_2, which is the fraction of total haemoglobin in its oxygenated form in arterial blood. Mathematically, this is the fraction of oxyHb divided by all haemoglobin species – namely oxyHb, deoxyHb, methaemoglobin, and carboxyhaemoglobin.

Signal processing

Starting with the LED's emission of light, five key processes take place to enable the SpO_2 value to be displayed.

1. Spectroscopy at two wavelengths of light.
2. Isolation of the arterial absorbance.
3. Comparison of the arterial absorbance at the two wavelengths.
4. Correlation of this ratio of absorbances to a SpO_2 value.
5. Data processing and display.

Step 1: Spectroscopy

Spectroscopy uses light of specific wavelengths to determine the concentration of an absorbing substance within its path. It is based on the laws of Beer and Lambert.

- Beer's law states that a beam of visible light passing through a chemical solution experiences absorption proportional to the solute concentration.
- Lambert's law states that the light absorbance of a layer of substance is proportional to the thickness of the layer.

These two laws are combined in the Beer-Lambert law, which states that total light absorption is equal to the product of the concentration of the absorbing substance, the distance light travels and the absorptive capacity (extinction coefficient) of the substance. Mathematically, this is written as:

$$A = \varepsilon LC$$

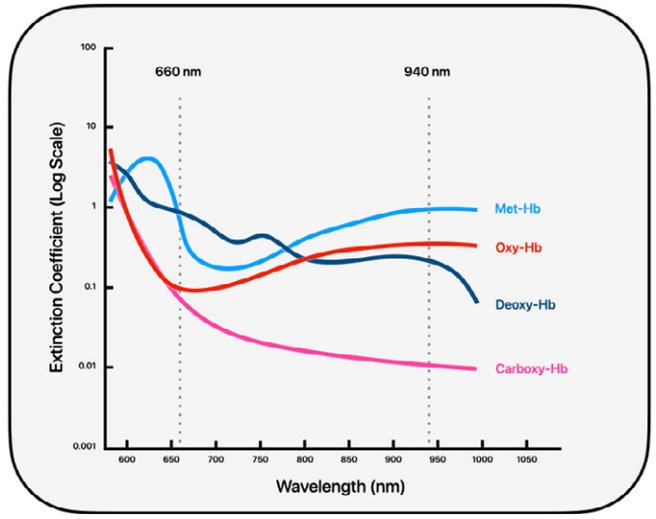
(Equation 1)

Where A is absorption, ε is the extinction coefficient of the substance, L is the path length, and C is the concentration of the substance.[5]

Spectroscopy is the technique used to determine the concentration of haemoglobin species within a blood sample. If the distance travelled by the light beam across the test tube and the substance's extinction coefficient are known, then the concentration can be determined.

Adult blood contains four species of haemoglobin: oxyhaemoglobin (oxyHb), reduced haemoglobin (deoxyHb), methaemoglobin (metHb) and carboxyhaemoglobin (COHb). Each haemoglobin species has a characteristic light absorption profile (Figure 1). When analysing a blood sample, it is necessary to use four different wavelengths of light to determine each species' concentration.

Figure 1. Absorption spectra of different haemoglobin species



The same basic principle is used in a pulse oximeter; however, in standard pulse oximeters, only two wavelengths of light are used. This is because the device only aims to measure the concentration of two substances, oxyHb and deoxyHb. The wavelengths used are 660 nm (red light) and 940 nm (near-infrared light).

The photodetectors used in pulse oximeters are not wavelength-specific. Therefore, the LEDs alternate brief light-emitting periods followed by a period where both are off. This happens 400 times a second. The device identifies which wavelength is being detected based on the timing of the signal received by the photodetector.[6]

In the situation where a mixture of two different substances (oxyHb and deoxyHb) are present within the light path, the Beer-Lambert equation becomes:

$$A = L(\varepsilon_0 C_0 + \varepsilon_d C_d)$$

(Equation 2)

Where ε_o is the extinction coefficient for oxyHb, C_o is the concentration of oxyHb, ε_d is the extinction coefficient for deoxyHb, C_d is the concentration of deoxyHb, and L is the path length.[4]

Unlike a test tube, a finger contains many different light-absorbing substances: bone, muscle, tendons, skin, and both arterial and venous blood. To determine the arterial concentration of oxyHb, the pulse oximeter cannot simply measure the total light absorption. Instead, it must isolate the component of light absorption occurring specifically within the arterial blood.

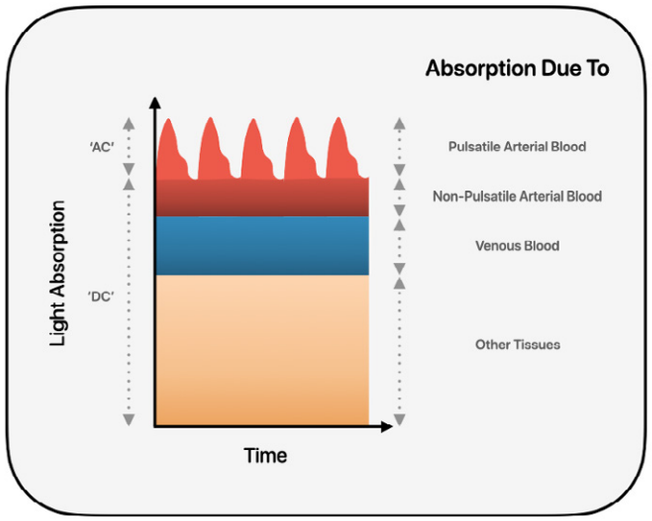
Step 2: Isolation of the arterial absorbance

The device exploits the pulsatile nature of arterial blood to exclude absorption occurring in tissues and venous blood. If we assume that the change in the volume of the fingertip during the cardiac cycle results mainly from arterial expansion, by comparing the absorption during systole to that during diastole, we can isolate the portion of absorption that occurs only within the arteries.

Figure 2 is a visual representation of this concept; the y-axis is absorption, and the x-axis is time. By convention, the pulsatile fraction of the absorption is referred to as "AC" absorption. This term is somewhat misleading as it does not refer to an alternating electrical current. In fact, it is not a current at all! A more

accurate description is “pulsatile absorption”, though “AC” remains the commonly used term in most texts. The static component of absorption is conventionally referred to as “DC”, which again is not “direct current”. This figure is not to scale as the AC component is often only 1-5% of the total absorption under normal physiological circumstances.[2]

Figure 2. Fractional absorption of light by different tissue components



Total absorption at any given time is the sum of the AC and DC absorption, which can be separated mathematically.[4]

Relating the AC absorption value back to the Beer-Lambert law, pulsatile expansion of the arteries increases the light path length (L), thereby increasing absorbance (Lambert’s law). This means that if we know the AC absorbance, we are a step closer to calculating the oxyHb concentration. Framing the previous equation in terms of pulsatile absorption only, we get the following:

$$A_{AC} = \Delta L(\varepsilon_0 C_0 + \varepsilon_d C_d)$$

(Equation 3)

There are still several unknowns in this equation. Path length is not measured by the device, so ΔL is unknown, and C_o and C_d have yet to be determined. This is where comparing the two wavelengths becomes important.[4]

Step 3: Comparison of the arterial absorbance at the two wavelengths

To solve the problem of the unknown path length, an *absorbance ratio* is calculated. This relies on the assumption that because both red and infrared light are travelling through the same tissue, the distance travelled (path length) is the same for both wavelengths. By dividing the absorbance of red light by the absorbance of infrared light, the change in length value (ΔL) can be removed from the equation. This ratio of absorbances is known as R.

The two remaining unknowns are the oxyHb and deoxyHb concentrations. But rather than the concentration of oxyHb, we want to determine the fraction of oxyHb. Conveniently, this is related to the fraction of deoxyHb! If we know that 80% of the Hb present is oxyHb, then the fraction of deoxyHb must be 20%, so we only need to determine one value, and the other will follow logically.

Rather than determining individual concentrations of oxy and deoxyHb, we could instead determine the total Hb concentration and the fraction in the oxyHb form. If we rewrite the R ratio with this in mind, we can remove Hb concentration (as this does not change regardless of whether red or infrared light is being used) and just express R in terms of the fraction of oxyHb (F_o). For the detailed mathematics of this, refer to Appendix 1.

The resulting equation looks like this:

$$R = \frac{\left(\varepsilon_0 F_0 + \varepsilon_d (1 - F_0)\right)_{660}}{\left(\varepsilon_0 F_0 + \varepsilon_d (1 - F_0)\right)_{940}}$$

(Equation 4)

This equation represents R as derived from the Beer-Lambert Law.

The device itself measures R from the received light intensity signals, which are converted mathematically to absorption values. R, as measured by the device, is expressed as:

$$R = \frac{AC_{660} \,/\, DC_{660}}{AC_{940} \,/\, DC_{940}}$$

(Equation 5)

Where AC_{660} is the pulsatile component of the red wavelength absorption, DC_{660} is the static component of the red absorption. AC_{940} is the pulsatile component of the infrared absorption, and DC_{940} is the static component of the infrared absorption.

Why has the DC signal been used in this measurement when we are interested in comparing only the pulsatile parts of the signal?

Because the red and infrared LEDs are different light sources, their emitted intensities are different. Both red and infrared received DC and AC signal amplitudes will be affected by the intensity of their corresponding LED emitter. Let’s say the received red signal has a DC amplitude of 10 and an AC amplitude of 1, while the received infrared DC amplitude is 40 and the AC amplitude is 2. Does this mean that the infrared light was less absorbed en route to the detector, or simply that the infrared LED was “brighter” to begin with?

In order to isolate any changes in pulse amplitude from changes in light intensity, the AC signal must be scaled by the DC signal at that wavelength. Dividing the AC signal by the DC signal gives a scaled AC signal, which is no longer a function of light intensity.[7] This is why the measured value of R is a scaled ratio (sometimes referred to as a “ratio of ratios”).

So, we have now reached a point where we have a value for R measured by the device. We can also convert that value to a fraction of oxyHb by substituting the measured R and the known extinction coefficients into Equation 4. Doesn’t that mean we have figured out SpO_2?

The answer is yes! This method of calculating saturation was used in the very first pulse oximeters from 1974-1981. They worked well for patients who were not hypoxic, but unfortunately, they were not very accurate at saturations below 90%.[8]

The reason for this inaccuracy has become clear more recently. Red and infrared light are strongly scattered by human tissue, so light does not take the most direct path between the LED and the photodetector. The detected light is actually a composite of light that has travelled many different paths of varying lengths.[3] It has been found that the scattering constants and light path length differ significantly between the red and infrared wavelengths. Consequently, the relationship between the oxyHb fraction and R cannot be derived directly from the Beer-Lambert law.[1] In essence, ΔL_{660} is not equal to ΔL_{940}, and therefore, these cannot be removed from the calculation of R.

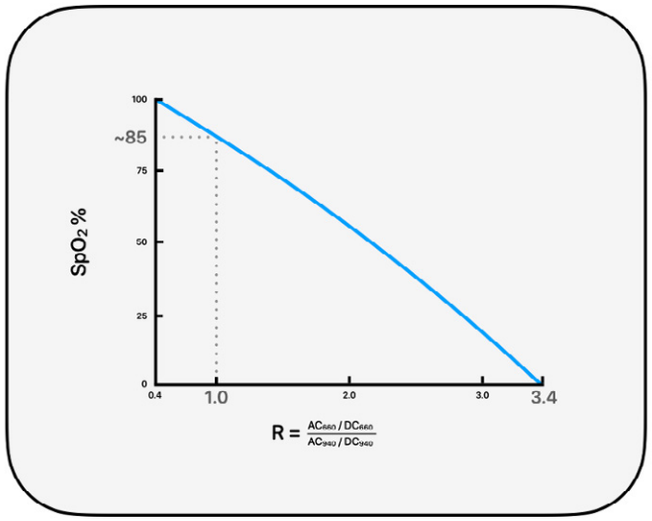
Fortunately, a way of linking the measured value of R to a value of SpO_2, which does not rely on knowing the difference in red vs infrared light path length, was found.

Step 4: Correlation of R to an SpO_2 value

In 1981, a device was developed that used a calibration curve to link measured R values to SpO_2 rather than the Beer-Lambert law, as described above.[8] This process experimentally determines the relationship between R and SaO_2. These pulse oximeters were found to have greater accuracy than those that used the Beer-Lambert law, and this has continued to be the process used in modern pulse oximeters.

To produce this calibration curve, subjects inhale hypoxic gas mixtures, and SpO_2 readings are compared to SaO_2 readings obtained simultaneously from a blood gas analyser. For ethical reasons, data is only obtained down to SpO_2 70%, and the remaining values are extrapolated (Figure 3).

Figure 3. Calibration curve for a pulse oximeter



Explaining this in terms of light absorption amplitude, each different model of pulse oximeter will have a slightly different relationship between the red light path length and the infrared light path length, depending on the physical positioning of the LEDs and photodetector.[9] This means that the calibration process must be performed for every new type of device that is manufactured.[10]

The calibration process allows the R value measured by the device to be linked to the correct calibration curve. It finds the equation linking R and SpO_2, which is expressed as:[9]

$$SpO_2 = K_1 + K_2R$$

(Equation 6)

A brief inspection of this curve demonstrates that low R values are associated with high values of SpO_2 and vice versa. Often, this curve is simplified to $SpO_2 = 110\text{-}25R$. Substitution of R = 1 into this equation results in the "when SpO_2 = 85% then R = 1", which is mentioned in many equipment texts. In reality, the exact equation will vary slightly from device to device.

Step 5: Data processing and display

The SpO_2 reading on a pulse oximeter is usually an average of readings over a period ranging from 2 to 20 seconds, depending on the device.

Signal averaging commonly follows a moving technique in which the pulsations analysed move sequentially. Signal averaging was developed to combat motion artefacts and decrease false alarms.

Increasing signal averaging time will reduce false alarms significantly, but this comes at the cost of longer start-up time (time from the application of probe until the reading is displayed), delayed detection of desaturation events (increased lag time) and missed short desaturations.[11]

Lag time depends on both signal averaging time and the location of the sensor, simply because it takes longer for the blood to reach the distant measurement site. Centrally located sensors in areas of high cardiac output will respond more rapidly than peripherally placed sensors, particularly when peripheral perfusion is poor.[2]

Application of principles to a clinical event

What makes a pulse oximeter useful is its ability to rapidly detect a desaturation event. Ideally, in terms of pulse oximeter design, we want changes in the relative concentrations of oxyHb and deoxyHb to result in proportional changes in the measured value of R. Imagine if there was one wavelength of light that was only

absorbed by oxyHb and another that was only absorbed by deoxyHb. Any change in relative haemoglobin fractions would result in an immediate and equal change in R. Unfortunately, this is not possible within the current range of wavelengths produced by commercial LEDs.

So, of all the wavelengths of light that could have been used, why were 660 nm and 940 nm chosen in the development of this device? Like many breakthroughs in science, the answer is part design and part luck! In 1939, an ear oximeter was developed that used two wavelengths of light. Red light was used as it was known to be absorbed by oxyhaemoglobin, while green light was selected because its transmission appeared to be unaffected by haemoglobin saturation. As it turned out, the production of the "green" light resulted in an unidentified infrared wavelength also being produced.[12]

In the early 1970s Aoyagi was using a later version of this device (employing both red and infrared wavelengths) to research cardiac output measurement. He was troubled by pulsatile flow in the ear interfering with his calculations. He found that by adjusting the ratio of red to infrared light used, he could cancel out the pulsatile "noise". Serendipitously, he then observed that when he held his breath, the pulsations returned. He hypothesised that this was because the change in ratio of oxygenated to deoxygenated haemoglobin had changed the degree of absorption in one wavelength of light relative to the other. This principle could then be used in reverse to estimate the degree of saturation.[13]

When commercial production of pulse oximeters began in the early 1980s LEDs were beginning to be mass produced, but there was a limited selection of wavelengths available. It is likely that 660 nm and 940 nm were the most readily available wavelengths in the red and infrared range at that time.

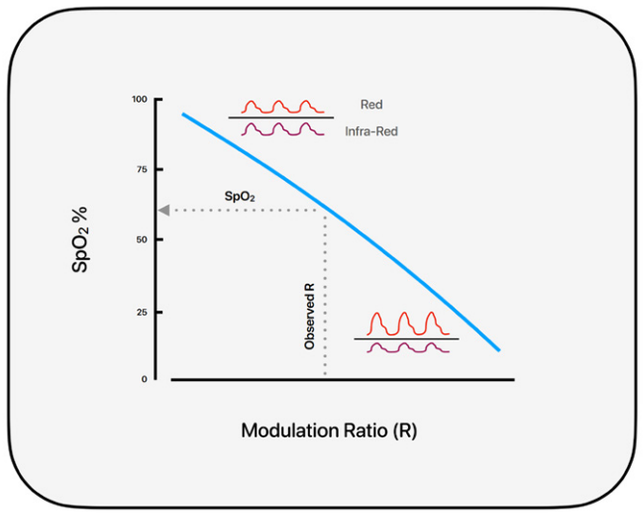
So, how exactly does desaturation cause a change in the relative absorbance of these two wavelengths of light?

Referring back to Figure 1, we can see that at 660 nm (red light), deoxyHb and oxyHb have wide separation in their absorptive capacity (ε), where deoxyHb absorbance is 10 times greater than oxyHb. However, at 940 nm (infrared) their absorptive capacities are similar (oxyHb is slightly greater). Additionally, the two wavelengths also fall on either side of an isobestic point where the absorption spectra cross.

Consider the situation where a desaturation occurs. Any decrease in oxyHb is met with a reciprocal increase in deoxyHb under normal physiological circumstances. With the red LED, the wide separation in extinction coefficients (10-fold), means that an increase in deoxyHb will result in a dramatic increase in overall light absorption (large increase in AC amplitude). However, at the infrared LED, reciprocal changes in oxyHb and deoxyHb will result in a much smaller amplitude change. This is because the increase in absorption by deoxyHb is partially offset by the reduction in absorption by oxyHb.

Figure 4 demonstrates this. The amplitude of the red AC component increases dramatically as saturations decrease while the infrared AC component changes minimally.

Figure 4. Red and infrared AC amplitude at different SpO_2 values



In summary, the value of R will increase whenever there is an increase in red light absorption relative to infrared light, which is reflected as a decrease in SpO_2.[3] The reciprocal nature of the changes in oxyHb and deoxyHb fractions and the wide versus narrow separation of extinction coefficients at these particular wavelengths is essential for R to change in this way.

ERRORS

Clinically, SpO_2 is assumed to reflect SaO_2 and thus provide data about patient oxygenation. However, a number of assumptions must be met for this to hold true.

- The ratio of path lengths for the red to infrared light in the patient is the same as during the empirical calibration.
- There are no other haemoglobin species present besides oxyhaemoglobin and deoxyhaemoglobin.
- The AC signal is entirely attributable to arterial blood.

Errors in the SpO_2 reading displayed may be conveniently classified into three related groups:

1. Errors due to the intrinsic accuracy and calibration of R with experimental data.
2. Errors due to the use of only two wavelengths of light.
3. Errors in isolating the pulsatile component of the signal.

Errors due to the intrinsic accuracy and calibration of R with experimental data

Intrinsic accuracy

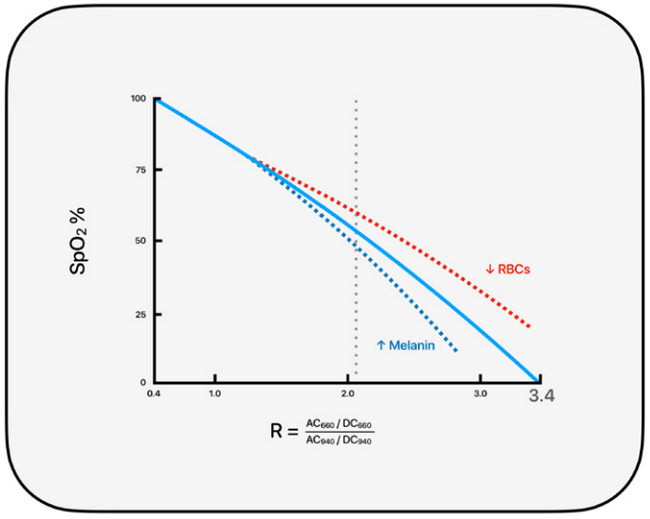
The accuracy of a pulse oximeter is evaluated by the difference between SpO_2 measured by the device and SaO_2 measured by laboratory co-oximetry. Between a SpO_2 of 70% and 100%, the accuracy of most devices is reported to be within 2-3%, and the international standard for manufacture requires ≤4% error in this range.[10] Below an SpO_2 of 70%, accuracy is not stated but will be less since this portion of the calibration curve is by extrapolation only.

Degradation of LEDs can occur over time. Interrogation of devices in current use has shown that actual wavelengths emitted by the LEDs may vary significantly from 660 nm and 940 nm.[10] Since the absorption curve for deoxyHb is steeper than oxyHb, an error of 4 nm in the red wavelength will produce an error that increases in magnitude as SpO_2 decreases.[10] Electrical integrity may also be compromised with repetitive use, where damage results in electrical noise being detected as part of the signal. This will cause the R-value to approach 1, resulting in SpO_2 readings approaching 85%.[10]

The empirical calibration process assumes that the red to infrared path length ratio will not change between subjects and will be consistent between the calibration subjects and the patients on whom the device will be used.[1] What this means in practice is that if an individual patient's finger differs in the way that it scatters light compared to the fingers of the calibration subjects, there is the potential for error. This could include differences in finger anatomy (i.e. clubbing[14]), tissue characteristics (i.e. nail thickness[15]) and sensor location (i.e. use of a finger probe on the helix of an ear[3]).

Under normal physiological conditions, the ratio of red to infrared path lengths decreases with desaturation (path length decreases as light absorption increases). In situations where the amount of light scatter differs from the calibration population in the red wavelength more than the infrared wavelength, there is the potential for errors to occur predominantly in conditions of hypoxaemia. In terms of the SpO_2 versus R relationship, the slope of this relationship is altered, resulting in a measured value of R that over or underestimates SpO_2 depending on whether the slope is increased or decreased. Additionally, the magnitude of the error increases with decreasing saturation. Clinically, this has been shown to occur in severe anaemia and darkly pigmented skin, albeit the errors are in opposite directions. Figure 5 demonstrates this.

Figure 5. Change in SpO_2 vs R relationship with change in red light scattering



Skin pigmentation

Historically, studies of the impact of skin pigmentation on pulse oximeter accuracy have been conflicting. Difficulties with these study results included how skin tone is measured and small sample sizes.[16]

In terms of device calibration, manufacturers are only required to have 15% of participants with darkly pigmented skin when calibrating R with SpO_2. If the ratio of red to infrared light path lengths in the calibration patients is not representative of the ratio of path lengths in patients with increased melanin, there is the potential to decrease accuracy.[9]

In the red-light spectrum, individuals with dark skin have an extinction coefficient which is more than 11 times that of fair-skinned individuals. In the infrared spectrum the difference is around 10 times greater.[17] Melanin light absorption decreases almost linearly with wavelength. Does increased melanin fraction potentially change the scattering properties of the two wavelengths?

A recent study investigated the effect of the range of wavelengths emitted by LEDs used in current pulse oximeters. Despite the fact that LEDs are theoretically emitting light of one specific wavelength, they actually emit light in a wavelength band (called bandwidth), which peaks at the specified 660 nm and 940 nm. When these devices were compared to devices that use a narrowband (smaller range) source, a systematic difference in the calculated R values was found.[9] So the R values obtained by conventional oximeters are inaccurate in darkly pigmented patients.

From first principles, if melanin increases the amount of light absorption disproportionately in the red wavelength, this will reduce sensitivity to the small increase in red light absorption that occurs with desaturation. This results in an undetected increase in the slope of the SpO_2 versus R relationship. Hence, for a given value of R, SpO_2 will be overestimated, with the difference between reported and actual values increasing as SpO_2 decreases.

Recent clinical trials in the wake of the COVID-19 pandemic have supported these theoretical concerns. A recent systematic review concluded that pulse oximetry can overestimate SaO_2 in patients with darkly pigmented skin and that the magnitude of the error is likely to be greater at lower SpO_2 values.[18]

Anaemia

A change in haemoglobin content compared to the normal healthy adults used for calibration can theoretically alter the red to infrared path length ratio and create a bias in R.[3] The amount of light scatter is influenced by the number of red cells in the light path.[5] In anaemia, reduced scattering shortens the optical path length and decreases total absorption. Under desaturation conditions, the increase in absorption due to deoxyHb will be overestimated. The result is an undetected decrease in the slope of the SpO_2 vs R relationship about a point near 80% SpO_2.[3] Hence, for a given value of R, SpO_2 will be underestimated, with the difference between reported and actual values increasing as SpO_2 decreases.

In clinical studies, hypoxaemic patients have been found to have falsely lower SpO_2 readings relative to their actual SaO_2 values, but only in severe anaemia.[19] Anaemia alone (without hypoxaemia) has not been found to cause errors in SpO_2 readings.[20]

Errors due to the use of only two wavelengths of light

Two wavelengths of light can only identify two absorbing substances. If there are more than two substances within the arterial blood absorbing light at the wavelengths used, this additional absorption cannot be isolated. The increased absorption will then be erroneously attributed to one of the two substances being measured.

Carbon monoxide poisoning

Carbon monoxide (CO) is a colourless, odourless gas formed by the incomplete combustion of carbon-containing fuels. CO has 210 times greater affinity for haemoglobin than oxygen. Carboxyhaemoglobin (COHb) results from the combination of CO with heme iron. In healthy non-smokers, HbCO levels are 1-2% due to endogenous production by the metabolism of heme-containing compounds and their presence as a low-level pollutant in the urban environment. Chronic smokers have levels ranging from 3-8%, increasing to 10-15% immediately post-smoking. CO poisoning occurs when symptoms of toxicity appear, generally at levels above 10%, escalating in severity with increasing concentration.[21]

The pulse oximeter assumes that all Hb present is either oxyHb or deoxyHb. Other haemoglobin species (MetHb and COHb) can only be measured using two additional wavelengths (as occurs in a laboratory with arterial blood samples).

The extinction coefficient of COHb at the red wavelength is similar to oxyHb. At the infrared wavelength, COHb absorbs virtually no light.[5] Most equipment textbooks state, "this results in an erroneously high reading". However, an increase in red absorption relative to infrared absorption will result in an increase in R, which corresponds to a decrease in SpO_2 (Figure 4). High COHb does result in an erroneously high reading, but this is not the explanation.

In fact, the haemoglobin oxygen dissociation curve is shifted to the left in the presence of high levels of COHb. Due to this shift, concentrations of deoxyHb are also significantly decreased because the O_2 that is bound is unable to be released at the tissue level.[21]

This decrease in deoxyHb results in a decrease in red light absorption. This effect will be larger than any increase in absorption due to the presence of COHb as the extinction coefficient (absorptive capacity) of deoxyHb is 10 times greater.[5] Infrared absorption will also decrease, but to a lesser extent, due to the lower extinction coefficients for both deoxyHb and oxyHb. Hence, R will decrease, and SpO_2 will falsely increase.

Methaemoglobin

Normal haemoglobin contains iron in the ferrous (Fe^{2+}) state. Methaemoglobin (MetHb) occurs when the ferrous iron is oxidised to its ferric (Fe^{3+}) form, which prevents oxygen from binding to the affected heme molecule. Clinically, increased levels of MetHb may occur in certain congenital conditions and as a result of exposure to oxidising compounds such as benzocaine, prilocaine, nitrates, aniline and dapsone. Additionally, MetHb impairs tissue oxygen delivery by causing a left shift of the oxyHb dissociation curve, impairing oxygen offloading by the other three heme molecules in the affected haemoglobin.[22]

Methaemoglobin readily absorbs both red and infrared light (extinction coefficients at both 660 and 940 nm are high). Consequently, significant levels of methaemoglobin will increase both red and infrared absorption. In situations where there is equal absorption of both types of light, the R value will trend towards 1. Saturations will, therefore, trend towards 85%, which may result in either an over or underestimation of the actual saturations depending on the clinical scenario.[5]

Sulfhaemoglobin

Sulfhaemoglobin (SHb) is formed by the irreversible oxidation of Fe^{2+} to Fe^{3+} and the binding of sulfur atoms to the porphyrin ring of the haemoglobin molecule.[5] Similar to MetHb, affected heme molecules in SHb are unable to carry oxygen. However unlike MetHb, the molecular changes in SHb result in a rightward shift of the oxyHb dissociation curve, which facilitates oxygen offloading at the tissues. As a consequence, the level of tissue hypoxia is generally less severe with SHb compared with MetHb.[23] Formation of SHb occurs with excess exposure to sulfur-containing compounds such as dapsone, sulphonamides, sumatriptan, sulfamethoxazole and phenazopyridine.[23] Clinically, this presents as blue-grey skin discolouration.

Considering the light absorption characteristics of SHb, the peak absorption of SHb occurs at 630 nm. At 660nm, absorption is significantly higher than metHb, oxyHb and deoxyHb. Absorption at 940 nm is not reported. Clinically, patients have low SpO_2 despite normal SaO_2 on laboratory testing, suggesting that the additional 660 nm absorption falsely increases the R value, resulting in falsely low SpO_2 readings. However, it is possible that absorption at 940 nm is also high, and R trends toward 1, since many clinical case reports state SpO_2 readings of 80-84%.[5]

Abnormal Hb species

Uncommon Hb variants have been linked to spuriously low SpO_2 readings. These include Hb Lansing, Hb Bonn, Hb Koln, Hb Hammersmith, and Hb Cheverly. The proposed mechanism in these instances appears to be related to high absorbance at 660 nm, resulting in falsely low SpO_2.[5]

Dyes

Methylene blue, patent blue V, and isosulfan blue (an isomer of patent blue used in the US) are injected subcutaneously during surgery to trace the lymphatic drainage of the region.

There are conflicting reports on the contribution of these compounds to SpO_2 errors when injected into tissues as intended. There is also contention about which dyes cause more significant errors.[24] The explanation for this is likely dependent on the extent of systemic absorption as IV injection has been demonstrated to cause errors with all blue dyes.[25–27]

Methylene blue has peak absorption at 665 nm. The patent blue V peak is at 637 nm, and isosulfan blue at 638 nm. All blue dyes exhibit significant absorption at 660 nm and very little absorption at 940 nm. The additional absorption at the 660 nm wavelength, while 940 nm absorption is unchanged, results in an increase in the value of R. An increase in R will result in a SpO_2 reading which is erroneously low.[5]

Indocyanine green and indigo carmine have absorption peaks around 800 nm and 600 nm, respectively. They do have some absorbance at 660 nm, but it is significantly lower than the blue dyes discussed above. Intravenous administration has demonstrated a decrease in saturation readings of only 3-4% with indocyanine green, and no change with indigo carmine.[25]

Nail polish

The majority of colours of nail polish do not interfere with pulse oximetry.[28] Some shades of blue, green, brown, purple and black nail polish absorb light at 660 nm. From first principles, you might expect this to result in artefact and a decrease in saturation readings. However, since nail polish is non-pulsatile, the increased absorption should not alter the AC absorbance, which is what is used to calculate R. There will, however, be a systematic change in red to infrared path length ratio compared to the calibration volunteers who were nail polish free and this may lead to a systematic bias in results.

Clinical studies of whether this is associated with a significant change in SpO_2 readings have been conflicting.[29] A recent meta-analysis suggests that blue, black and brown nail polishes are associated with a small decrease in SpO_2 (less than 2%), which is within the accepted margin of error of pulse oximetry values.[28]

Errors due to isolation of the pulsatile signal

Poor perfusion

Low perfusion interferes with the device's ability to correctly isolate the AC from the DC component of the absorbance signal. Under normal conditions, this is only 1-5% of the total signal.[30]

When the pulsatile component of the absorbance signal is very small relative to the background signal (low AC to DC ratio), the pulse oximeter amplifies the signal more.[31] This allows the pulse oximeter to determine saturations from a range of patients who generate different amplitudes of pulsatile absorbance.

With very high amplification (for example, vasoconstriction), there is an increase in the likelihood of an artefact being analysed as part of the pulsatile signal.[31] This is analogous to how the edges of an object in a photo become blurred when you zoom in. In this scenario, you have difficulty pinpointing where the exact edge of the object is. In the same way, the device has difficulty isolating where the AC component begins and ends.

Because this artefact is equally present in both the red and infrared absorbance signals, both red and infrared absorbances will increase, and therefore, the ratio will approach R = 1. This gives SpO_2 trending towards 85%. SpO_2 will be either over or underestimated, depending on the clinical situation.[31]

Other factors that contribute to erroneous readings in this situation include an increase in the ratio of venous blood relative to arterial blood in the digit, and an increase in tissue oxygen extraction, such that the venous blood present will have a lower saturation. Therefore, any DC components that are erroneously included will have a lower saturation than usual. Hence, readings may be lower than 85% in some situations.[11]

Improvements in device design to address this issue include having a minimum signal-to-noise ratio below which no value will be displayed (rather than further amplification occurring). In addition, there is some evidence that reflectance-type oximeters placed on the forehead may have greater accuracy in low-perfusion states.[32]

Movement

Motion interferes with the ability to accurately isolate the pulsatile component of the signal in a similar way to poor perfusion. However, rather than reducing the AC:DC ratio, the size of the AC signal is artefactually increased.[31] Finger motion causes some of the venous and tissue components (particularly venous blood and tissue fluid) to form part of the AC signal (essentially a fake AC signal). In this situation, venous blood and tissue fluid are the components artefactually included in the AC signal, rather than the nonspecific artefact described for poor perfusion. Since the tissue and venous components have lower saturation, SpO_2 will be artefactually decreased.[11]

Solutions to this problem used in modern oximeters include data averaging, holding data, alarm delays, and the use of motion-resistant technologies such as adaptive filtering, frequency domain analysis, and cardiac gated averaging.[11]

Probe malposition or poor fit

If the device is malpositioned on the patient's digit, the light of one or both wavelengths may bypass the finger and reach the photodetector directly or without passing through pulsatile tissue. This is referred to as shunting. Unless the shunting changes the path length of each wavelength in exactly the same ratio as determined in the calibration, SpO_2 readings will be erroneous. Whether this results in an over or underestimation of the actual SaO_2 will depend on which of the wavelengths is more strongly shunted.[3]

Increased venous pulsations

Artefact from venous pulsations most commonly occurs when the venous outflow to the finger is occluded (e.g during NIBP cuff deflation), or in patients with severe tricuspid regurgitation. It can also occur when the probe is placed on the earlobe or forehead of patients in the Trendelenberg position. In this situation, part of the analysed AC signal will be from venous blood, resulting in an artefactually decreased SpO_2 reading.[5]

Ambient light

The photodetector is not wavelength-sensitive, so its input is only referenced to the wavelength by the timing of the LEDs. The LEDs cycle red, infrared, and both off at a rate of 400 Hz.[6]

If a contaminating light source were to have a particular frequency that coincided with only the red detection window or only the infrared detection window, then this would lead to an error. Such errors were more common with older models of pulse oximeters, which had a lower LED switching frequency.[33]

Due to the very high frequency of modern oximeters, this issue is no longer a common source of error with ambient operating room lighting.[34] The off period allows quantification of the amount of light that passes through the finger from external sources, and this is subtracted from the received signal when the LEDs are on. In addition, most devices have physical shielding to prevent ambient light from reaching the photodetector.

CONCLUSION

It has been more than 50 years since the invention of the pulse oximeter. It has become a universal device for monitoring patient oxygenation and has made significant contributions to improving patient safety. Despite many technological advances, assumptions remain inherent in the design of the device, which underpin significant errors that can occur. Understanding the design of the device helps us interpret the data it provides and allows us to identify and respond appropriately to these errors.

Acknowledgement

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APPENDIX 1

Using Equation 2, the ratio of pulsatile absorbance at 660 nm to that at 940 nm is expressed as:

$$R = \frac{\Delta L(\varepsilon_0 C_0 + \varepsilon_d C_d)_{660}}{\Delta L(\varepsilon_0 C_0 + \varepsilon_d C_d)_{940}}$$

(Equation 2b)

If we assume that the light path length is the distance between the LED and the photodetector and that this does not differ between the two wavelengths, then ΔL will cancel out from this equation and it becomes:

$$R = \frac{(\varepsilon_0 C_0 + \varepsilon_d C_d)_{660}}{(\varepsilon_0 C_0 + \varepsilon_d C_d)_{940}}$$

(Equation 2c)

If we assume that oxyHb and deoxyHb are the only species present in arterial blood, then their relative proportions are related to one another by:

$$F_0 + F_d = 1$$

(Equation 2d)

Where F_o is the fraction of oxyHbO_2 present, and F_d is the fraction of deoxyHb present, substituting Equation 2d into Equation 2c gives the following:

$$R = \frac{\left(\varepsilon_0 F_0 + \varepsilon_d (1 - F_0)\right)_{660} cHb}{\left(\varepsilon_0 F_0 + \varepsilon_d (1 - F_0)\right)_{940} cHb}$$

(Equation 2e)

Assuming that the concentration of Hb does not vary between the two wavelengths, this can now be cancelled out leaving:

$$R = \frac{\left(\varepsilon_0 F_0 + \varepsilon_d (1 - F_0)\right)_{660}}{\left(\varepsilon_0 F_0 + \varepsilon_d (1 - F_0)\right)_{940}}$$

(Equation 3)

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Goal-directed bleeding management: Understanding and implementing viscoelastic haemostatic assays across patient blood management

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Edited by Dr Kate Drummond

INTRODUCTION

Recent decades have seen increasing awareness of the risks of transfusion, along with recognition of the need for a sustainable approach to managing finite blood products.[1,2] These concepts, combined with an increasing body of work addressing strategies that optimise and conserve patients' own blood, have led to the emergence of the patient blood management (PBM) paradigm.[3] The concept of PBM is to support the health of an individual's blood and the physiological integration and impact on all other body systems which, as a corollary, often reduces the risk of requiring allogeneic blood transfusion.[4,5] Specifically, this paradigm seeks to decrease avoidable blood loss and support prompt cessation of bleeding with the aim to reduce transfusion-related morbidity and mortality.[6,7]

The World Health Organization has mandated the evidence-based, ethical, and economic argument to implement PBM globally; a sentiment that has been echoed by our Australian National Blood Authority

(NBA).[8,9] The mandate to improve blood health and apply PBM strategies will become more important over time as the balance of demand and supply for blood products shifts.[8,9] Adding to the change in the supply/demand balance is a population that is living longer, where more complex surgeries are being offered to older patients with increased comorbidities and an increased likelihood of requiring perioperative blood transfusion.[10-14] Furthermore, emerging evidence about the carbon footprint of transfusion-related products supports the need to improve the sustainability of healthcare practices.[15] Perioperative clinicians are well-placed to have an impact on blood product demand through goal-directed bleeding management (GDBM).

GDBM is an important and effective strategy to address PBM.[6] Appropriate management of perioperative blood loss, bleeding and acquired coagulopathy improves patient outcomes.[6,16] A "one size fits all" approach to critical bleeding management may lead to unnecessary morbidity and mortality. For example, only a quarter of patients with massive bleeding in severe trauma or obstetric haemorrhage experience significant coagulopathy.[6] Viscoelastic haemostatic assays (VHAs) as part of the PBM paradigm support the rapid identification of patients with coagulopathy at the point of care.[6] Moving away from ratio-based product transfusion to targeted individualised treatment during critical bleeding rationalises blood product use which, as a sequela, reduces the risk of transfusion-related morbidity and mortality. This is important as short-term risks of transfusion include product-related risks, volume-related risks and iatrogenic injury.

VHAs provide clinicians with an evidence-based tool to better approach GDBM in critical care and perioperative settings. The assays provide real-time diagnostic data on the presence or absence of coagulopathy, the likely causes, as well as the effectiveness of interventions. By empowering clinicians to use evidence-based methods to guide bleeding management and transfusion, anaesthetists can improve patient outcomes and support a more sustainable health system.[17] Despite the known benefits of PBM and particularly the use of VHAs, the greatest challenge is the translation from evidence-based research to clinical anaesthetic practice.[18]

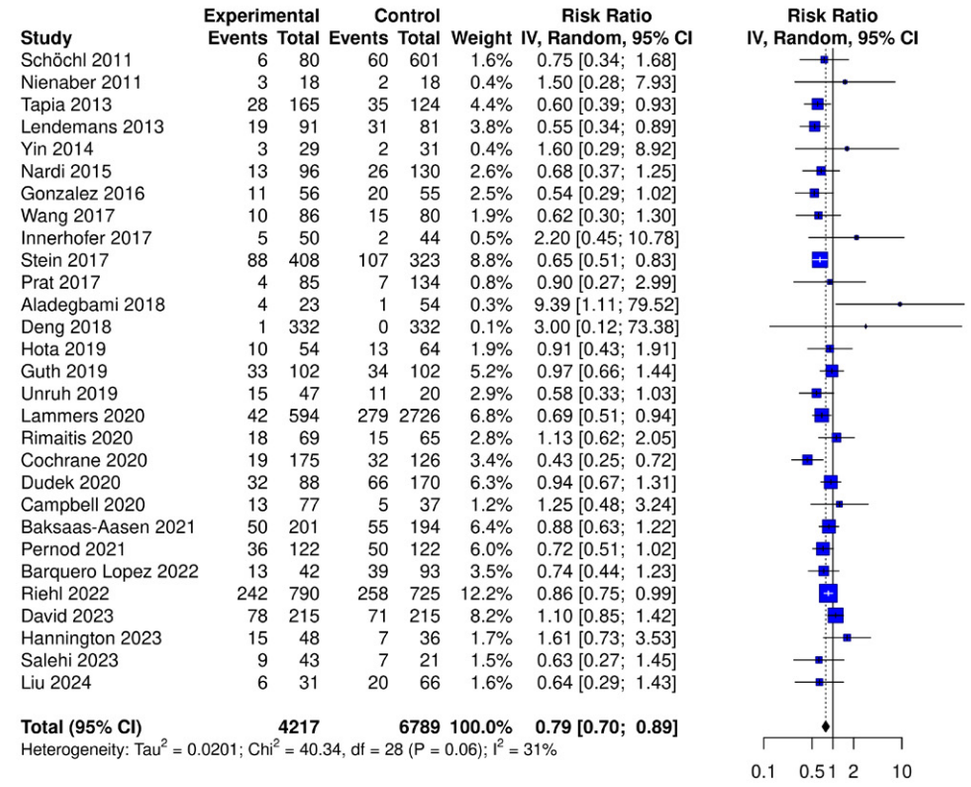
While managing intraoperative bleeding is complex, there is a growing body of evidence and numerous guidelines providing clarity for anaesthetists on VHAs and treatment.[19-26] Timely and effective treatment requires a critical care physician to lead multidisciplinary collaboratives.[27,28] These episodes can occur with varying degrees of complexity and urgency. Given the potential for poor to catastrophic outcomes, therapeutic inertia is not an option.

The challenges of implementing change initiatives vary widely, as unique cohorts and contexts require specific implementation activities to achieve success. This article aims to assist local implementation initiatives of GDBM with VHAs by defining clear, translatable strategies. We have included clinical examples where relevant but have chosen not to name any specific site. All examples are from Australia.

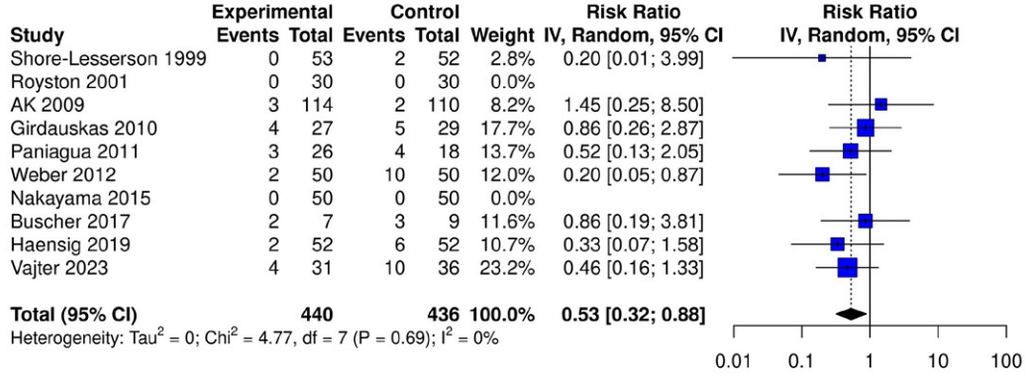
EVIDENCE FOR VHA TESTING IN GDBM

In 2023, the Australian NBA recommended that all hospitals establish a major *haemorrhage* protocol to manage critical bleeding effectively, shifting away from a massive *transfusion* protocol, highlighting the importance of individualised response to the type of bleeding and identifying specific haemostatic defects.[9] This name change emphasises the evolution away from transfusing large volumes of blood products, towards early intervention with goal-directed therapies to reduce reliance on transfusion. VHA-guided GDBM is an effective strategy to address blind large volume transfusion and to avoid complications and poorer outcomes associated with the additive negative effect of bleeding and transfusion.[6] Together, transfusion associated circulatory overload (TACO), transfusion-related acute lung injury (TRALI), and the immune-modulating effects of transfusion account for more than two-thirds of transfusion-related mortality, with the main culprits being plasma-rich products.[6,29] In non-cardiac and cardiac surgery, there is considerable variation in intraoperative blood transfusion practice, both among clinicians and across healthcare organisations. These differences cannot be explained by patient preference, patient cohort, or disease severity.[30] Intraoperative red blood cell transfusion in coronary surgery is associated with increased mortality.[31] A growing number of randomised controlled trials show reduced morbidity and mortality with GDBM, particularly in cardiothoracic surgery where transfusion is common (Figure 1). Ensuring that patients only receive necessary blood product transfusion minimises these risks.

Figure 1. Effect of VHA on mortality in severe trauma and cardiovascular/lung transplant/ECMO surgery – meta-analysis



A. Trauma



B. Cardiac

Randomised controlled trials across trauma (Figure 1a) and cardiac surgery (Figure 1b) demonstrating the reduction in mortality risk ratios when GDBM with VHA is applied. Information sourced from Görlinger et al. (2024),[32] Görlinger et al. (2024),[33] Görlinger et al. (2025)[34]

Clinicians who have access to VHAs as part of their practice describe working without this guidance as "managing a major haemorrhage with a blindfold" (personal communication from a senior anaesthetist, 7 March 2018). Taking the blindfold off allows the perioperative clinician to identify which deficit(s) may be contributing to coagulopathic bleeding, such as residual heparin, hypofibrinogenemia, platelet dysfunction, decreased contribution of extrinsic or intrinsic coagulation factors, or hyperfibrinolysis.

Using algorithmic tools with VHAs provides a decision support matrix (Figure 3). The first question to be answered is: Does the patient have clinically significant bleeding? If yes, the next step is to identify early hyperfibrinolysis (EXTEM A5/CRT A10) and fibrinogen (FIBTEM A5/CFF A10). Once this has been corrected, the next step is to consider and correct platelet (EXTEM A5/CRT A10) contribution to clot quality, and finally, coagulation factor deficits. Addressing fibrinogen early in a decision support matrix is supported by a 2024 study which concluded fibrinogen replacement can reduce the EXTEM CT independent of coagulation factor repletion (fresh frozen plasma (FFP) and/or prothrombin complex concentrate (PCC)).[35] This vertical algorithm uses a sequential approach and requires the clinician to check the treatment effect before considering additional blood product transfusion where appropriate. The stepwise strategy of factor correction can significantly reduce patient exposure to unnecessary blood products, namely FFP and PCC, and may reduce thrombotic risk and optimise resource utilisation.[35,36,37]

Fibrinogen can be replaced with either fibrinogen concentrate (FC) or cryoprecipitate. In Australia, cryoprecipitate is commonly used as a first-line agent for fibrinogen replacement and importantly it contains additional factors other than fibrinogen, such as Factor VIII, Factor XIII, von Willebrand factor and fibronectin. However, off-label prescription of FC is increasing in Australia due to its ease of use. This is especially where fibrinogen levels are subtherapeutic and associated with bleeding, where the delay awaiting cryoprecipitate is considered unsafe. It is essential to understand the key role of fibrinogen in critical bleeding, as it is the most abundant coagulation factor and the first to fall during a major haemorrhage. Additionally, addressing fibrinolysis early in a decision support bleeding management algorithm enables effective fibrinogen replacement.

The potential cost benefits for local health systems that implement PBM as their standard of care have been demonstrated. A Western Australian study of four hospitals showed $18.5 million in savings on blood product acquisition and an additional $80-100 million in activity-based cost savings over a five-year period.[38] Additionally, a Queensland hospital implemented a tailored bleeding management protocol based on VHA testing, which resulted in a decrease in the acquisition cost of blood products by more than $1 million in 15 months, alongside reductions in reoperations for bleeding, superficial chest and leg wound infections, as well as a 12 per cent reduction in postoperative length of stay.[39] These results are supported by a more recent prospective cohort study that demonstrated bleeding patients had 1.76 (CI, 1.64–1.90) times higher costs associated with their cardiac surgery than those without a bleeding event.[39,40]

A recent life-cycle analysis from Great Britain addressing transfusion-related environmental impact found that the majority of total CO_2 emissions from packed red blood cell transfusions were related to transportation costs.[15] Given the significant geographical challenges in Australia and New Zealand, these emissions costs are anticipated to be amplified.[15] Moving towards net-zero and more sustainable healthcare models, GDBM offers a key point-of-care strategy for clinicians to reduce healthcare-related emissions.

GUIDELINES SUPPORTING GOAL-DIRECTED BLEEDING MANAGEMENT

There are numerous clinical practice guidelines (CPGs) available for critical care clinicians to help support decision-making around appropriate therapies and strategies to manage bleeding (Table 1). In 2021, the Society of Thoracic Surgeons (STS), Society of Cardiovascular Anaesthesiologists (SCA), American Society of ExtraCorporeal Technology (AmSECT) and Society for the Advancement of Patient Blood Management (SABM) came together to recommend that, "Goal-directed transfusion algorithms that incorporate point-of-care testing, such as with [VHAs], are recommended to reduce peri-procedural bleeding and transfusion in cardiac surgical patients (class I, level B-R)".[24] In 2023, the European Society of Anaesthesiology and Intensive Care recommended "the use of intervention algorithms incorporating predefined triggers and targets based on coagulation monitoring to guide individualised haemostatic intervention in the case of perioperative bleeding".[41] That year, the European Society of Cardiologists also recommended the

use of "point-of-care diagnostics for guidance of blood component therapy, when available" as a class I recommendation.[23] In 2019, guidance for obstetric management was published in a global consensus statement by the Network for the Advancement of Patient Blood Management, Haemostasis and Thrombosis (NATA), which recommended the use of "viscoelastic haemostatic tests to guide appropriate, goal-directed use of haemostatic blood components and pro-haemostatic agents (1B)".[42]

These and other recommendations are highlighted in Table 1.

Table 1. Recent GDBM guidelines

Year	Guideline
2025	AAGBI Association of Anaesthetists guidelines: The use of blood components and their alternatives.[19]
2025	Cardiac surgical bleeding, transfusion, and quality metrics: Joint consensus statement by the Enhanced Recovery After Surgery Cardiac Society and Society for the Advancement of Patient Blood Management.[43]
2024	EACTS/EACTA/EBCP Guidelines on cardiopulmonary bypass in adult cardiac surgery.[21] (Incorporates bleeding management strategies.)
2024	Patient blood management guideline for adults with critical bleeding. Medical Journal of Australia (MJA).[44]
2023	The European guideline on management of major bleeding and coagulopathy following trauma: sixth edition.[45]
2022	Management of severe perioperative bleeding: Guidelines from the European Society of Anaesthesiology and Intensive Care. Second update 2022.[22]
2022	ESC Guidelines on cardiovascular assessment and management of patients undergoing non-cardiac surgery: Developed by the task force for cardiovascular assessment and management of patients undergoing non-cardiac surgery of the European Society of Cardiology (ESC). Endorsed by the European Society of Anaesthesiology and Intensive Care (ESAIC).[23]
2022	International Federation of Gynaecology and Obstetrics (FIGO) recommendations on the management of postpartum haemorrhage.[46]
2021	STS/SCA/AmSECT/SABM: Update to the clinical practice guidelines on patient blood management.[24]
2020	Guidelines for the management of adult acute and acute-on-chronic liver failure in the ICU: cardiovascular, endocrine, haematologic, pulmonary, and renal considerations.[47]
2019	Patient blood management in obstetrics: prevention and treatment of postpartum haemorrhage. A NATA consensus statement.[42]
2018	The use of viscoelastic haemostatic assays in the management of major bleeding: A British Society for Haematology guideline.[48]
Journals:	
European Association for Cardio-Thoracic Surgery (EACTS), European Association of Cardiothoracic Anaesthesiology (EACTA), European Board of Cardiovascular Perfusion (EBCP), National Health Service (NHS), European Society of Anaesthesiology (ESA), Medical Journal of Australia (MJA).	

TRANSLATING GUIDELINES INTO CLINICAL SUCCESS

While guidelines provide a useful foundation to support clinician decision-making, the process of changing practices and attitudes towards GDBM is complex and must be delivered with both empathy and rigorous logic.[27,49-51] Senior clinicians must first "unlearn" strategies they were taught as students. During the period of change they may temporarily experience a feeling loss of competence, clarity and control. Transition through this process can be facilitated by the solutions we propose here.

These include learning VHAs as a single concept, independent of the testing platform, and recognising and understanding the key role of correcting fibrinogen deficits early. By combining the two common VHAs (thromboelastography (TEG) and rotational thromboelastometry (ROTEM)) into a single learning concept, clinicians can feel confident using both VHA technologies across different units. Uptake of VHA-guided GDBM requires recognition that the two distinct viscoelastic haemostatic measuring instruments (ROTEM and TEG) are common across Australian sites. Some hospitals currently have both technologies in different subspecialties – for example, obstetric departments may favour technology with highly accurate dual inhibited fibrinogen assessment, while cardiac departments may prioritise assessment of platelet function. Therefore, VHA must be taught as an all-encompassing subject.

We propose a shift in the way VHA-guided GDBM is taught, and how algorithm graphics are depicted and used. This new paradigm requires:

1. Teaching knowledge and skills around VHA interpretation as a "general concept".
2. Applying an understanding of the "general concept" of VHAs to appreciate the strengths and weaknesses of each test.
3. Understanding the key role of addressing fibrinogen deficiency early.[36]

The structure of the algorithm is very important to simplify bleeding management into a stepwise approach following a physiologic process.[35,53] These algorithms are devised for clinical use and as teaching tools to support ease of comprehension and simulation training. They are also being developed into tools, such as mobile applications (for example, the TEGRotem app).

Figure 2. General surgical and obstetric ROTEM and TEG goal-directed bleeding management algorithm – product details simplified

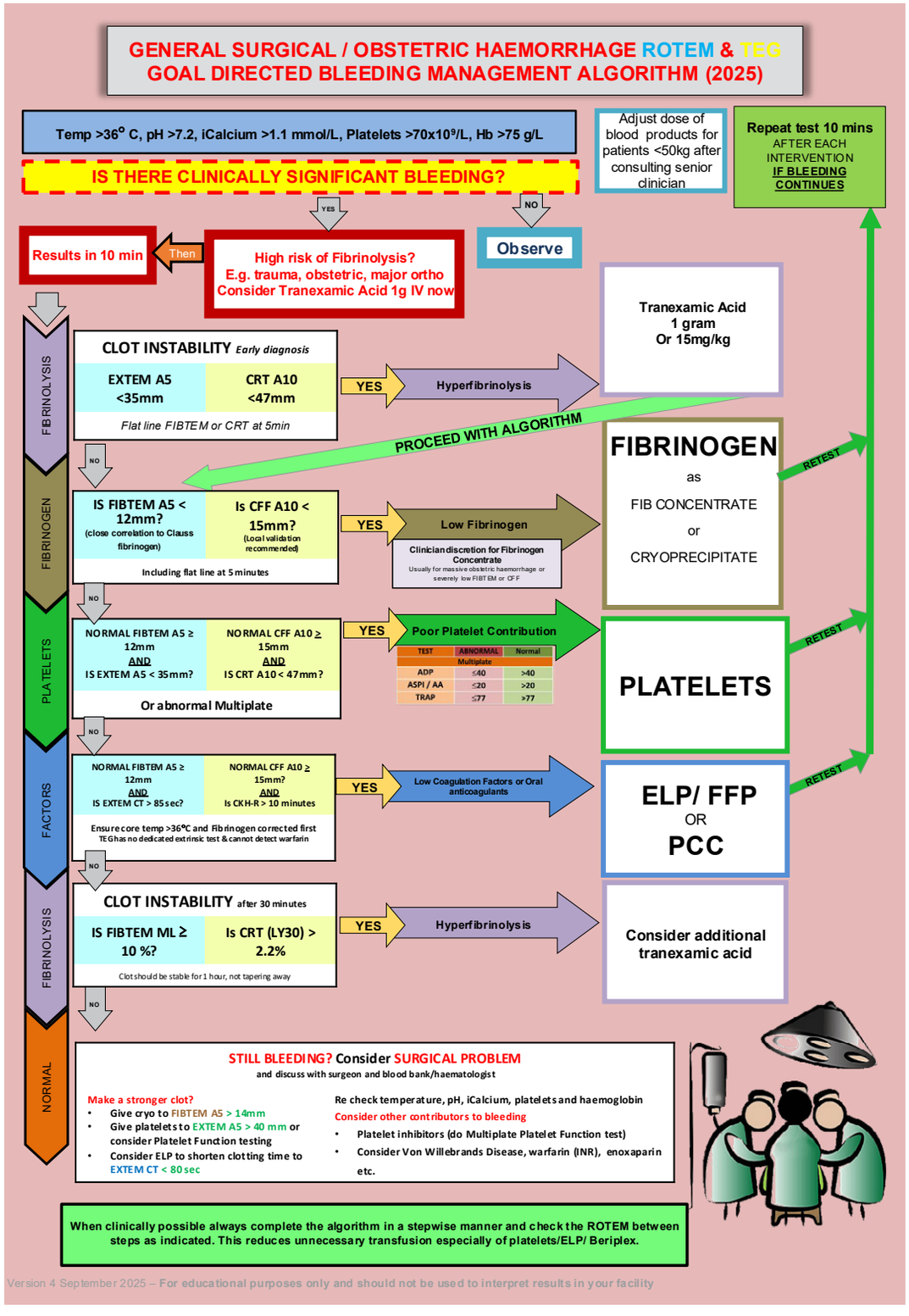
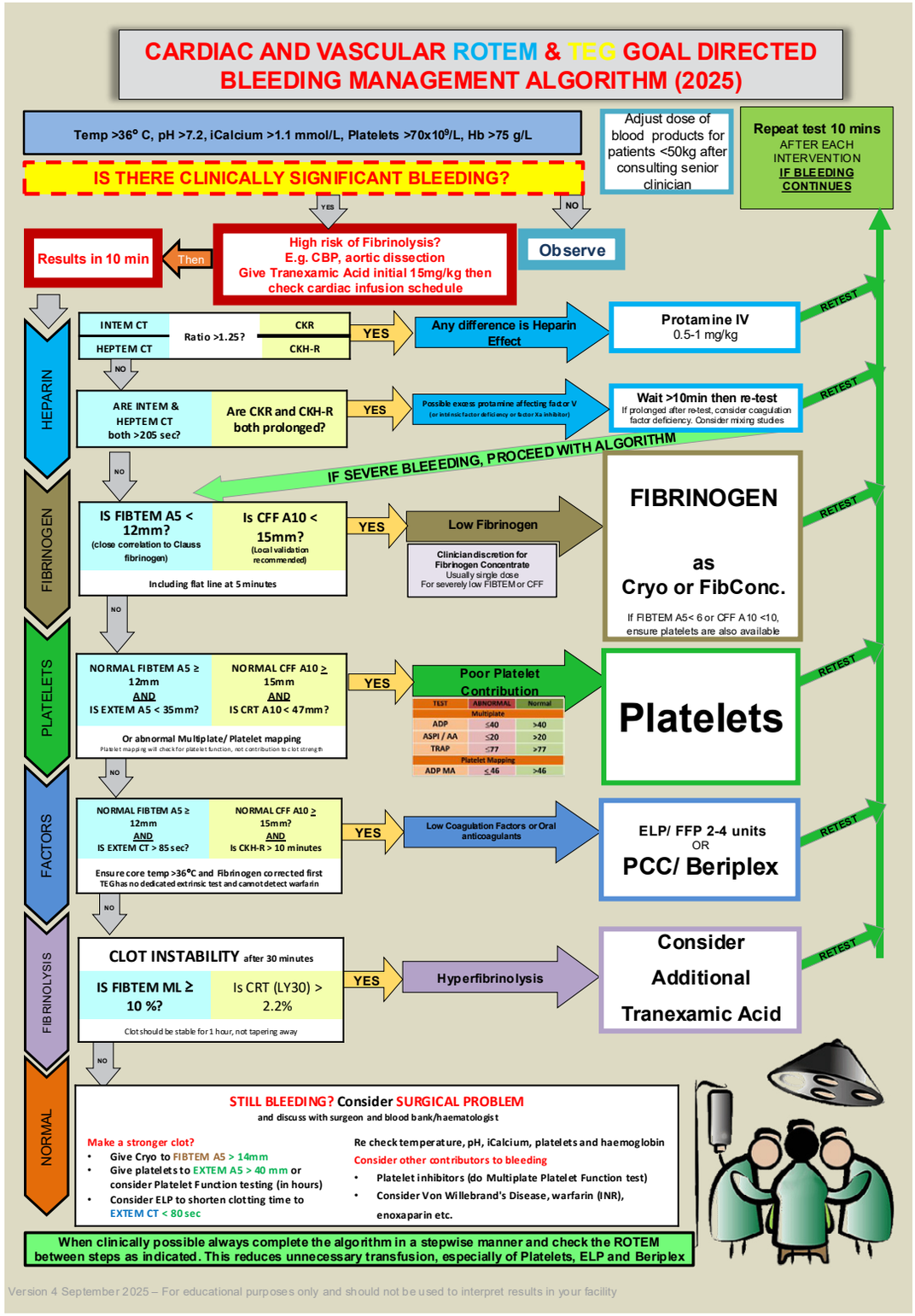


Figure 3. Cardiac and vascular ROTEM and TEG goal-directed bleeding management algorithm – product details simplified



These tools form an important strategy to support clinician decision-making, as managing intraoperative bleeding is technically and contextually complex.[30] However, there is a significant body of evidence and numerous guidelines providing clarity for critical care physicians on diagnostic assays and treatment.[16,19,25,43,45,53]

GDBM during major haemorrhage requires critical care physicians to make timely, effective treatment decisions and to lead a multidisciplinary collaborative effort.[27,28,54-57] These episodes can occur with varying degrees of complexity and urgency at one or many timepoints during the critical bleed. However, critical care physicians may either lack confidence in their skills to lead multidisciplinary teams, or not be aware of the latest evidence-based recommendations. They may not have access to the most appropriate diagnostic assays, have the knowledge or skills to interpret assays, or have access to the most appropriate blood products.[27,58-60]

By considering hurdles clinicians face in the implementation of evidence in GDBM and VHA, strategies to overcome these barriers emerge.

THE SCIENCE OF CHANGE MANAGEMENT

Variable compliance with evidence-based recommendations and guidelines is of great concern to the clinical community.[51] Implementation science is focused on the promotion of methods to recognise, understand, and develop processes that can support practice improvement, and ultimately patient outcomes.[18] The abundance of research on the management of bleeding demonstrates the necessity of uncovering new evidence and improved treatment strategies.[18] Clinicians are, however, less efficient at translating the evidence into practice. This continued challenge in efficiently translating knowledge into action can result in frustration, ineffective care, or potentially harmful care, along with individual and organisational health inequity.[61] It is important to recognise that "unassisted" translation of knowledge into practice is not efficient, effective, economically viable, or sustainable.[61] Implementation strategies or activities to support the translation of knowledge into practice are rarely discussed during medical training or in guidelines by societies or colleges.

To introduce new practices, a clinician or group of clinicians must:

1. Decide if the evidence is compelling and relevant enough to integrate it into their practice.
2. Convince peers and administrators that supporting this initiative is worth it as it will improve patient outcomes, and that the associated costs can be met.
3. Implement activities to make change, with no guarantee that their peers will accept it.[62]

These are significant challenges and may in fact become overwhelming barriers for clinicians, departments and healthcare organisations attempting to implement evidence-based change initiatives.

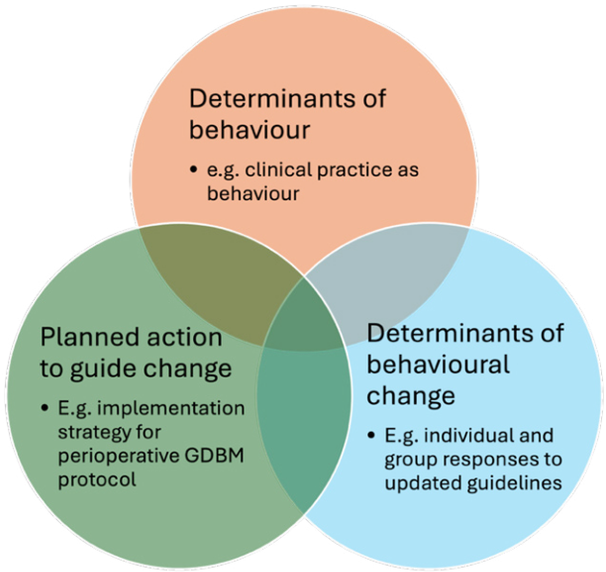
Analysing behaviour – a moment of self-reflection

Clinical practice is a form of behaviour. Therefore, understanding the influences on existing behaviours, in the context in which they occur, is necessary to "change practice". Clinical practice as a behaviour in the perioperative environment is part of a social process with complex relationships, where the dyad relationship between surgeon and anaesthetist is of particular importance.[57] Clinical practice behaviours can be described, categorised, and understood with theories, frameworks, and models.[63] Understanding behaviours in the relevant context supports the selection of activities or interventions that are likely to be effective in each situation, consequently increasing the probability of translating knowledge into practice.[57] This is of particular importance for perioperative clinicians, where patient cohorts, consultant groups, and healthcare contexts are diverse, yet unique, requiring targeted implementation activities to achieve successful practice improvements.

Frameworks, models, and theories

Frameworks, models, and theories can be categorised into those that focus on psychological barriers and facilitators of change, and those that focus on change itself (Figure 4). These will be explored in more detail throughout the article with clinical examples.

Figure 4. Frameworks



Determinants of behaviour

The theoretical domains framework (TDF) helps to identify and define cognitive, affective, social, and environmental influences on clinicians' behaviour in relation to implementation of evidence-based recommendations. This first step identifies and categorises given barriers and/or facilitators to behaviour.

Determinants of behavioural change

The capability, opportunity, motivation, behaviour model (COM-B) describes how capability, opportunity, and motivation interact to positively, or negatively, influence behaviour. Capability determines the psychological and physical capacity to adopt or change a particular behaviour. Opportunity identifies external factors that make a behaviour possible. Motivation covers the thought processes that direct changes in behaviour. Both capability and opportunity can influence motivation. While motivation determines whether clinicians will or won't adopt a particular behaviour, capability and opportunity determine whether a clinician can or can't adopt it.[27,64]

Provide planned action to guide change

The knowledge to action (KTA) framework provides planned guidance for implementing change (Table 2).[62]

Table 2. Knowledge to action framework

Action phases	Examples
Correlating evidence to address identified clinical concerns	Audit of current practice Literature reviews
Understanding barriers to and facilitators of change implementation	TDF and COM-B, surveys, interviews, working groups
Developing and introducing evidence-based strategies and/or technology	VHAs algorithms, quality assurance protocols, live streaming of VHA results
Developing intervention activities to support behaviour change and the uptake of evidence	Education sessions Simulation training procedures, training packages
Monitoring use of the intervention	Number of VHAs performed Compliance with algorithm, surveys, interviews Real-time changes with VHA parameters against treatment
Evaluating clinical outcomes	Auditing of blood product utilisation, blood loss, length of stay (ICU/hospital), leg/chest wound infection, reoperation rates for bleeding
Ensuring sustainability of the intervention	Development of long-term interest groups within departments for continual improvement Embedding VHA monitoring as standard agenda items within PBM committee meetings

The guidance developed from these models and frameworks, supports clinicians in controlling variables that increase the likelihood of positive change.

FACILITATORS AND BARRIERS TO BLEEDING MANAGEMENT PRACTICE IMPROVEMENT

There is an emerging body of literature addressing adherence to evidence-based bleeding management strategies, variability of transfusion practice, and the role of clinician behaviours in the perioperative environment.[27,28,54-57,59,60] This literature demonstrates clinicians may not always have the capability and opportunity to provide evidence-based bleeding management, even when they perceive patients would benefit from such interventions.[58-60]

Complexity

In critical bleeding scenarios, clinicians can find themselves overwhelmed with multiple competing priorities. The cognitive load of calling upon a plethora of existing and emerging evidence can be difficult even among experienced clinicians. One solution is the use of contextually relevant algorithms for bleeding management with a step-by-step matrix.[65]

Standardised practice using decision support tools (such as algorithms, guidelines and procedures) supports clinicians' ability to manage bleeding and is an accepted philosophy for the provision of high-quality, consistent, and safe healthcare delivery. Initially, evidence must be contextualised into tools that provide behaviour regulation through standardisation, prompts, reinforcement, and enhancement of appropriate routines.[27,66-69] Flexibility in decision-making must be woven into standardised tools, as rigid application of guidelines is not always appropriate for every patient or context.[27,70]

Standardised algorithms (see Figures 2 and 3) assist clinicians in focusing on stepwise methods to correcting coagulopathy.[22] Such algorithms should be made available at key points of care – for example, in emergency and cardiac theatres – as well as online for staff members to easily access in remote settings. In one tertiary centre, such algorithms are made accessible via QR codes on staff ID badges to assist in emergency scenarios. Translating evidence into contextually relevant decision support tools, guidelines, and procedures is time-consuming. The burden of creating these is often left to innovators who possess the "capability" and "motivation", and who extend themselves to create "opportunities". Standardisation should be supported at individual, departmental, organisational, and national levels, with existing algorithms from centres running successful GDBM programs shared widely for adoption by clinicians at new sites.

Strengths and weaknesses of individual VHAs also need to be understood. One weakness is that the TEG 6 global haemostasis cartridge does not have a pure tissue factor activated test for the extrinsic pathway as this test also contains kaolin and it can also be affected by heparin.[71] Consequently, due to limitations of the available information, clinicians may unnecessarily give PCC products without specific evidence that patients are devoid of extrinsic clotting factors – this is not GDBM. Similarly, neither the global haemostasis cartridge of TEG 6s nor ROTEM Sigma system gives a comprehensive picture of platelet function. Therefore, their use in conjunction with a specific platelet test, such as the TEG platelet ADP test or the Multiplate ADP, TRAP and AA (aspirin) test, is useful in the presence of platelet inhibitors. The complexity of these tests is substantial; however, understanding VHA holistically is essential if we are to progress GDBM.[53,71,72]

Human factors can confound even the best clinical trials. Despite the known benefits and demonstrated accuracy of results, such as the FIBTEM correlation with Clauss fibrinogen,[73] randomised controlled trials may be confounded by human factors and other barriers discussed in this article.[74]

Challenges in teaching cross-disciplinary evidence-based medicine

Clinicians and other healthcare workers across a myriad of disciplines may be involved in major haemorrhage situations. While each craft group brings specific skills or expertise to such scenarios, cross-discipline education ensures these teams work effectively with a shared mental model. Human factors in healthcare can have both profoundly advantageous or disastrous influences on teams. Dysfunctional relationships and human error causes up to 50 per cent of adverse events in a healthcare context.[75-78] Cross-discipline training programs involving key perioperative clinicians help capture the complexities of bleeding management scenarios, supporting multiple disciplines to "speak the same language".[27,79]

Long-term change includes early learning at key stages of development as a clinician. By embedding the concept of PBM beginning in medical school and then expanding into VHA testing and advanced GDBM in specialist training programs, we can capture clinicians at key stages of their learning experience. A shared mental model of GDBM (and the role of VHA in achieving this) needs to be multidisciplinary. Figure 5 highlights key stakeholder groups that need to share this mental model in an Australian context, but is by no means exhaustive.

Figure 5. Key group stakeholders

CICM: College of Intensive Care Medicine, RACS: Royal Australasian College of Surgeons, RANZCOG: Royal Australian and New Zealand College of Obstetricians and Gynaecologists, ACEM: Australasian College for Emergency Medicine, RACP: Royal Australasian College of Physicians, ACORN: Australian College of Perioperative Nurses, ACM: Australian College of Midwives, ANZCP: Australian and New Zealand College of Perfusionists, ACNP: Australian College of Nurse Practitioners, ACCCN: Australian College of Critical Care Nurses, MDANZ: Medical Deans Australia and New Zealand, CPMC: Council of Presidents of Medical Colleges, ANZSBT: Australian and New Zealand Society of Blood Transfusion, RCPA: Royal College of Pathologists Australia.

By incorporating these concepts into the curriculum of these institutions and colleges, we can help instil evidence-based blood management practice in the next generation of clinical leaders. However, the group of key stakeholders is large and heterogeneous, which presents challenges in reaching different craft groups. This highlights the need for flexible and innovative ways of delivering education tailored to the needs of individual groups or practitioners.

Within anaesthesia itself, a recent study in the United States showed there was a significant gap in transfusion medicine knowledge.[80] Teaching evidence-based medicine (EBM) is challenging; however, including key concepts from pre-clinical stages of student learning can lead to long-term behavioural change in students.[81-83] Systematic reviews have shown there is a gap between EBM and clinical practice, while also highlighting that a variety of teaching strategies are required to embed concepts in developing clinicians.[81] There is insufficient evidence to support one teaching style over another, but what is known is that teaching and assessment of key concepts needs to be interactive and multifaceted to achieve better clinical implementation of EBM.[81]

Discipline-specific training provides the addition of context to address patterns of coagulopathy that are unique to specific cohorts.[66,67,69] Multidisciplinary and multidimensional training supports the team, develops a common language and shared mental model, and removes dependence on the attributes of individuals.[66,70,84-86] This layered training exposes clinicians to unpredictable variations of practice, miscommunications, and misunderstandings.[66,70,85-87]

Multidisciplinary clinicians working together are considered to be a "team of experts".[87] Unfortunately, this does not necessarily translate to multidisciplinary clinicians being "experts at teams". Often, there may be unacknowledged tension amongst team members with other social motives existing that involve personal working relationships (e.g. anaesthetists relying on surgeons for private work), where familiarity can be perceived as shared trust but may actually involve dysfunctionality.[57]

To provide another example, within the cardiac surgical context there is no stable centre of authority; the leadership role is determined by the clinical priority at any given time. Different specialties are motivated by varied objectives, all of which are valid and appropriate. Drawing all the threads from each team member together to make informed decisions cannot be learned from a book or didactic lecture.

Communication – variability in non-technical skills

Anaesthetists are highly qualified and accomplished clinicians who possess "hard skills", or technical skills, that require significant cognitive intelligence, extensive medical knowledge, and skills learned through training and education.[88] Considerably less attention and formal training is given to the development of "soft skills", or non-technical skills.[57,79,89-91] Soft skills are often inherent, perceptive, and social personal resources that support effective communication and collaboration.[92] Literature suggests clinicians understand the implications of non-technical skills, but not necessarily how to improve them in real-world practice.[57,79,89-91]

Individuals learn in different ways, but everyone can still learn a variety of skills and concepts through various learning styles. Traditional teaching methods, such as didactic teaching, are being increasingly superseded by more interactive methods, for example, problem-based learning and simulation-based medical education (SBME).[81,93,94] However, traditional methods still play a role, especially in teaching basic sciences. Evidence shows that reinforcing didactic teaching with a variety of alternate training methods leads to better practice of EBM, and both technical and non-technical skills.[81,82,94]

Through immersive roleplay, SBME provides a transformative method of upskilling clinicians in both technical and non-technical management of crises.[93] SBME has been shown to increase proficiency in the management of time-critical, low-frequency, and high-morbidity conditions. However, SBME can be resource- and time-intensive to implement, particularly with increasing levels of fidelity to clinical practice. While high-fidelity simulations are ideal, even low-fidelity SBME can improve a learner's skills and facilitate the development of non-technical skills.

Psychosocial barriers and social influences

Change can be daunting, and clinicians looking to implement new practices can face an uphill battle in changing departmental culture. Established clinicians must first "unlearn" what they were taught and still believe about bleeding management. Clinicians may have reasonable reservations regarding new evidence or technologies. Their views should be acknowledged, and robust discussion within departments should be

supported as part of any change process. However, some reservations may be based on outdated evidence or may not withstand scrutiny. While these reservations can be challenging to address, forming groups of interested clinicians can help encourage change. Once a critical mass of clinicians has adopted a new approach, improved patient outcomes can become apparent and widespread change becomes possible. Clinical sites with experience implementing VHA provide an invaluable resource for other individuals or small groups of clinicians. Mentoring as an aide in the implementation of evidence-based practices has been used in other disciplines.[95] Learned experience, particularly regarding unforeseen and unexpected barriers, can help streamline the incorporation of VHA and GDBM at new sites. The authors of this article have mentored many new hospitals as they initiate GDBM programs.

Clinical setting, environment and cost

Governance and resourcing inconsistencies between regional and metropolitan or between public and private hospitals may influence the ability to implement VHA as a standard of care.

Unfortunately, the mere existence of standardised decision support tools and necessary technology is not sufficient for change. Clinical environments need to foster ease of access to resources for healthcare workers to use in crises. When implementing GDBM protocols, clinicians need to be mindful of physical barriers or challenges – for example, the physical distance from the bedside to where VHA testing technology is located. The location of equipment is important to consider when introducing VHAs, as learned by one Australian hospital where they initially installed the machines in the laboratory, geographically distanced from the bedside, before realising this created undue burden. That site has recently moved the VHA device to the point of care. However, this may not be a barrier at other sites where workflows may allow VHA instruments to reside in the laboratory and be managed by laboratory staff. The use of technology, such as livestreaming results of VHA tests to individual theatres or to bedside devices, can help address these resourcing issues but requires support from hospital administrators and digital technology teams. Additionally, confidentiality around patient information must be considered and addressed.

Other aspects of the clinical environment are easier to manage. For example, standardised algorithms should be conveniently available to clinicians at points of care, either physically or electronically. As previously described, training teams using SBME can help ensure clinicians know where and how to access decision support tools in a crisis.

Varied cost models exist and need to be negotiated based on context. In some jurisdictions, the Local Health Networks (LHN) may have a VHA service provided by contracts delivered through their pathology providers. The cost of VHA in other jurisdictions may be absorbed by the LHN, including the costs to purchase machines, consumables and quality assurance programs. Unlike pathology providers, LHNs in most areas cannot access financial rebates through the Medicare benefits schedule for VHA testing. Furthermore, complicating the financial barrier, direct savings through reduced blood product use may not be from the LHN budget. Additionally, a VHA service driven by clinicians places additional workload on doctors, nurses and perfusionists at the point of care to manage the device, consumables and quality control programs, all with a cost and no direct local financial incentive.

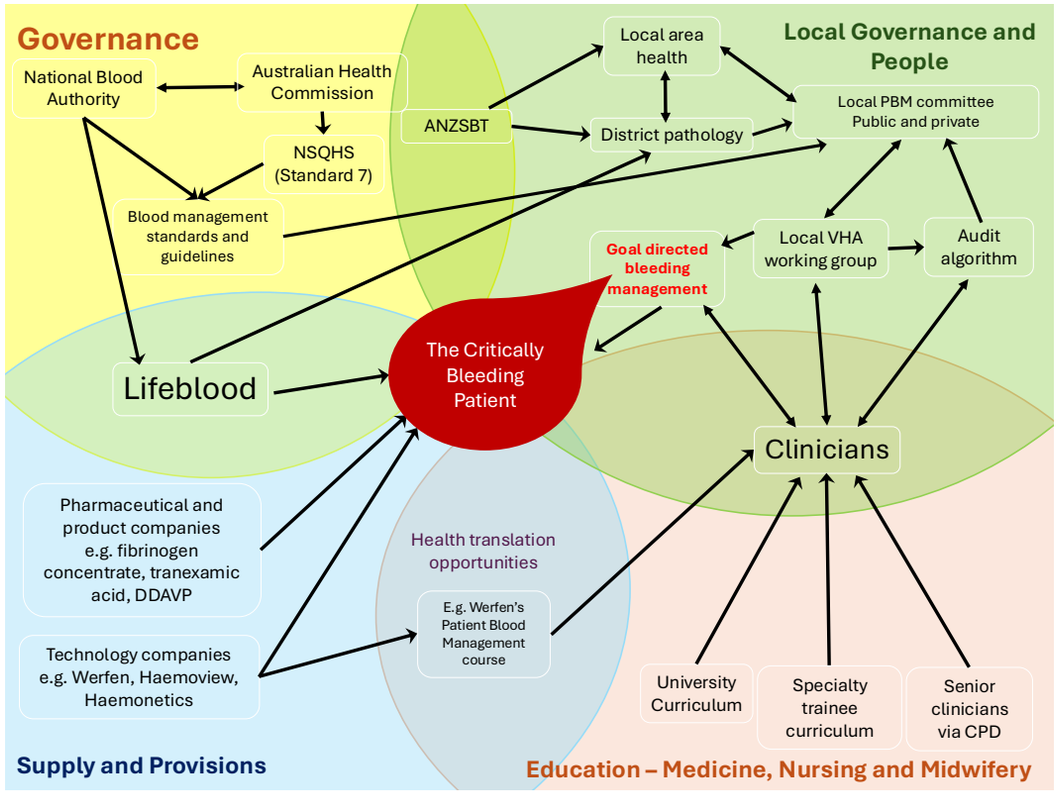
Governance

In Australia, the NBA manages and co-ordinates the supply of blood products and services. The Australian Health Commission provides the National Safety and Quality Health Service (NSQHS) standards which ensure organisations provide a consistent quality of care – defined in Standard 7 (Blood Management Standard).[91] The Australian Red Cross Lifeblood is the sole provider of domestic blood and blood products within Australia (see Figure 5). Disparate funding systems exist across Australian public and private healthcare. Under the National Blood Agreement, blood products are funded 63% by the Commonwealth and 37% by the states and territories. Queensland and New South Wales have passed on the 37% cost to individual public (but not private) healthcare services, while other states and territories may not pass on the cost. In New Zealand, the New Zealand Blood Service is responsible for the governance and performance of functions in relation to blood and controlled human substances, and hospital and healthcare services are responsible for 100% of the cost of blood products. Passing on the partial or full cost of blood products to the hospital and healthcare services will be an additional driver as a financial incentive to implement evidenced-based strategies.

Historically, blood product governance and oversight at local levels have been guided by haematologists predominantly working within laboratory settings. This structure may present barriers to the implementation of VHAs into routine practice, as haematologists may have varied experience and interest in the use of VHAs in managing critical bleeding. Concerns from haematologists may stem from loss of oversight of the testing modalities used in GDBM as they often reside outside laboratories. Encouragingly, VHA testing platforms are increasingly integrated into laboratories with automated streaming to pathology systems, enrolment in Royal College of Pathologists of Australasia quality assurance programs, and better oversight for batch/lot consumables.

Local governance involves multidisciplinary clinicians with an interest and involvement in both PBM and the judicious use of blood and blood products participating in local PBM committee meetings and quality initiatives (Figure 6). These committees provide organisation-wide oversight for the implementation of quality improvement systems. This includes ensuring best practice procedures for managing patients' own blood, appropriate clinical use of blood products, managing the availability and safety of blood products, and minimising wastage. This is achieved through ongoing quality activities to monitor and address outlying practice, updating procedures, algorithms, training manuals, documentation of education strategies and presentation of audit results. During the implementation of VHA into standard of care, governance should be provided by the local PBM committee to ensure practice change is safe, appropriate, efficient, and effective.

Figure 6. Systems map for the critically bleeding patient



In Australia, NSQHS Standard 7 (Blood Management) requires that facilities provide evidence-based care and implement strategies that improve blood management, including haemovigilance to monitor and evaluate the safety of blood transfusion and blood product wastage.[96] This must be facilitated through governance groups, such as PBM committees, which bring together team members from the laboratory, specialist haematologists, critical care physicians, and nursing staff to collaborate and address gaps or outliers in practice and benchmarking outcomes. This is particularly important in larger facilities that have laboratories and blood banks on site. These national standards further stipulate that clinicians should determine clinical need for products and minimise the inappropriate use of products, which can be achieved

by integrating VHAs.

Organisational support

There is little uniformity in navigating the delivery of care, both within and between public and private systems and organisations.[27,50,97] Unfortunately, these systems are growing more complicated, measures of success are increasingly vague and often without an apparent relationship to patient outcomes, and all within an atmosphere of healthcare crisis. Healthcare organisations need to stay within budget, where rationing, rationalising, cost-effectiveness, and "creating efficiencies" are buzzwords. This places clinicians in the challenging position of advancing evidence-based practice while simultaneously understanding and navigating competing organisational priorities and external agencies to achieve their goal. The practicalities, or simply the ability to "find a way", often appear to be the most difficult; a strong motivation for practice improvement can still drive clinicians forward, even when they are limited by a lack of managerial support or resources.

A good understanding of site-specific restrictions and considerations is vital for the successful implementation of VHA and GDBM protocols. There are likely to be nuances related to how certain blood products are accessed across blood banks as well as variations in institutional practices. For example, some sites may require haematology specialist approval for certain blood products (i.e. fibrinogen concentrate), some products may only be approved for specific indications, and some facilities may not have timely access to all blood products.

In recent years, a regional teaching hospital in Australia attempted to implement VHA and standardised algorithms for GDBM. However, the anaesthetist involved had no prior experience in implementing a major project and was facing challenges, from organisational through to departmental levels. This was overcome through mentorship from a clinician from another metropolitan hospital that had successfully implemented the same intervention. The mentor was able to guide the project lead through logistical steps and pre-emptively identify and address barriers, while the project lead could provide the contextual knowledge and on-site expertise of key considerations specific to their facility. Such mentorship is currently ad hoc and relies on the mentor's good will and motivation.

Networks of clinicians who have been successful in implementing improvements are also useful. Sharing knowledge of barriers, and helping clinicians feel empowered to approach management and administrators, can simplify a process foreign to most healthcare practitioners. With GDBM and VHA, this may involve the formation of special interest groups within professional bodies such as ANZCA. These groups would function as a support mechanism, formalise mentorship, and provide an avenue to share knowledge and develop resources for use by individual sites or clinicians wishing to implement changes at their sites.

Continuing motivation and improvement

Despite initial enthusiasm, without continued motivation from healthcare providers, implementation of EBM can face ongoing barriers. Unless continued improvement in patient outcomes or other key performance indices (such as ICU or hospital length of stay) can be demonstrated, clinicians may become apathetic towards a particular innovation before it becomes standard practice.

Continued audit and feedback cycles are necessary processes to address these issues and at multiple organisational levels:

1. Convincing clinicians by demonstrating improved patient outcomes.

2. Convincing managers with appropriate resource utilisation.

3. Convincing administrators with cost savings.[27]

To be effective, audits need buy-in from perioperative teams.[98] Audit and feedback can be particularly relevant for anaesthetists and surgeons as they are often a highly driven and competitive group of clinicians. For example, a recent sustainability quality improvement project used site-specific and live data to motivate clinicians at a major American paediatric centre to reduce their greenhouse gas emissions, helping to reduce emissions by 87 per cent over a five-year period.[99]

Furthermore, audits provide an opportunity for working parties or PBM committees to regularly review their algorithms and decision support tools and update them as new evidence becomes available. Audit cycles can also identify new challenges faced by clinicians. For example, at one site with established VHA, algorithms were made available online, but hospital internet reception was poor and clinicians struggled to use electronic versions of decision support tools. This highlighted the need for easily accessible physical copies until digital infrastructure and connectivity were improved.

Audits should not be tokenistic. They should be meaningful and aimed at providing evidence of clinical benefit or highlighting areas of improvement. Reasons for non-compliance with a standardised algorithm may be valid – for example, clinicians may have deviated due to advice from haematology or a lack of timely access to certain products. Auditors should use these events as an opportunity to reflect on the utility of the algorithm objectively. By doing so, clinicians can be reassured that there is no threat to clinical autonomy.[98] Similarly, if audits show poorer patient outcomes or significant non-compliance with protocols, feedback should be received as an opportunity for improvement. Audits can also provide an avenue for junior doctors and nursing staff to engage in quality assurance within departments, offering valuable professional development opportunities.

Technological advances

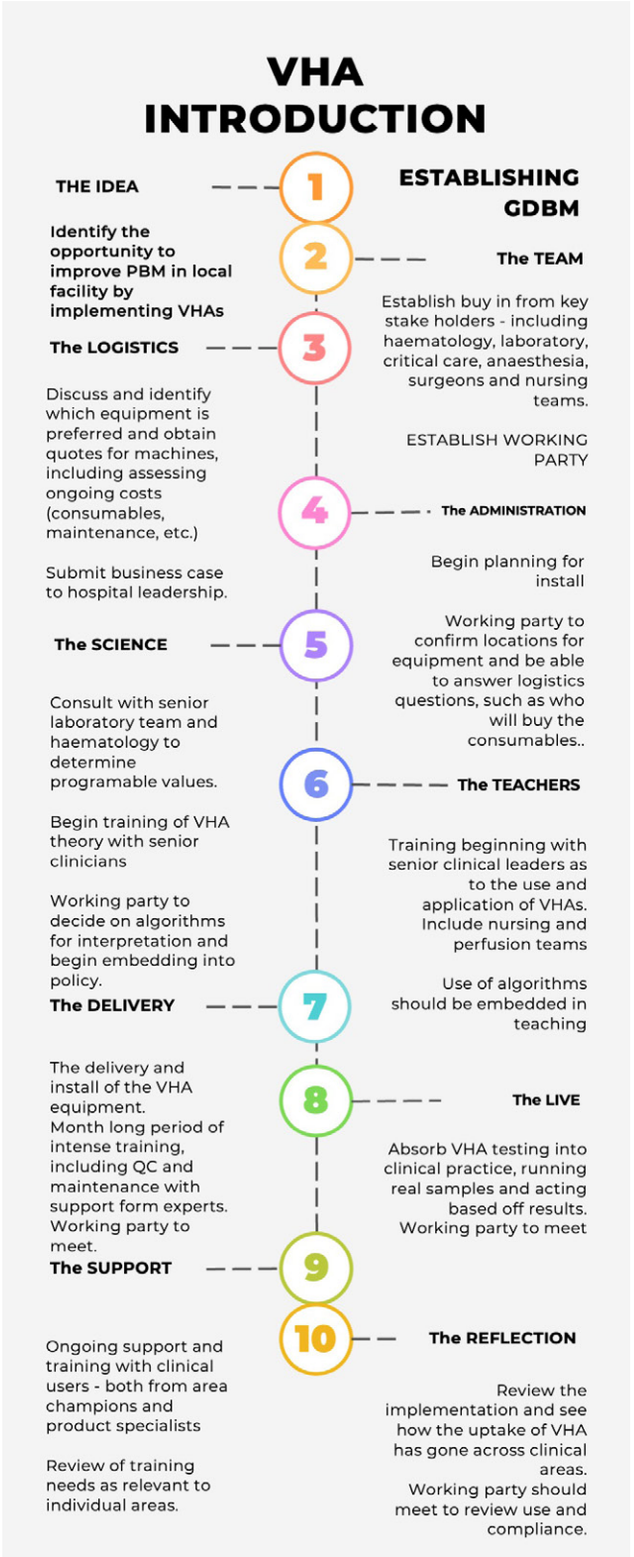
Rapid technological advancements in the biomedical field provide ongoing challenges as well as opportunities in the implementation of EBM. Current technology is now laying the foundation of understanding for how PBM will evolve in the future as new VHAs are developed. Clinician feedback can assist developers in evolving and meeting complex challenges faced by clinicians. For example, incorporating point-of-care platelet function testing into existing VHAs, or the development of assays better able to assess the impact of newer anticoagulants, will help clinicians in providing better care.

Support from, and partnership with, industry is vital for the clinical implementation of new technologies. From early user training to ongoing maintenance and troubleshooting support, clinicians and industry can collaboratively improve patient outcomes. Furthermore, industry can learn from clinicians about new and emerging requirements as patient care evolves. For example, advances in mechanical circulatory support, as well as research into correlation coefficients in real clinical scenarios and outcomes, helped determine earlier detectable time points on VHA, with results available after five instead of 10 minutes.[100] This has assisted clinicians in treating coagulation issues earlier in a rapidly evolving bleeding scenario. In addition, industry can support logistical concerns, for example by providing secure web-based software so that the results of VHA testing can be accessed in real time by clinicians in theatres or resuscitation scenarios.

IDEAL IMPLEMENTATION TIMELINE

Figure 7 provides a theoretical timeline outlining actions involved in implementing GDBM, from the initial idea to implement VHAs to the successful use of GDBM. The timeline includes ongoing review after VHAs have been installed, with input from key stakeholders, including laboratory, senior clinicians, administration and users. Ongoing external quality control is also necessary for long-term quality assurance.

Figure 7. Implementation timeline: theoretical example



CONCLUSION

The use of GDBM to manage perioperative blood loss, bleeding and acquired coagulopathy is an important and effective strategy to improve patient outcomes. VHAs provide rapid identification of both the presence and cause of coagulopathy, and real-time feedback regarding the effectiveness of treatment. Critical care clinicians must lead multidisciplinary collaboratives to provide timely and effective treatment in dynamic situations. However, despite the known benefits of PBM and VHAs, the implementation of bleeding management treatment algorithms remains challenging. We propose that the best way to enable widespread holistic understanding is through cross-disciplinary education with stepwise, evidence-based decision support algorithms, treating fibrinogen first, and teaching available technologies (such as ROTEM and TEG) side by side. The challenges in implementing change initiatives vary widely, where unique cohorts and contexts require specific implementation activities to achieve success. Empowering clinicians to use evidence-based methods to guide bleeding management and transfusion can improve patient outcomes and support a more sustainable health system.

Appendices and further resources are available here: downs.com.au/rotemteg-project

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Hyperangulated videolaryngoscopy

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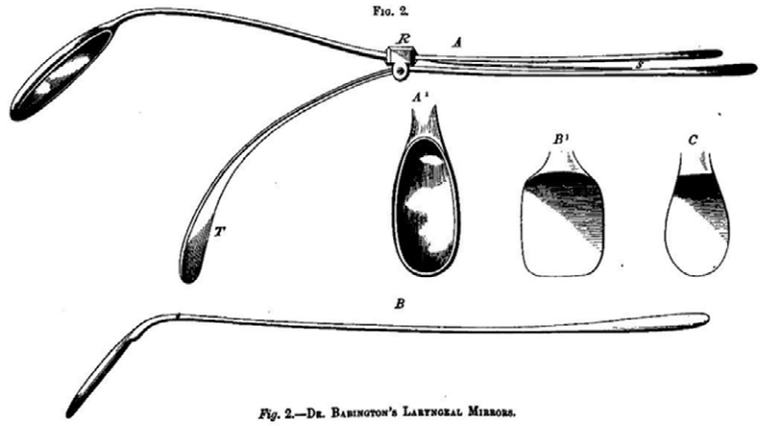
INTRODUCTION

In the recent history of airway management, one of the most notable airway advances has been the development, widespread uptake and use of videolaryngoscopy. Most anaesthetic clinicians will be familiar and comfortable using standard geometry or Macintosh videolaryngoscopy blades, which utilise a similar technique to traditional direct laryngoscopy. Hyperangulated videolaryngoscopy, although less familiar, has emerging evidence regarding its potential benefits, particularly in managing difficult airways. This article aims to explore the perceived challenges associated with using hyperangulated blades by understanding the equipment and its interaction with the airway anatomy.

We aim to reassure and empower readers that by understanding the technical nuances of these devices and how to best employ reliable adjuncts, this is a skill everyone can easily hone with practice and add to their airway management armamentarium.

Laryngoscopy and tracheal intubation are core airway skills for all anaesthetists. The original instruments developed for visualisation of the glottis in the 19th century relied on indirect methods using systems of mirrors and sunlight (see Figure 1).[1]

Figure 1. Babington's laryngeal mirror



Sourced from Mackenzie (1865)[2]

Direct laryngoscopy took off in the early twentieth century with the development of the Miller and MacIntosh blades in the 1940s.[1] A recent return to indirect laryngoscopy has occurred with the development of videolaryngoscopes in the 2000s and their increasing clinical use over the past twenty years.

While most anaesthetists are comfortable with using standard geometry (Macintosh) videolaryngoscopy (VL) blades, the use of their hyperangulated counterparts raises some questions, which we aim to address throughout this summary.

WHAT TYPES OF VIDEOLARYNGOSCOPES ARE AVAILABLE?

Videolaryngoscopes can be classified broadly into channelled and non-channelled blades (see Figure 2). Channelled blades incorporate a groove within the blade, which aims to direct the endotracheal tube into the trachea. Non-channelled blades can be further subdivided into standard geometry (Macintosh style) blades and hyperangulated blades, which have a more acute curve (see Figure 3).

Figure 2. Videolaryngoscope classification

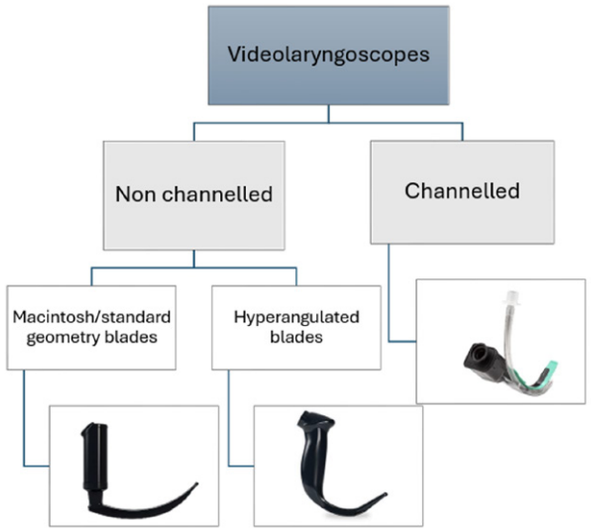
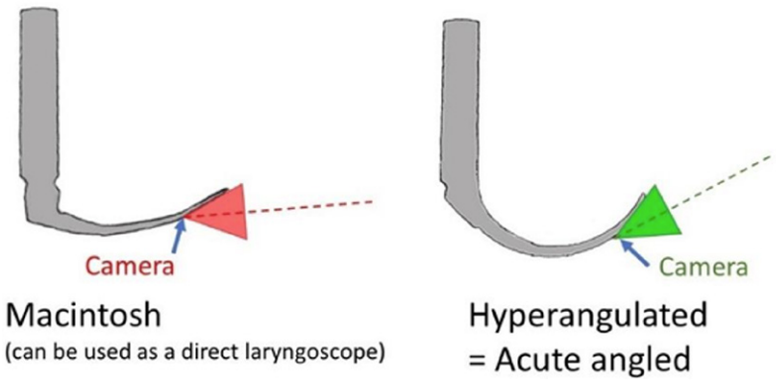


Figure 3. Non-channelled videolaryngoscope blades



All videolaryngoscopes incorporate a light source and a camera close to the blade tip.[3] This provides a wider angle of view and allows visualisation of airway structures. The light source is commonly a light-emitting diode powered either by an internal battery or by the monitor.[3] The camera uses a complementary metal oxide semiconductor (CMOS) sensor, which converts light energy to electrical energy. It is the technology

used in many digital cameras.[3] The Airtraq is slightly different as it uses optical mirrors to transmit the image to the eyepiece. It can, however, be connected to a Wi-Fi camera to digitally view the image, which uses a CMOS chip.

The image from the camera on the blade can either be displayed by an LCD display mounted on the device or on a standalone unit via a cable connection.[3] One advantage of a separate display unit is that the larger picture can be simultaneously viewed by multiple members of the team. This helps the team have a shared mental model of the airway management and facilitates teaching. Devices with mounted displays are portable, facilitating improved access to videolaryngoscopy in remote areas of the hospital or as part of a mobile emergency airway response team. Possible disadvantages of these devices are added weight to the blade, which may compromise manoeuvrability. The smaller screen limits the ability of others to visualise the airway, which may subsequently limit their ability to help the operator via external laryngeal manipulation or to predict the need for additional or alternative equipment.

WHAT ARE THE DIFFERENCES BETWEEN MACINTOSH AND HAVL?

The hyperangulated videolaryngoscopy (HAVL) technique is distinct from that used with Macintosh-style blades. An appreciation of their differences allows the airway operator to optimise their technique and plan for, and overcome, the challenges when using these devices. Often, good visualisation of airway structures with hyperangulated blades doesn't equate with ease of placing the endotracheal tube (ETT), but by understanding the equipment the clinician will be able to devise a reliable strategy for successful ETT insertion.

Airway anatomy has been described using the two-curve theory as shown in Figure 4:

1. Primary curve – oropharyngeal curve.
2. Secondary curve – pharyngo-glotto-tracheal curve.

Figure 4. Two-curve airway theory

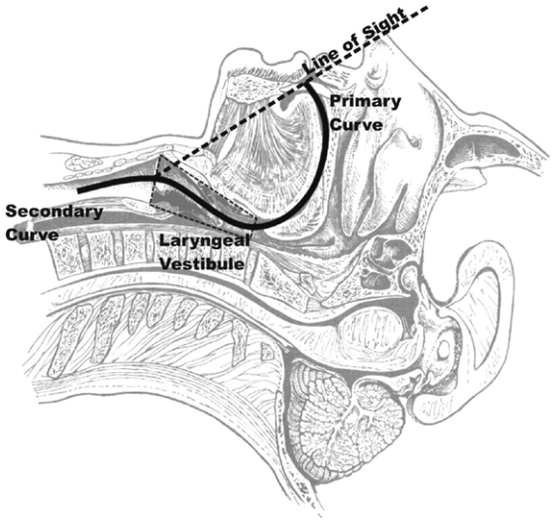
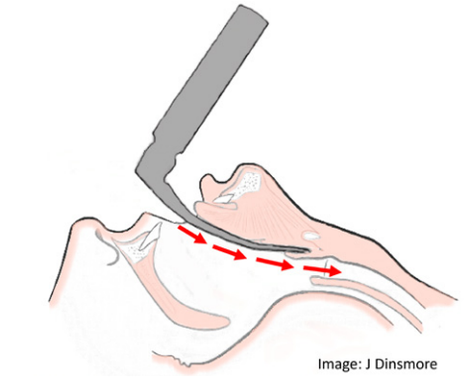


Figure sourced from Greenland et al. (2010)[4]

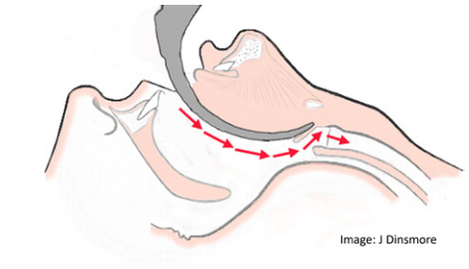
During Macintosh videolaryngoscopy (MacVL), the aim is to flatten the primary airway curve, creating a straight path to the glottis, which allows either direct (line of sight) or indirect (via the video screen) visualisation of the glottis. The straight path created has the advantage of making the delivery of the endotracheal tube to the glottis and passage into the trachea straightforward. Macintosh laryngoscopy is achieved by inserting the blade on the right side of the mouth and tongue, sweeping the tongue to the left and out of the way (Figure 5). The tip of the blade is placed in the vallecula, and a lifting motion allows exposure and visualisation of the glottis. This technique remains largely unchanged whether one is using a Macintosh-style blade for direct or videolaryngoscopy.

Figure 5. Macintosh laryngoscopy



In contrast, hyperangulated videolaryngoscopes have a similar shape to the primary airway curve and aim to look around the corner to achieve a view of the glottis. This means that a direct (line of sight) view cannot be achieved, and it is purely used as an indirect intubation technique. The blade is inserted in the midline of the tongue with the tip still inserted in the vallecula (see Figure 6). Despite achieving a good view of the glottis, the more acute angles involved can make the delivery of the endotracheal tube to the glottis and subsequent passage into the trachea the more challenging aspect of the technique. These challenges can be reliably overcome with the appropriate technique.

Figure 6. Hyperangulated videolaryngoscopy



What are the benefits of HAVL over MacVL?

The 2022 Cochrane review evaluated the performance of videolaryngoscopy in comparison to direct laryngoscopy.[5] This meta-analysis included 222 studies with over 26,000 adult intubations looking at four critical outcomes:[5]

1. Failed intubation.
2. Hypoxaemia (desaturation below 94%).
3. Successful first attempt at tracheal intubation.
4. Oesophageal intubation.

The results demonstrated that Macintosh videolaryngoscopy reduced the rate of failed intubation with a risk ratio (RR) of 0.41 (0.26 – 0.65) and the risk of hypoxaemia, RR 0.72 (0.52 – 0.99).[5] There was also an increased chance of successful first-attempt intubation, RR 1.05 (1.02 – 1.09).[5]

Hyperangulated videolaryngoscopy was separately evaluated and showed reduced rates of failed intubation, RR 0.51 (0.34 – 0.76), which was particularly pronounced if there were predictors of a difficult airway, RR 0.29 (0.17 – 0.48).[5] Hyperangulated blades decreased the risk of oesophageal intubation, RR 0.39 (0.18 – 0.81), which was not seen with the use of MacVL.[5]

Following the Cochrane review, there has been increasing acceptance of the clinical safety benefits of videolaryngoscopy over direct laryngoscopy as the primary airway technique when endotracheal intubation is planned. The argument for universal or default videolaryngoscopy is emerging, and this is reflected in recent recommendations in international airway guidelines.

1. The Project for Universal Management of Airways (PUMA) guidelines for the prevention of unrecognised oesophageal intubation state to, “routinely use a videolaryngoscope whenever feasible”.[6]
2. The Canadian Airway Focus Group recommends, “routine primary use of VL with an appropriate blade type for all tracheal intubations. If difficulty is predicted with glottic exposure using DL or MacVL, first-attempt use of HAVL to facilitate tracheal intubation should be strongly considered”.[7]

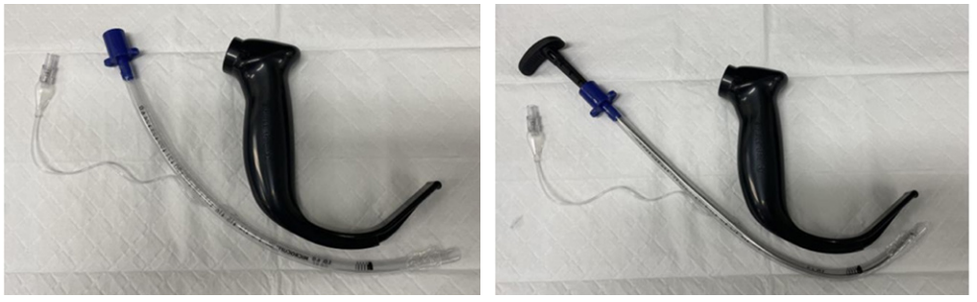
The question of which type of VL device is optimal remains open.

A recent study by Kohl et al. sought to examine the performance of hyperangulated videolaryngoscopy in comparison to Macintosh videolaryngoscopy. This randomised controlled trial of 182 adult patients undergoing elective head and neck surgery with a predicted difficult airway compared CMAC D blade with CMAC MacVL performance.[8] The primary outcome of percentage of glottic opening (POGO) showed an improved view with the hyperangulated D blade (89% vs 54%, p<0.001).[8] This result is perhaps unsurprising; however, achieving a view with a videolaryngoscope is only part of the procedure, with the goal being quick and successful first-pass intubation of the trachea. This was evaluated in the study’s secondary outcomes, which demonstrated successful first-line technique intubation of 99% with HAVL vs 87% with MacVL (p = 0.002).[8] The paper describes one episode of failed intubation with a hyperangulated blade, which ultimately resulted in a tracheostomy to secure the airway, compared to twelve failed MacVL intubations, which were all successfully rescued with HAVL.[8] There was also an improved first attempt success with HAVL 97% vs 67% (p<0.001) and first attempt success without complications 92% vs 64% (p<0.001).[8] Intubation time was evaluated, with this being shorter overall in the hyperangulated group (19 vs 27 seconds); however, this represents the Macintosh VL group requiring multiple attempts as when time was compared for first attempt time, there was no difference (19 vs 20 seconds).[8]

HOW DO I USE ADJUNCTS TO RELIABLY DELIVER THE TUBE TO THE LARYNX?

The use of an introducer is required when using HAVL, as without one, the endotracheal tube will naturally advance posteriorly into the oesophagus, as shown in Figure 7.

Figure 7. Path of ETT compared to HAVL blade curve without and with a stylet



Different adjuncts have potential benefits and limitations, so it is essential that the airway operator is familiar with these to make informed choices.

Can I use a bougie with HAVL?

While bougies work well with Macintosh blades, the lack of stability when shaped makes malleable designs less suitable for HAVL use. Despite pre-shaping prior to intubation, the curve of malleable bougies often unfurls in the airway, making them less reliable than more rigid or fixed adjuncts. The Steerable Tracheal Intubation Guide (STIG) bougie, available in Australia, has a stable curve, although this is relatively shallow compared to stylets optimised for HAVL (see Figure 8). As the name suggests, this specialised bougie has a flexible tip which is controlled by a thumb slider tab allowing it to be flexed and retroflexed into the trachea. It performed well when used with a CMAC D-blade in a recent critical care study by Taboada et al.[9] It is

unclear how it performs in patients who are conventionally considered difficult to intubate. The STIG can only be used for ETTs 7.0 and larger, making it unsuitable for paediatric use or with smaller adult tubes.

Figure 8. Steerable Tracheal Intubation Guide (STIG) bougie

If a bougie can be placed in the upper trachea, then tube advancement into the trachea is usually not challenging if it is rotated 90° anti-clockwise before reaching the vocal cords. This rotation creates a more optimal alignment of the bevel at the tip of the endotracheal tube and the glottic opening, facilitating the advancement of the tube into the trachea.

STYLETS

Several manufacturers produce preformed rigid stylets, the distal section of which has a similar curve to their model of hyperangulated blades and which are thus optimised for use with them. The rigidity of the stylet ensures the curve is maintained during insertion into the mouth, in contrast to a malleable stylet, which may lose some of the preformed curve if careful insertion alongside the blade is not performed.

Verathon produces the Gliderite stylet in various sizes (see Figure 9) to complement their hyperangulated blades:

1. Small ETT 3.0 – 4.0
2. Medium ETT 4.5 – 5.5
3. Large ETT 6.0 and larger

It is important to note that a medium Gliderite stylet is not suitable for use with a 5.0 Microlaryngoscopy ETT, as it is too short and the curve is not matched to the smaller Lopro blades. Therefore, when performing an adult intubation with an ETT smaller than a 6.0, an alternative stylet system should be used.

Figure 9. Verathon Gliderite preformed stylets

Figure sourced from Verathon[10]

Storz CMAC also produces a rigid preformed stylet to conform to their D blade.

Malleable stylets are a cheap and widely available alternative. Shiley intubating stylets come in a variety of sizes, as shown in Table 1.

Table 1. Shiley intubating stylet sizes

Size (Fr)	ID tube recommendation (mm)	Length (cm)
6	2.5 – 4.5	280
10	4.0 – 6.0	350
14	> 5.0	350

Data sourced from Medtronic[11]

When using malleable stylets, it is paramount to curve the stylet to match the blade being used to achieve accurate delivery to the glottis.

Which is the optimal adjunct when using HAVL?

If the appropriate technique is matched with an appropriately shaped stylet, then there is a high likelihood of a successful HAVL intubation. Recent studies (by Ruetzler et al. and Kohl et al.) used rigid stylets to achieve first-pass success rates of 98.3% (>4000 patients requiring intubation) and 97% (a convincingly difficult group of patients undergoing head and neck surgery).[8,12]

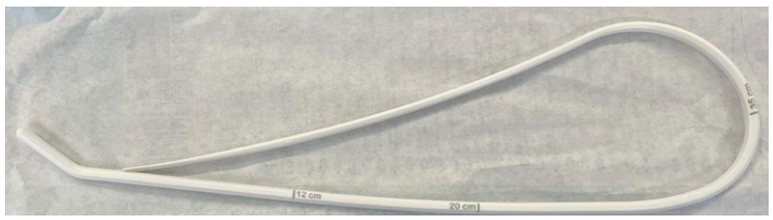
It is equally apparent from recent publications that if there are issues with technique or stylet shaping, then failure can occur frequently. Eum et al. reported an 88% first-pass success rate when using malleable stylets in 83 patients with soft features of intubation difficulty.[13] This contrasted with a 98% first pass success rate in a malleable bougie group. Most stylet failures occurred because the stylet shaping resulted in the tube missing the larynx posteriorly, suggesting a stylet shaping issue. Of note, the study protocol involved the complete removal of the stylet after the tube tip had been passed through the cords. We would not recommend this. This is the same technique used in the (malleable) stylet group of the Taboada et al. critical care study, which had only an 83% first pass success rate.[9]

Due to conflicting studies, there is currently no consensus on the optimal adjunct when using HAVL. If a bougie is to be used, it is recommended that one with a stable curve be used in preference.[14]

Alternative adjuncts and special situations

The recent development of the universal stylet bougie aims to combine the desirable features of both adjuncts, allowing it to be used as either. It has two malleable sections that allow it to be curved to shape (see Figure 10).

Figure 10. Universal stylet bougie



Another method is using a Ducanto suction catheter to direct the bougie anteriorly to the glottis. This type of suction catheter has a larger diameter and is more curved than a standard Yankauer, making it suitable as a “bougie introducer”. This technique has recently been presented in a case report.[15] In the authors’ practice, this method has been successful when using a paediatric bougie in order to subsequently railroad a 4.5 laser endotracheal tube.

Video-assisted fibreoptic intubation (VAFI)

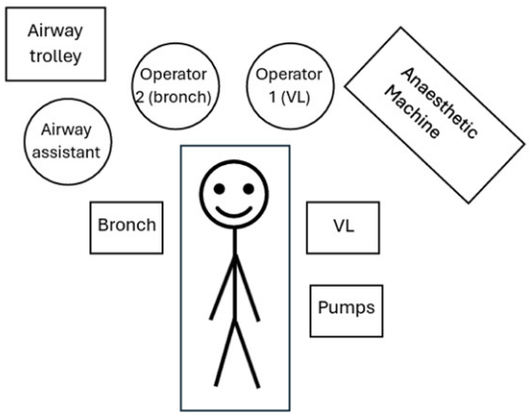
A flexible bronchoscope can be used as the endotracheal tube introducer in conjunction with a hyperangulated blade. In this technique, the flexible bronchoscope acts like the ultimate steerable bougie. This technique requires two operators: person one performs laryngoscopy and maintains a view of the glottis on screen. In contrast, person two operates the flexible scope with an ETT pre-loaded to manoeuvre the bronchoscope into the trachea and then pass the ETT. There is a wide range of scope sizes. The Ambu A5 scope range includes a slim scope with an outer diameter of 2.7 mm, which will fit a 3.5 ETT.

An additional advantage of this technique is that it facilitates the training and maintenance of flexible bronchoscopy skills in trainees and anaesthetists. Degradation of flexible bronchoscopy skills in an environment where awake fibreoptic intubation seems to be becoming less frequent is a topical issue. Any opportunity to maintain manual dexterity with the scope reduces the cognitive load during an awake fibreoptic intubation, where small gains can make the difference between success and failure.

Disadvantages include the cost of the bronchoscope compared with the cheaper stylet and bougie alternatives. In many institutions, disposable bronchoscopes are the mainstay, which also raises concerns about waste in an era where green and sustainable practices are increasingly important.

The ergonomics of using both a HAVL and a flexible bronchoscope can often require the use of two displays (see Figure 11). Some systems, such as Verathon's Glidescope, can attach both devices and display them on one screen as a split screen. This helps with the ergonomics and ease of performance, as the operators only have one screen to pay attention to. It can, however, easily be done with two screens positioned on either side of the patient.

Figure 11. VAFI ergonomics



WHICH TECHNIQUES HELP RELIABLY DELIVER THE TUBE TO THE LARYNX?

Compromising glottic view

Accepting a restricted glottic view helps reduce the angles required to manoeuvre the ETT into the trachea. In Figure 12, the top image shows a POGO of 100% with Kovacs sign (visualisation of the anterior cricoid ring and tracheal wall), which also corresponds with increased angles between the pharynx, glottis and trachea, making passage of the tube potentially more difficult. In the lower image of Figure 12, a more compromised glottic view is accepted by dropping the blade tip so it is parallel to the floor and withdrawing the tip slightly out of the vallecula. This achieves the recommended restricted glottic view of 50% POGO in the upper 50% of the screen, creating a straighter path for endotracheal tube delivery.

Figure 12. Restricted glottic view

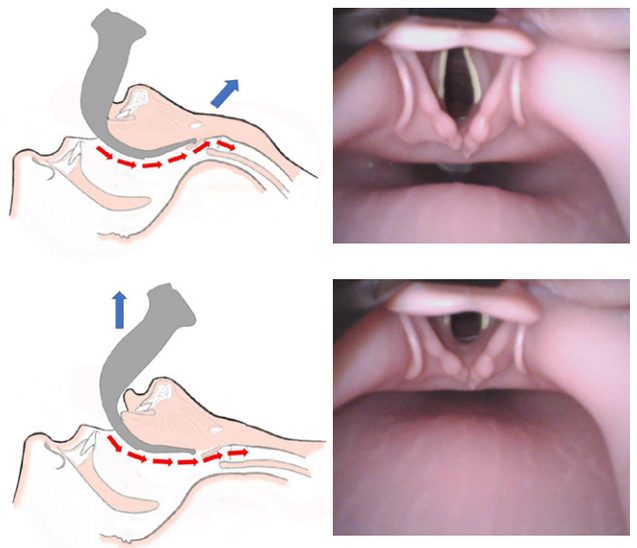


Image: J Dinsmore

A 2016 randomised parallel group superiority clinical trial by Gu et al. evaluated a full glottic vs restricted (<50% POGO) view for intubation using a Glidescope GVL plus Gliderite rigid stylet. The results demonstrated a faster intubation time in the restricted view group (27 vs 36 seconds, p<0.001) and an operator rated easier intubation on a visual analogue score (14 vs 50, p<0.001).[16] Interestingly, in three cases in the "full view" group, the tube was able to be advanced past the cords but not into the trachea. When they converted these cases to a restricted view, tracheal intubation was easily completed, which highlights how the reduced angles achieved with more restricted views help avoid anterior tracheal wall impingement of the ETT.[16]

Apart from the changes in airway angles, another potential benefit of this restricted view is achieving a wider field of view, allowing for earlier visualisation of the ETT and thus enabling earlier redirections to improve passage into the airway.

Endotracheal tube rotation

Anterior tracheal wall impingement of the endotracheal tube is a potential issue when using HAVL, particularly when advancing a standard pre-curved (Magill) tube off a preformed stylet.

After placing the tube tip gently through the vocal cords, 90° clockwise tube rotation is recommended before tube advancement (see Figures 13 and 14). This aligns the curve of the tube with the trachea, allowing easy and atraumatic advancement. Clockwise rotation is preferred to anti-clockwise rotation as the bevel orientation means the tube tip is less likely to dig into the anterior tracheal wall.

This 90° clockwise rotation of the endotracheal tube can be achieved by rotating the whole stylet-tube assembly, rotating the tube on the stylet, or a combination of both. While rotating the stylet-tube assembly can result in very slick, one-operator intubations, it may not be possible to rotate adequately due to the anatomy of some patients. Rotating the endotracheal tube on the stylet requires an assistant to stabilise the stylet, but may be more reliable in achieving success.

Figure 13. ETT rotation

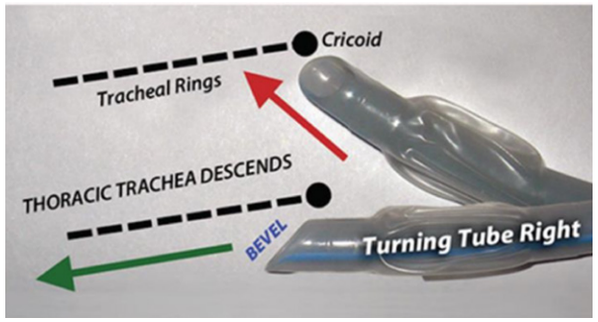
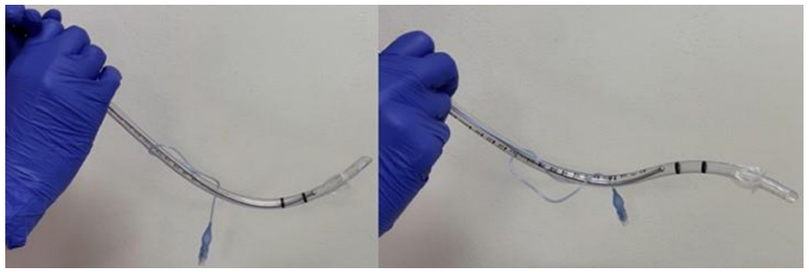


Image sourced from Levitan (2015)[17]

Figure 14. Clockwise rotation of ETT off a preformed rigid stylet



An alternative approach is the "backward" loading of the ETT onto the stylet. This effectively means the ETT is already rotated when it is loaded. By loading the ETT with its natural curve in the opposite orientation when it is advanced off the stylet at the glottis, its tip should follow the descending path of the trachea. In practice, standard pre-curved tubes tend to be unrotated on their own by the time intubation is attempted.

THE AIRWAY IS SOILED – IS IT BETTER TO USE DL OR VL?

A prospective observational study by Sakles et al. in 2017 examined first-pass success during rapid sequence intubation with direct laryngoscopy compared to Glidescope hyperangulated videolaryngoscopy for clean and soiled airways.[18] There were a total of 1985 intubations included, of which 590 were soiled with either blood, vomitus or both.[18] A summary of the first pass success results is displayed in Table 2.

Table 2. First pass success intubation

	Glidescope	Direct laryngoscopy
Clean	91%	75.8%
Soiled	81.4%	65.5%

Data sourced from Sakles et al. (2017)[18]

These results show that both devices perform worse in a soiled airway; however, importantly, the videolaryngoscopy group still outperforms direct laryngoscopy. To the authors' knowledge, there is no study directly comparing Macintosh and HAVL in soiled airways. Given that the hyperangulated Glidescope performed well in the Sakles trial, it would seem appropriate to use it in this circumstance, although one potential advantage of a Macintosh VL blade would be the ability to also be utilised for direct laryngoscopy in the low instance of airway soiling that obscures the video imaging.

A useful technique to optimise soiled airway management with videolaryngoscopy is suction-assisted laryngoscopy and airway decontamination, or SALAD.[19] This technique involves using a large-bore suction

to perform oral decontamination and simultaneous compression of the tongue to create a clear space for the insertion of the laryngoscope. The laryngoscope is inserted, hugging the tongue to avoid interfering with the optics. Once a view of the glottis has been achieved, the suction catheter is moved to the left of the laryngoscope blade to provide continuous suction but also to a clear path for the intubation to occur.

HOW DO I IMPROVE MY SKILLS IN HAVL?

Training

Feeling comfortable using hyperangulated blades is like any other practical skill; it requires practice. It is essential that this skill is honed on normal airways initially. This ensures that when the device is used in a truly difficult airway, where there are limited alternative options, the operator is more comfortable, confident, and skilled with the equipment.

A sub-analysis of a randomised controlled trial by Ott et al. examined the number of intubations required to achieve proficiency when using hyperangulated videolaryngoscopes. The study evaluated 4312 intubations performed by 223 clinicians.[20] The median number of procedures to achieve proficiency in tracheal intubation with hyperangulated videolaryngoscopy was 12 (12-26).[20] This number was achieved by clinicians independent of their previous experience with direct laryngoscopy, suggesting that the learning curve is relatively independent of previous experience. The low number required to achieve proficiency serves as a reassurance that this is an effective airway technique that can be easily and quickly mastered with some education and practice. To gain further practice and experience, the following link is for a HAVL skills and instruction video:

Technique training video

High-flow nasal oxygen

There is no evidence that, in the hands of a skilled and practised clinician, hyperangulated blades result in longer intubation times. It is important, however, that training conditions are optimal for novice users or those upskilling with these devices. The use of high-flow nasal oxygenation to provide pre- and intraprocedural oxygenation is helpful to prolong the apnoeic time, allowing a calm and non-time pressured environment to hone this skill. The authors find using high-flow nasal oxygen alongside a video-assisted fibreoptic intubation (VAFI) particularly beneficial.

With the advent of the Optiflow Switch Nasal Interface, the use of high flow during induction and airway management has become seamless.[21] Some caution with interpreting the end tidal oxygen and capnography must be exercised when using this system.

HOW DO I DOCUMENT MY AIRWAY GRADE WITH HAVL?

Given that HAVL is a purely indirect method of intubation, the traditional Cormack-Lehane grading is not applicable. Alternative scoring systems have been developed to try to address this problem. The Fremantle score is shown in Figure 15. It demonstrates good accuracy and intra- and inter-rater reliability in a study comparing its use for documenting videos of intubation with the Cormack-Lehane grading and POGO (percentage of glottic opening).[22] A Video Classification of Intubation (VCI) score has also been developed.[23] This is a three-part score that evaluates the type of blade used (MAC vs hyperangulated), POGO, and the subjective ease of intubation, as summarised in Figure 16. There is no absolute consensus on a classification of videolaryngoscopy intubation; however, both systems include most of the pertinent information that a subsequent anaesthetist would use for planning. As with any airway documentation, other parameters are important to include, such as ease of mask ventilation and any adjuncts needed for successful management.

Figure 15. Fremantle score

Fremantle score component			Comparison scores
View	**F** (full)		CL grade 1 POGO 100%
	P (partial)		CL grade 2a POGO 50%
	N (none)		CL grade 3 POGO 0%
Ease	**1** - Easy	TT passed first time using manufactures technique	
	2 - Modified	TT passed with more than 1 attempt or a modified technique or adjunct used	
	3 – Unachievable	Unable to pass TT	
Device		Name of the device and blade used	

Image sourced from O'Loughlin et al. (2017)[22]

Figure 16. VCI score

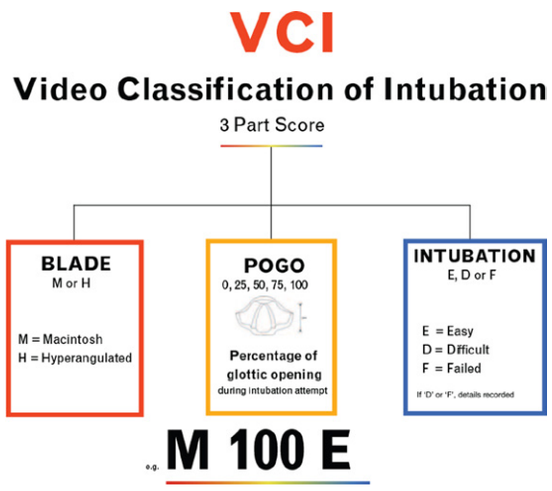


Image sourced from Chaggar et al. (2021)[23]

CONCLUSION

Hyperangulated videolaryngoscopy is a purely indirect airway technique using a blade with an acute curve to look "around the corner" for glottic visualisation. HAVL offers significant benefits, including reduced failed intubation rates, particularly in predicted difficult airways. Despite often providing a good view, a challenge with HAVL is reliably delivering the ETT into the trachea. This challenge can be easily overcome by using an introducer and incorporating specific techniques, such as accepting a slightly restricted glottic view and rotating the ETT at the cords. Learning HAVL proficiency is relatively quick and largely independent of prior direct laryngoscopy experience. Standards for documenting HAVL intubation require alternative scoring systems like Fremantle or VCI, as the traditional Cormack-Lehane grade does not apply to this indirect method.

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Airway management of tracheal tumours

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Edited by Associate Professor Benjamin Cheung

INTRODUCTION

Tracheal tumours, although rare, pose significant challenges to anaesthetic management due to their potential to compromise airway patency and ventilation. These tumours originate in the tissues of the trachea and can obstruct the airway to varying degrees depending on their size, location, and growth pattern. Their rarity means most anaesthetists may only encounter them infrequently, typically only in tertiary centres. Despite this, a sound understanding of their implications and the strategies available for their management is essential.

This narrative review aims to provide anaesthetists with a practical and clinically focused overview of tracheal tumours, exploring their clinical presentation, relevant pathophysiology and classification systems. Anaesthetic implications, detailed strategies for airway assessment and management will be discussed. The goal is to support informed decision-making in both elective and emergency settings.

CLINICAL PRESENTATION

Symptoms of tracheal tumours are often insidious and non-specific. They typically relate to the mass effect of the tumour and may mimic more common respiratory conditions such as asthma or chronic obstructive pulmonary disease.[1] Due to the trachea's considerable diameter, symptoms may only appear after significant tumour growth – typically at 50 to 70 per cent of luminal narrowing.[1] Dyspnoea is the most common presenting symptom seen on exertion (tracheal lumen narrowing less than 8 mm) and at rest (tracheal lumen narrowing less than 5 mm).[2] Cough is common, which may be persistent and non-productive.[3] Stridor, a respiratory sound caused by turbulent airflow through a partially obstructed airway, occurs later in tumour progression. Stridor can be inspiratory, expiratory, or biphasic, depending on the level of airway obstruction. Inspiratory stridor occurs with obstruction of the extrathoracic trachea, expiratory stridor when only the intrathoracic trachea is involved and biphasic stridor when the obstruction is at the level of the glottis or subglottis. Haemoptysis, due to mucosal irritation, may be present, and some patients may rarely complain of hoarseness if the tumour affects the vocal cords or the recurrent laryngeal nerve.[1] The subtlety of symptoms often leads to diagnostic delays, resulting in more advanced disease at presentation and more complex surgical and anaesthetic management.

CLASSIFICATION OF TRACHEAL TUMOURS

Tracheal tumours can be classified by histology, anatomical location, friability, and their mechanical effect on airflow. Each of these classifications carries important implications for anaesthetic planning.

Histology

Histologically, tracheal tumours may be malignant or benign (see Table 1). Primary neoplasm is rare, accounting for 0.1–0.4 per cent of all malignancies worldwide.[4] Patients may be older with associated risk factors, including smoking and alcohol use, while in younger patients, human papillomavirus exposure

might be the cause of cancer development.[5] Distant metastases are rare (around 10 per cent at the time of diagnosis) and most commonly are found in the patient's lungs.[4] The majority of cancers are secondary tumours, which occur due to the invasion of the trachea from cancers located in surrounding structures, including the larynx, lungs, oesophagus and thyroid glands.[4] The airway management implications for secondary tumours may be similar to the primary neoplasms, though patients will likely require more complex surgical treatments.

The most common malignant tumours include squamous cell carcinoma and adenoid cystic carcinoma (see Table 2). Less common malignant types include mucoepidermoid carcinoma, carcinoid tumours, and sarcomas.[2,6] Benign tumours, such as papillomas, hamartomas, and chondromas are typically managed surgically and have a more favourable prognosis.[6] Secondary tumours, which invade the trachea from adjacent structures such as the oesophagus, lung, or thyroid, are more prevalent overall and often present with more complex multidisciplinary team (MDT) requirements.[6]

Table 1. Breakdown of tumour type by prevalence and histology

	More Common	Less Common
Malignant	Squamous cell carcinoma (50–75%) Adenoid Cystic (10–15%)	Mucoepidermoid carcinoma Carcinoid tumour Sarcoma Primary tracheobronchial lymphoma Inflammatory myofibroblastic tumour
Benign	Papilloma	Hamartoma Chondroma Lipoma Amyloidoma Leiomyoma Neurogenic tumour Salivary gland tumour

Table 2. Comparison between the most common primary malignancies

	Demographics	Disease Progression	Usual time to diagnosis	Options
Squamous cell carcinoma	60–70 years Male > Female Smoker	Poorly differentiated Rapid growth Early metastases and regional spread	4–6 months after symptom onset	Less amenable to tracheal resection
Adenoid cystic carcinoma	40–50 years Male = Female Non-smoker	Well differentiated Slow growth Mass effect > regional invasion	>1 year after symptom onset	More amenable to tracheal resection

Differentiation between malignant and benign tumours is important as it affects decision-making regarding the timing of surgery, type of surgery and treatment modalities. As malignant tumours require more urgent surgery, there will be less time for patient optimisation and prehabilitation. Surgical resection provides improved patient outcomes, especially for benign and low-grade malignant tumours.[7] Tracheal tumours are considered resectable if the involved segment can be resected and reconstructed with primary anastomosis.[2]

Malignant lesions may initially be managed with neoadjuvant chemotherapy alone, as radiotherapy may negatively impact the healing of a resection. Patients unsuitable for surgical resections may be offered alternative treatments, including radiation therapy and interventional bronchoscopy.[7]

Anatomical location

In addition to the size of the lesion, the anatomical location also significantly influences management (see Figure 1). Tumour location can be defined as in the subglottic region (upper third), proper trachea region (middle third), and the carina region (lower third). Tumours located in the upper third may be amenable to tracheostomy or intubation using advanced airway management techniques. In contrast, tumours in the middle or lower thirds (thoracic) pose greater challenges for airway management due to restricted access and limited airway options.

It may be more appropriate for the anaesthetist to visualise the tumour's location as intrathoracic (thoracic trachea) or extrathoracic (cervical trachea), as this will have the most significant impact on airway strategy from an anaesthetic and surgical viewpoint. Intrathoracic lesions occur from the level of the second thoracic vertebra within the thoracic cavity.

Tracheal lumen narrowing is due to tumour growth from the lumen wall (primary or secondary invasion) or narrowing of the gap lumen by extraluminal tumour (secondary tumours).[2]

Airway obstruction can be classified based on the origin and location of the tumour (see Figure 2):[2]

- Endoluminal – located inside the lumen.
- Extraluminal – tissues external to the trachea, causing mass effect.
- Extraluminal with endoluminal extension.

Mechanistically, tumours may create a ball-valve effect – allowing air entry during inspiration but restricting expiration, leading to gas trapping and dynamic hyperinflation. Alternatively, a "cork in a bottle" phenomenon can occur when instrumentation dislodges or compresses a partially occluding tumour, resulting in complete obstruction.

Figure 1. Anatomical division of the trachea

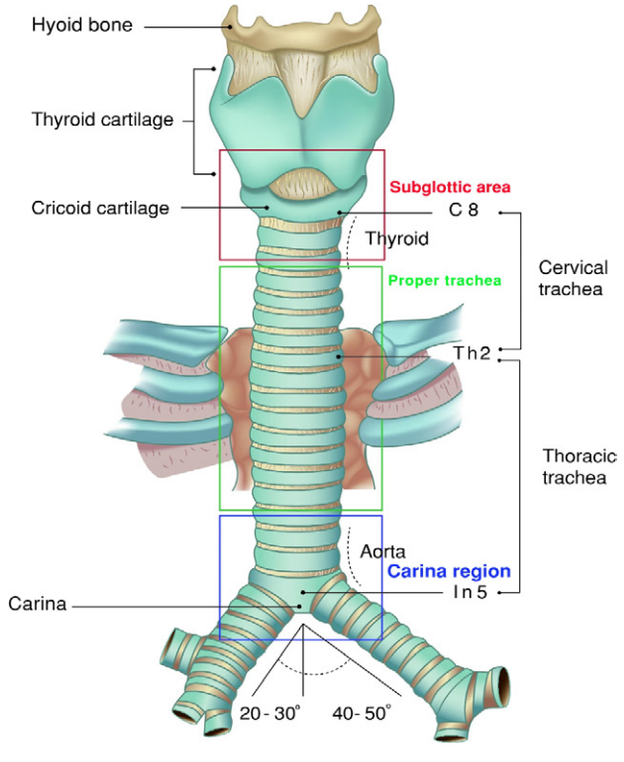
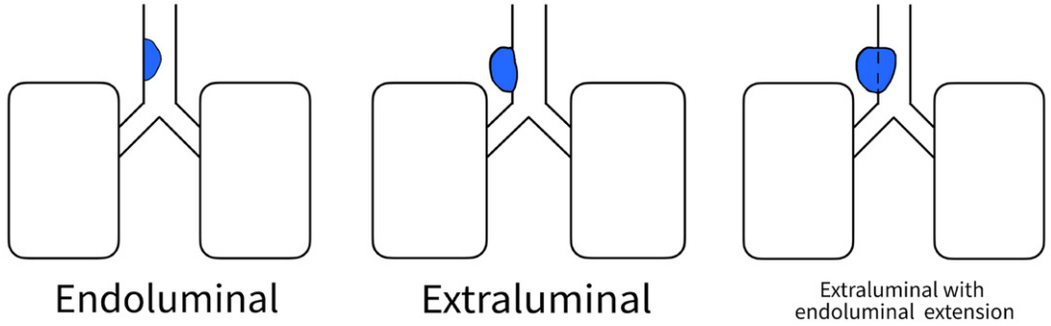


Image sourced from Dorn and Kocher (2020).[8]

Figure 2. Airway obstruction classification by tumour location and origin



Bleeding potential

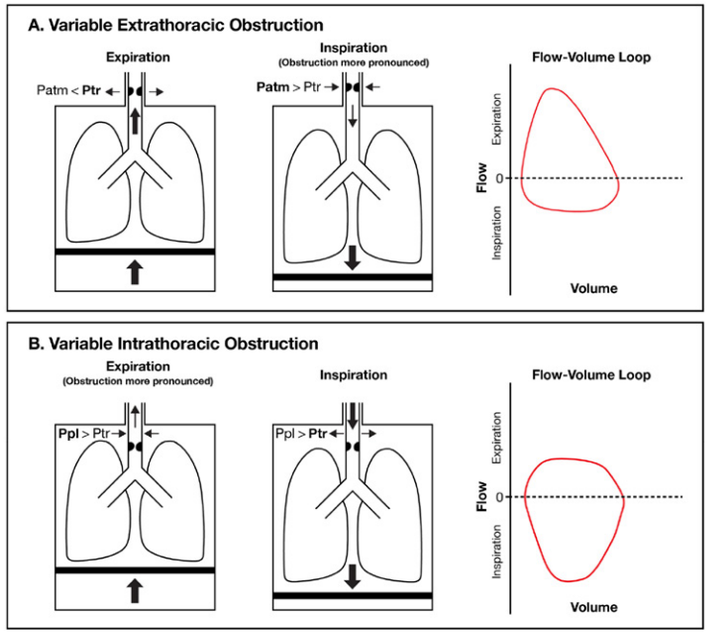
Tumour friability and bleeding potential are critical to airway instrumentation. Friable tumours may bleed with minimal contact, complicating flexible bronchoscopy or other visual-guided techniques. Ongoing anticoagulation therapy, coagulopathy, or malignant histology can further increase this risk.

ASSESSMENT AND IMAGING

A thorough airway assessment is fundamental to effective planning. While history, physical examination, and review of prior anaesthetic records are essential, imaging and endoscopic evaluations provide the most accurate anatomical detail. Tumour progression can result in significant changes within a short timeframe. When signs or symptoms are not consistent with findings on previous records or images, the value of repeating scans should be considered.

Chest X-rays are often the first investigation in non-specific symptomatic patients. Findings are usually non-diagnostic, have low sensitivity, and the entire length of the trachea might not be captured.[9] Computed tomography (CT) of the neck and chest is the modality of choice, offering high-resolution, multiplanar views of the lesion's extent, degree of obstruction and proximity to the carina and surrounding structures.[9,10] Ultrasound, as part of a bedside review of the patient by the anaesthetist, may assist in identifying surface landmarks and planning for front of neck access (FONA).[12] Bronchoscopy offers a real-time assessment of tumour friability, intraluminal position, and bypass potential, though it carries risks in highly vascular or obstructive lesions.[11] Biopsies can be taken, which can guide histological diagnosis.[2] Virtual bronchoscopy derived from CT scans may be a valuable option when conventional bronchoscopy is contraindicated.[9] There is little evidence in the literature regarding pulmonary function tests, and they are only recommended for their usual indications. Notably, flow-volume loops (see Figure 3) may reflect typical patterns of obstruction based on lesion characteristics and location.[2]

Figure 3. Influence of location of obstructing tumour on flow-volume loop



a) Variable Extrathoracic Obstruction: Maximal airflow limitation occurs during inspiration when the combination of positive atmospheric pressure and negative intraluminal pressure reduces the extrathoracic airway diameter, thereby increasing resistance to airflow due to the obstruction;

b) Variable Intrathoracic Obstruction: Maximal airflow limitation occurs during expiration when pleural pressure becomes positive relative to intraluminal airway pressure, reducing the diameter of the intrathoracic airways and making any obstruction more pronounced. Image sourced from Amaza et al. (2018).[13]

AIRWAY MANAGEMENT STRATEGIES

Airway management in patients with tracheal tumours must be adapted to individual patient and tumour characteristics. A thorough preoperative discussion with the surgical and critical care teams is vital. Anaesthetic backup plans should be developed and communicated clearly to all team members.

High-flow nasal oxygenation

High-flow nasal oxygenation (HFNO) may be helpful in maintaining spontaneous ventilation during short procedures or as a bridge technique. It may be used as an apnoeic oxygenation technique but can also be used as a spontaneous ventilation technique, thereby avoiding the need for neuromuscular blockade and preserving airway tone. However, HFNO requires a patent airway at all times, does not protect against aspiration, and is unsuitable for lengthy procedures that may require controlled ventilation.[14] Concerns have been raised regarding the spread of viral particles in the case of HSV-associated papilloma.

Jet ventilation

Jet ventilation delivers oxygen via a jet stream originating from a high-pressure source. There are options for low-frequency and high-frequency jet ventilation. While effective in maintaining a tubeless field, it requires specialised equipment and expertise. It carries risks, including barotrauma, impaired CO_2 clearance, and aspiration.[15,16] With the advent of HFNO and improved supraglottic devices, jet ventilation has become less mainstream.

Heliox

Heliox (a mixture of helium and oxygen gas) confers a theoretical advantage in the management of airway obstruction as a low-density gas that lowers Reynolds number and decreases turbulent flow. It has limited utility in modern-day anaesthetic practice as it requires specialised cylinders, calibration of ventilators for use, and does not allow for higher fractions of oxygen delivery, risking hypoxia. There is no mention of its use in any recent literature around tracheal tumour airway management.[17]

Supraglottic airway

Supraglottic airways (SGA), especially second-generation models, allow for oxygenation and flexible bronchoscopy access while minimising airway manipulation. Spontaneous ventilation can be achieved as muscle relaxation is not required. This minimises the loss of muscle tone while under general anaesthesia.[16] Second-generation devices are more suited to complex airway surgery, given features like improved cuff design, a gastric port and incorporated bite block.[16] Flexible bronchoscopes can be passed down the lumen of an SGA, allowing for surgical access while maintaining an airway. We note the internal diameter of an IGEL 5 (13 mm) compared to a size 8.5 endotracheal tube (8.5 mm).[16] SGAs are limited by bleeding risk, the potential for laryngospasm, risk of aspiration, airway contamination due to bleeding, and the concern of not providing a definitive airway.[16]

Endotracheal intubation

Endotracheal intubation may not only be challenging in patients with tracheal tumours but also, depending on cancer location, the endotracheal tube (ETT) may impede surgical access in cases of high lesions, and may not be able to overcome obstruction in cases of low-lying tumours. ETT selection is important, considering the advantages and disadvantages of microlaryngoscopy tubes, reinforced tubes and laser-safe ETTs.[16] Sizing of endotracheal tubes must consider the actual outer diameter, noting that ETTs are named for their internal diameter (see Table 3). For laser-safe tubes, the outer diameter is likely to be larger than conventional ETTs due to the presence of additional insulation layers.

Table 3. Conventional endotracheal tube sizing by internal and outer diameter

PVC ETT	Internal diameter (mm)	Outer diameter (mm)
#5.0	5.0	6.7
#5.5	5.5	7.3
#6.0	6.0	8.0
#6.5	6.5	8.5
#7.0	7.0	9.2
#7.5	7.5	10
#8.0	8.0	10.7
#8.5	8.5	11.3
#9.0	9.0	12.2

Crossfield intubation

Crossfield intubation, where the surgical team places a sterile ETT through the surgical field following tracheal transection, offers excellent airway security without compromising surgical access.[18] This technique requires strict suppression of cough reflexes and clear communication between surgeons and anaesthetists. The ETT must be transitioned to another method prior to extubation.[18]

Rigid bronchoscopy

Rigid bronchoscopy has not been extensively described in the anaesthetic literature for elective indications, but it may be a technique of choice for the surgeon. Patients require deep muscle relaxation and a good range of motion of the cervical spine to allow for appropriate neck extension. Depending on the type of scope used, passive oxygenation via the rigid bronchoscope is possible, with consideration for the risks of barotrauma and pneumotrauma.[16] It may be utilised for the process of tumour debulking within the trachea as part of a multi-step approach to the management of the tumour.

Awake flexible bronchoscopy

Awake flexible bronchoscopy (traditionally referred to as awake fibre-optic intubation) allows for guided placement of an endotracheal tube past the tumour.[16] It requires expertise to topicalise and guide the tube, and may cause bleeding in friable tissue. Concerns about the narrowing of the tracheal lumen leading to a "cork in the bottle" phenomenon may preclude its use in a range of patients.[19] The diameter of the scope and its ability to fit the internal diameter of the required endotracheal tube may play a role in decision-making (see Table 4). Case reports describe the use of ketamine, dexmedetomidine, remifentanil or low-dose propofol for anxiolysis.[16] Great care must be taken in ensuring that respiratory drive and muscle tone are not affected when using sedation medications.

Table 4. Examples of flexible bronchoscopy sizing (Ambu ascope) with endotracheal use

Ambu ascope brand	Flexible bronchoscope outer diameter (mm)	Smallest ETT that can be passed over scope	Smallest ETT outer diameter (mm)
Slim	3.8	#5.0	6.7
Regular	5.0	#5.5	7.3
Large	5.8	#6.0	8.0

Awake tracheostomy

Awake tracheostomy can provide a secure airway without the need for general anaesthesia. This technique requires patient cooperation and excellent neck extension and carries its risks, including bleeding and airway soiling.[19] The location of the tumour dictates the viability of this technique, as the tracheostomy must be placed below the tumour. Hence, tracheostomy is not appropriate in lower tumours closer to the carina.

Extracorporeal membrane oxygenation

Extracorporeal membrane oxygenation (ECMO) may be indicated in cases of near-total obstruction, in patients at substantial risk of worsening respiratory function, or in patients who are unsuitable for conventional airway strategies. Veno-venous ECMO has been described successfully for elective use in complex airway tumours.[16,20] ECMO is not an emergency airway strategy as it requires MDT planning and discussion, and a well-prepared patient and team. Ideally, the patient is cannulated peripherally while awake. ECMO can be established before or after induction and may be weaned after a definitive airway has been secured.[20]

Specific concerns around ECMO use may include the risk of bleeding with a requirement for heparinisation to maintain line patency.[20] This requires close communication and consideration by both the surgeons and perfusion teams with regular monitoring of activated partial thromboplastin time or activated clotting time intraoperatively.

ELECTIVE AIRWAY MANAGEMENT: DECISION-MAKING

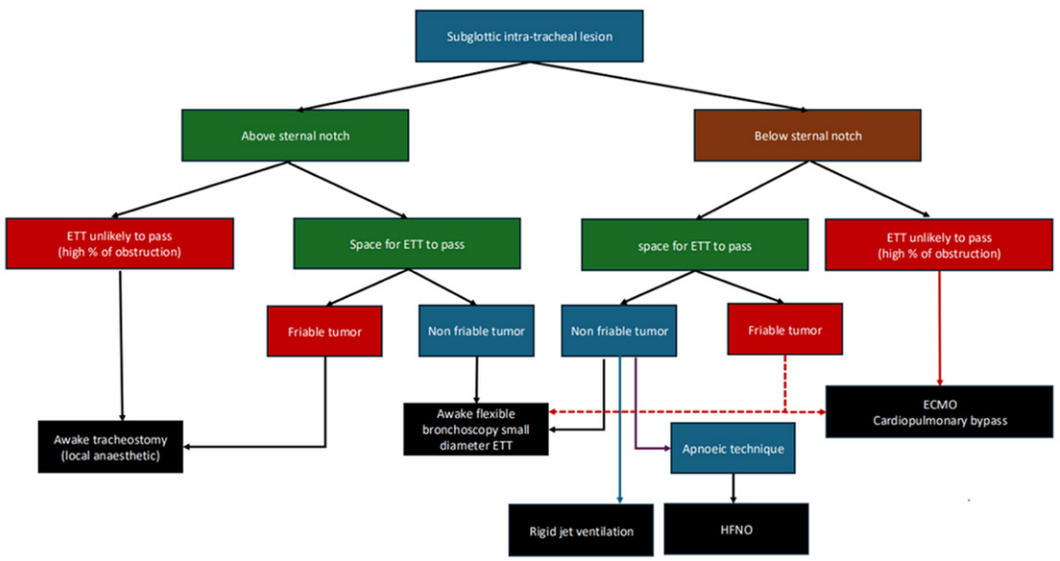
The elective management of patients with subglottic intratracheal lesions requires careful preoperative planning and a tailored approach based on the location of the lesion, degree of airway obstruction, and tumour characteristics.

First phase: Airway control

The first phase allows for initial neck dissection and preparation for tracheal resection.

The first consideration is whether the lesion lies above or below the sternal notch, as this influences both the accessibility of the airway and the feasibility of surgical or endoscopic interventions. Figure 4 demonstrates a suggested algorithm to guide decision-making.

Figure 4. Algorithm for the first phase of airway control for intratracheal lesions (elective)



For lesions above the sternal notch

The first step is to assess whether there is sufficient space for an ETT to pass. Many studies quote *less than 80 per cent obstruction* of the tracheal area as the benchmark for being able to pass an ETT successfully.[16]

Considering the average diameter of an adult trachea is 18 mm, 80 per cent area obstruction leaves a functional airway diameter of about 8 mm. With such a reduction, flow resistance increases exponentially, the work of breathing is dramatically increased, and the airway can become significantly compromised, especially under stress and sedation. Careful individual consideration of the tumour size, its location, the level of obstruction and the available airway equipment is required to guide appropriate and patient-specific decision-making. If the airway remains partially patent and the obstruction is not severe, awake flexible bronchoscopy with insertion of a small-diameter ETT is a preferred approach. When using a fibre-optic scope, it is crucial to ensure that the ETT ID is compatible with scope size. This technique allows for real-time visualisation and minimises the risk of complete airway obstruction during manipulation. However, if there is a high degree of obstruction and the ETT is unlikely to pass the tumour safely, or the lesion is highly friable, an awake tracheostomy under local anaesthetic becomes a safer option, bypassing the obstructed segment entirely.

For lesions below the sternal notch

The first step is to assess the ability of an ETT to bypass the obstruction (as above).

The decision-making process also takes into consideration the friability of the tumour. If the tumour is non-friable and there is enough space for tube passage, cautious intubation may still be considered. Additionally, apnoeic techniques such as rigid jet ventilation or high-flow nasal oxygen (HFNO) may provide effective oxygenation while maintaining a clear surgical field. However, when the lesion below the sternum is considered friable or is severely obstructing the airway, instrumentation risks provoking bleeding or total obstruction.

In such cases, careful MDT planning and consideration of ECMO for airway management may be the better choice. This technique provides a bridge to secure airway control, allowing time-critical interventions without compromising oxygenation and perfusion. In the most complex scenarios, particularly when the airway is nearly or completely occluded, or when neither intubation nor tracheostomy is viable, advanced planning for extracorporeal oxygenation using ECMO or cardiopulmonary bypass is essential. Ultimately, multidisciplinary coordination, including anaesthesia, Ear Nose Throat or thoracic surgeon involvement, and coordination with the perfusion team, is critical to ensure safe and effective management in these high-stakes situations.

Second phase: Open airway phase

Once the trachea is opened, resection and formation of an anastomosis begins. A change in airway may be required to meet the goals of reliable ventilation, a motionless surgical field and minimisation of airway soiling.[21]

The choice of airway must be made in consultation with the surgeon, as this will impact their ability to complete the reconstruction.

Options

- **Continuing with the initial airway placed**
  – Recognising impediment to view and risk of dislodgement.
- **Change in airway management plan**
  – Crossfield intubation.
  – Conventional and safe approach that allows for surgical flexibility.
  – Jet ventilation.
  – ECMO.

VENTILATION STRATEGIES

The literature makes no formal recommendations on ventilation strategy. It is essential to consider the increased airway resistance associated with endotracheal tubes that have an internal diameter smaller than those typically used.

EMERGENCY AIRWAY MANAGEMENT: DECISION-MAKING

Rarely, tracheal lesions may present in an emergency scenario, causing airway obstruction.

Partial airway obstruction (with symptoms such as dyspnoea and stridor) can rapidly evolve into complete airway obstruction and respiratory arrest.

Securing the airway is a critical intervention that can alleviate symptoms and enable the placement of temporary stents. These procedures not only provide immediate relief but also facilitate ongoing multidisciplinary discussions aimed at developing a comprehensive long-term management plan for the lesion.

Decision-making around airway management depends on an evaluation of patient factors, location factors, and team factors. Adam Rehak's synopsis of airway trauma management in the 2019 edition of this journal provides an excellent explanation of how to approach a situation involving a threatened airway, and offers many suggestions applicable to airway obstruction secondary to a tracheal tumour.[22]

Airway completely obstructed

A patient in extremis secondary to an obstructing tracheal tumour requires an immediate response and plan. If unable to optimise or further investigate due to patient deterioration, the initial approach may be to attempt rapid sequence induction, videolaryngoscopy and flexible bronchoscopically-guided ETT placement past the obstructing lesion.

Failure of this technique will require Ear Nose Throat support with rigid bronchoscopy or the implementation of veno-venous ECMO, a technique that requires time to set up and the correct expertise to implement. Respiratory and subsequent cardiovascular arrest are distinct possibilities in these patients.

Airway partially obstructed

If the patient's condition allows time for preparation, planning for airway management and gathering of the appropriate equipment and personnel is essential.

Awake options (such as tracheostomy or flexible bronchoscopy) require a compliant patient and time for local anaesthesia to take effect. An alternative plan should be ready to be implemented should the awake technique fail. If an awake technique cannot be used spontaneous ventilation techniques, where the patient maintains overall airway tone until the airway is secured, are usually preferred.

EXTUBATION PLANNING

Postoperative extubation requires careful consideration. Airway oedema, anastomotic integrity, and residual tumour burden may all impact timing. The presence of a guardian suture (to prevent neck extension and tearing of the anastomosis) coupled with an oedematous, bleeding airway will make re-intubation challenging. However, extubation decreases the trauma of positive pressure ventilation and an endotracheal cuff on a fresh anastomosis.[20]

If extubation is planned in the theatre, bronchoscopy should be performed to visualise the final anastomosis and for airway toileting. Extubation should be smooth and cough-free. A supraglottic device can be placed in the spontaneously ventilating patient as part of a controlled extubation.

A staged approach in the ICU, including bronchoscopic evaluation prior to extubation and a controlled trial of spontaneous ventilation, is common in highly resourced centres. The use of airway exchange catheters or staged airway kits has been considered in previous difficult extubations.[23] Of note, airway exchange catheters are not recommended by the manufacturer as re-intubation adjuncts. Staged extubation kits (containing a soft-tipped wire and a blunt atraumatic catheter) can be utilised for high-risk patients. However, clinicians should be mindful of the fragile tracheal anastomosis and risks of blindly advancing an endotracheal tube during a re-intubation scenario. We recommend a videolaryngoscope-assisted bronchoscopic technique, where the flexible bronchoscope is used as a railroad to safely guide the endotracheal tube past the reconstruction. Where concerns exist, delayed extubation or tracheostomy 2 cm below the anastomosis should be considered.

CONCLUSION

Tracheal tumours pose significant challenges for anaesthetists in airway management. Effectively addressing these cases requires a deep understanding of tumour characteristics, mastery of airway techniques, and a collaborative, team-oriented approach. With careful assessment, thorough preparation, and the ability to adapt intraoperatively, even the most difficult cases can be managed safely.

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The perioperative management of lung transplantation

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This article is dedicated to my lovely Mam, Pamela Johnstone, who lost her battle to cancer just prior to the article's inception.

Edited by Associate Professor Matt Doane

INTRODUCTION

Lung transplantation is an established standard of care to treat end-stage lung disease. Since the first successful lung transplant 30 years ago, advances in lung preservation, surgical technique and immunosuppression regimens have allowed lung transplantation to become a destination therapy for a diverse spectrum of lung disorders. In a carefully selected patient group, where all medical treatments have been exhausted, it represents an opportunity to regain quality of life and longevity.

This review article aims to give the reader an overview of lung transplantation and its evolution. It will detail current indications for lung transplants and considerations in the preassessment process.

Delivery of anaesthesia for lung transplantation is universally challenging. Inherent in the challenges is the opportunity for the cardiac anaesthetist to utilise every one of their specific skill sets. If they can execute these skills to a high standard, they have the potential to directly and significantly impact perioperative morbidity and mortality.

TIMELINE OF LUNG TRANSPLANT

1946. The first lung transplant in the Soviet Union was a single lung transplant in a dog.[1] Ultimately, this was unsuccessful due to bronchial anastomotic dehiscence.

1963. Haglin demonstrates reimplanted lungs in a primate that can maintain function post-operatively despite denervation.[2] The same year, Hardy and his team reported the first human lung transplant. The patient was deceased by day 18 post-surgery.[3]

1971. Derom's team is regarded as reporting the first real survivor of lung transplantation, although survival was only 10 months duration.[4] In the early days of lung transplantation, the overriding themes of failure were secondary to inadequate immunosuppression and difficulties with bronchial anastomoses.

The development of the immunosuppressant drug cyclosporine and demonstrable improvements in survival following liver and kidney transplantation led to renewed interest in cardiothoracic transplant.

1982. The first successful combined heart-lung transplant was performed.[5]

1983. The Toronto group showed that corticosteroid use appeared to be a significant factor in the weakness of bronchial anastomosis. By using the calcineurin inhibitor cyclosporine, corticosteroid use could be reduced, and bronchial healing could be improved.

1986. The Toronto Lung Transplant Programme performed the first successful single lung transplantation in two patients with pulmonary fibrosis.[6] This team also performed the first successful double-lung transplant using a tracheal anastomosis. They are credited with developing our standard technique today, which involves bilateral sequential transplantation. (This has the benefit of avoiding cardiopulmonary bypass).[7] In this same year, Australasia's first heart-lung transplant was performed at Sydney's St Vincent's Hospital in Dr Victor Chang's unit.

1990. The first isolated lung transplant was performed in Australia in 1990, also at St Vincent's Hospital, Sydney.[8]

LUNG TRANSPLANTATION: THE CURRENT CLIMATE

The number of adult lung transplants performed worldwide is almost 70,000.[9] In 2022, the NHS Blood and Transplant published its annual report. The report detailed the indications for lung transplantation (and their respective contributions to the overall total) as fibrotic (53%), obstructive (26%), vascular lung disease (9%) and septic (8%).[53] The leading indication for lung transplantation globally is Chronic Obstructive Pulmonary Disease. This breakdown in prevalence has remained static in Europe, but in North America and elsewhere, there have been an increasing number of transplants performed for idiopathic pulmonary fibrosis.[9]

In Australasia, five centres perform lung transplants: The Alfred (Melbourne), St Vincent's (Sydney), the Prince Charles (Brisbane), and the Fiona Stanley (Perth). In New Zealand, lung transplants are performed via the New Zealand Heart and Lung Transplant Service at Auckland City Hospital.

In 2021, there were 197 lung transplant recipients in Australia and New Zealand.[10] This breaks down to 6.5 transplant recipients per million of the population (pmp) in Australia (an increase of 16% on the previous year) and 5.8 pmp in New Zealand (a rise of 57.9% on the last year). The number of patients being put forward for lung transplantation is ever-increasing.

The landscape for donation has changed somewhat with the acceptance of donations after circulatory death (DCD), which has increased the pool of potential donors. The Australian Donation and Transplant Activity Report 2022 saw a 122% increase in deceased donation rates over the past 10 years.[11]

Last year, DCD transplantation represented 23% of total activity in the UK.[53] In donations after brainstem death (DBD), donor optimisation has increased the number of hearts and lungs retrieved from DBD donors. This increased success comes from a bundle of care involving a trained cardiothoracic retrieval team member attending to the donor before the rest of the team to assist with optimisation.

The COVID-19 pandemic significantly impacted this increased donation trend, and lung transplant rates have declined from pre-pandemic levels across most states. In 2022, 142 lung transplants were performed in Australia, 29 fewer than in 2021, when there were 171.[11]

Pre-transplantation considerations

Lung transplantation represents a conflicting paradigm; it offers the possibility of returning a severely debilitated patient to an acceptable quality of life. Conversely, the high-risk nature of the perioperative journey means it has the potential to cause the patient not only significant morbidity but even premature death.

In the first year, 20% of patients will die from primary graft dysfunction or infection with or without multi-organ failure.[12] Survival is 60% at five years, and 40% at 10 years.[13,14] These high stakes of the operation itself, combined with the comorbid state of most transplant recipients (poor respiratory reserve, often significant cardiac disease, and chronic infection), make delivery of anaesthesia for this patient group an extreme challenge.

Eligibility of recipients

Lung transplantation is recommended based on a balance of benefits, risks, and alternatives.[15] Donor lungs remain a scarce commodity, and a critical determinant of outcomes is the appropriate selection of recipients in the first instance. This is based on the patient's clinical need and capacity to benefit. Every transplant unit is responsible for maximising overall benefit by ensuring optimal organ allocation. Early referral is essential, allowing robust patient assessment and thorough education of patients and their families.

Lung transplantation is considered for adults with advanced lung disease, on maximal medical therapy. They must meet the following general criteria[16]:

- There is a high (50%) risk of death from lung disease within two years if lung transplantation is not performed.
- High (80%) likelihood of surviving at least 90 days after lung transplantation.
- High (80%) likelihood of 5-year post-transplant survival from a general medical perspective, provided there is adequate graft function.

Pre-transplant listing

A multi-disciplinary team decides to list a patient. The process encompasses four distinct phases:

- Referral.
- Pre-assessment in an outpatient or inpatient setting.
- Listing decision (via a multi-disciplinary team).
- Follow-up on the waiting list.

Given the rapidly progressive nature of some lung disorders, such as interstitial lung disease (ILD), and the unpredictable course of others, such as pulmonary arterial hypertension (PAH), early referral is critical. This gives the transplant team time to assess the patient and allows the patient time to prepare psychologically and get their affairs in order. Mortality on the waiting list remains high, and an essential component of proactive MDT planning is early referral and liaison with palliative care services at the time of listing. Data from the United States in 2019 placed the mortality rate on the waiting list at 14.6%.[17] The NHSBT data collected between 2017 and 2019 showed that three years after being placed on the transplant list, 45% of people had received a transplant, and 18% had died.[53]

Referral

Transplant teams use detailed inclusion and exclusion criteria to list or delist a patient for lung transplantation. The International Society for Heart and Lung Transplantation (ISHLT) provides disease-specific thresholds for listing a patient for transplant.[18–20]

In Australia, transplant lists are nationally coordinated systems. In 2009, the Commonwealth Government created the National Organ and Tissue Authority. This group works alongside all Australian states and territories to improve organ and tissue donation.

In Australasia, lungs are offered to the jurisdiction's home state first. If there is no lung transplant centre in the state, the organ is put forward according to the specific ADTCA/TSANZ Organ Allocation Rotation. When there are urgent listings, a recipient in the donor's state is offered the organ before offering it to the transplant unit of the urgent listing.[47]

There is no specific national priority urgent lung listing category in Australasia. However, to increase a person's chance of being allocated donor lungs, a lung transplant wait list patient from one state may be notified to another state's lung transplant program. This is termed national notification and is at the discretion of the lung transplant unit director.[47]

Given the diversity of lung diseases, recipient eligibility criteria are disease-specific, as summarised in Tables 1-4.[21]

Table 1. Diffuse parenchymal lung disease referral criteria

Diffuse parenchymal lung disease	Referral criteria
Includes lung fibrosis of any aetiology, chronic hypersensitivity pneumonitis and sarcoidosis	Decline in forced vital capacity (FVC) of 10% or more and in diffusing capacity of the lungs for carbon monoxide (DLCO) of 10% or more within the prior 6 months Development of pulmonary hypertension Hospitalisation because of respiratory decline, acute exacerbation, or pneumothorax Significant exercise-associated desaturation or requirement for oxygen

Table 2. Obstructive lung disease referral criteria

Obstructive lung diseases	Referral criteria
Includes smoking-related COPD, alpha 1 antitrypsin deficiency, obliterative bronchiolitis and chronic asthma	Forced expiratory volume in one second (FEV_1) <20% of predicted Body-mass, airflow obstruction, dyspnoea, and exercise (BODE) index >7 Severe exacerbation with hypercapnic respiratory failure or recurrent exacerbations Moderate to severe pulmonary hypertension PCO_2 >50 mmHg and/or PO_2 <60 mmHg

Table 3. Pulmonary vascular lung disease referral criteria

Pulmonary vascular disease	Referral criteria
Includes idiopathic PAH or that associated with connective tissue disease, complex congenital heart disease with Eisenmenger's syndrome, chronic thromboembolic pulmonary hypertension	NYHA Functional class III or IV despite escalation of pulmonary vasodilator therapy Refractory or progressive right heart failure

Table 4. Suppurative lung disease referral criteria

Suppurative lung disease	CF referral criteria
Includes Cystic Fibrosis (CF) and non-CF bronchiectasis	Frequent hospitalisation FEV_1 <30% of predicted especially if a rapid downward trajectory is observed Increasing antibiotic dependence or resistance Life threatening haemoptysis or pneumothorax Requirement for non-invasive ventilation Development of pulmonary hypertension PCO_2 >50 mmHg and/or PO_2 <60 mmHg

Considerations for exclusion from the transplant list

Not all patients who meet transplantation criteria are suitable. Careful evaluation of extra-pulmonary medical comorbidities, mental health and social circumstances are undertaken to ascertain the prospect of post-transplant success and survival. Absolute contraindications include malignancy within the last 5 years, BMI>35 kg/m^2 and untreatable advanced dysfunction of another organ system.

Medical conditions that have not resulted in end-organ damage should be optimised before transplant, such as gastroesophageal reflux disease (GORD) or systemic hypertension. HIV is a relative contraindication, and patients with viral Hepatitis B and C may be considered, provided there is no active disease or viral replication. Table 5 describes absolute exclusion criteria for lung transplantation.[15,20]

Table 5. Exclusion criteria for lung transplantation

ABSOLUTE contraindications

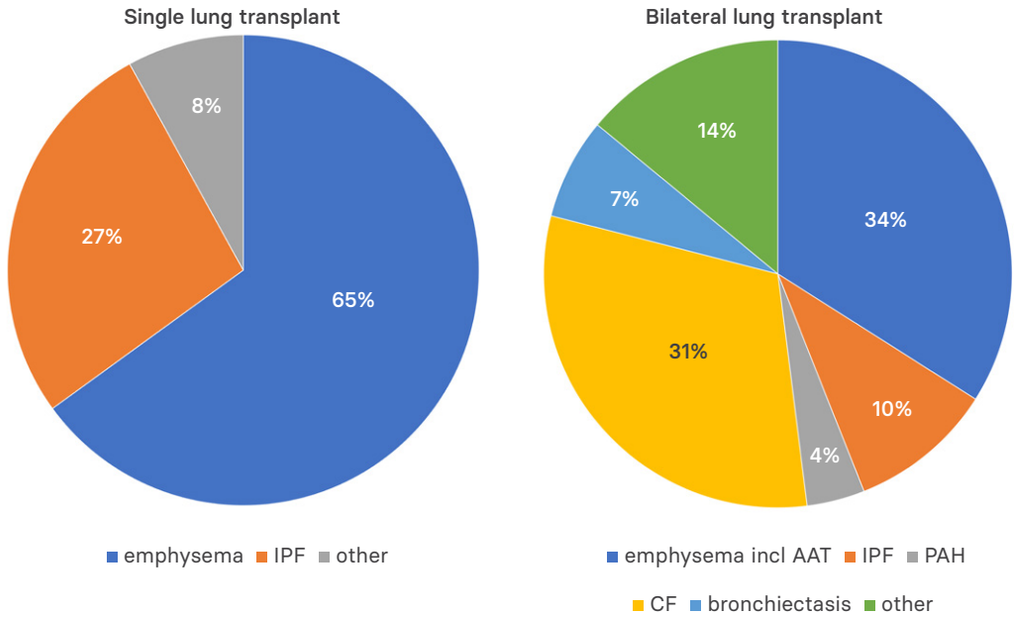
- Active malignancy
- BMI >35 kg/m^2
- Advanced dysfunction in another body system that impacts perioperative survival or 5-year survival
- Unstable critical condition (e.g., sepsis)
- Significant chest wall or spinal deformity causing restrictive lung disease
- Uncontrolled extrapulmonary manifestations of systemic disease
- Substance addiction or abuse
- Documented nonadherence to medical therapy
- Mental health conditions that fail to respond to treatment and are associated with poor quality of life and compliance to medical therapy
- Absence of reliable social support

Single and bilateral transplants

Generally, lung transplantations are bilateral. During the initial suitability assessment, a decision is made whether single lung transplantation is an option. Occasionally, a single lung transplant will be opted for where the primary disease process is COPD or ILD and only in an older patient demographic. Suppurative lung disease or pulmonary hypertension are contraindications to single lung transplantation.[22]

Figure 1 describes the prevalence of indications for single and bilateral lung transplantation in Australia.[23]

Figure 1. Indications for single and bilateral lung transplantation in Australia



Alpha-1 Antitrypsin Disease (AAT) Idiopathic Pulmonary Fibrosis (IPF)

Consent

Consent for transplantation is robust. It includes a discussion of the surgical and anaesthetic risks and benefits and a donor acceptance form. In this form, the recipient consents to the criteria for selecting their organ. This includes, for example, whether they would be happy to receive lungs from smoking donors.

Specific prospective recipients are placed at much higher risk for adverse events, and at the time of listing, they should be counselled about this. Higher-risk patients include those who have:

- Pre-transplant extracorporeal membrane oxygenation (ECMO)
- Oxygen requirement > 5L/min
- Severe PAH
- Chronic steroid use
- Donor-to-recipient weight ratio <0.7
- Cytomegalovirus (CMV) mismatch

Objectives of pre-listing assessment

Assessing the appropriateness of listing for lung transplantation encompasses clinical, social, and psychological suitability. Table 6 delineates these considerations in more detail.

Clinical urgency is graded by the required support level and evidence of rapid deterioration from the underlying indication for transplant.

Table 6. Potential clinical investigations before listing for lung transplantation

Blood tests haematology, biochemistry, serology, immunology	blood group, antibody screen, FBC, APTT PT, INR, fibrinogen urea and electrolytes, creatinine, uric acid, calcium, phosphate, liver function tests, thyroid function tests, fasting blood glucose, fasting blood lipids, alpha 1-antitrypsin (if indicated) HIV, hepatitis B and C, syphilis, rubella, toxoplasma, Epstein Barr Virus, varicella- auto-immune screen, aspergillus serology, human leucocyte antigen (HLA) typing and antibody screen zoster, herpes simplex, CMV
Pulmonary assessment	LFT: Flow volume loop, lung volumes, gas diffusion, plethysmography 6-minute walk test (6MWT) with oximetry Arterial blood gas Respiratory muscle function tests VQ scan Thoracic CT: exclude malignancy, assess pulmonary vasculature and collaterals
Cardiac high likelihood of concomitant cardiovascular disease in patients with end stage pulmonary disease, means high risk patients warrant assessment by a cardiologist	ECG TTE: RV function and pulmonary arterial (PA) pressures Cardiac catheterisation Right heart catheterisation

Microbiology	Sputum culture and sensitivity (C & S) Midstream urine: urinalysis (C & S)
DEXA bone scan	To assess for severe or symptomatic osteoporosis (defined as bone mineral density > 2 SD less than predicted for the patient's age)

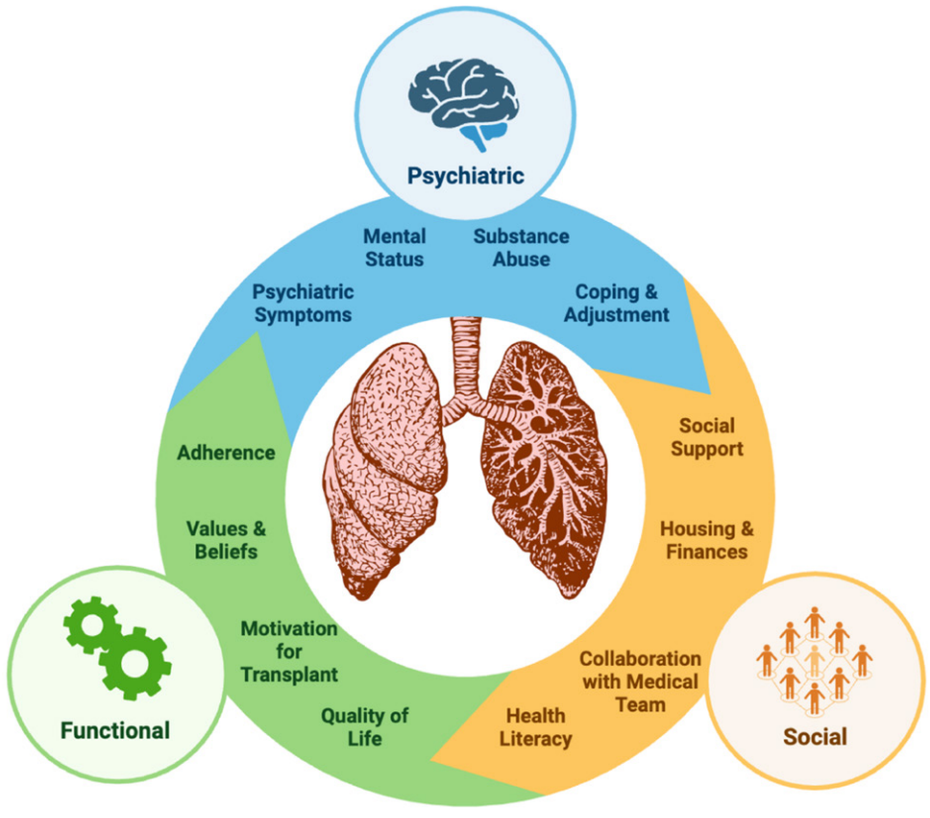
Psychosocial evaluation

To live with a lung transplant is a life-long commitment to medical follow-up and compliance. Nonadherence to even one dose of immunosuppressant can have catastrophic consequences for the recipient.

Psychiatric assessment focuses on previous history and current stability, coping mechanisms, and recent and past substance abuse. Social assessment examines health literacy, the ability to collaborate with the medical team, and the quality of social support and housing. Functional evaluation reviews individual values and beliefs. Ensuring potential recipients understand the responsibilities of receiving a transplant and their motivation is essential for long-term success.[48]

Figure 2 describes key elements of a lung transplant candidate's psychosocial and functional assessment.[48]

Figure 2. The psychological functional assessment of the lung transplant candidate



Other considerations

Candidates for lung transplantation are approaching their physiological reserve. The underlying lung disorder has often altered their respiratory mechanics, causing a pathological breathing pattern:

- Increased breathing effort due to chronic hyperinflation and unfavourable diaphragmatic position
- Increased airway resistance and decreased lung compliance
- Impairment of secretion clearance and mucociliary transport.

Lack of respiratory reserve often renders these patients inactive, with consecutive deconditioning in strength, endurance, and cardiopulmonary performance. This is usually compounded by reduced trunk mobility (for example, in emphysema), leading to shortening of the respiratory muscles and steroid-induced myopathy.

Enrolment in a pulmonary rehabilitation program is mandatory. For those patients on long-term corticosteroid therapy, there is a gradual reduction in their dosing, ideally tapering entirely off.

Prehabilitation encompasses aerobic load training to optimise body composition, intending to increase muscle mass while reducing body fat. It includes improving posture, chest, and joint mobility. The overall goal is to optimise the functional capacity of the transplant candidate despite the existing terminal underlying disease and maintain this until transplantation.

Follow up on the waitlist

All patients on the list are regularly reviewed by their respiratory physician to ensure their condition still meets transplantation criteria. Fundamental investigations are updated, and ongoing pulmonary rehabilitation continues.

Extracorporeal life support in lung transplantation

Extracorporeal life support (ECLS) describes a spectrum of mechanical support that oxygenates, removes CO_2 and/or improves haemodynamic stability. It includes extracorporeal membrane oxygenation (ECMO) and interventional lung assist devices such as the Novalung (trademark Fresenius Medical Care North America). ECMO is the only form of ECLS for both the heart and lungs. It can be utilised at each discrete stage of the lung transplantation process. The indications for ECMO in lung transplantation are listed in Table 7.

Table 7. Perioperative indications for ECMO in lung transplantation

Bridge to lung transplantation (BTT)
Intraoperative cardiopulmonary support
Bridge to recovery post-operatively

Broadly speaking, ECMO can be veno-arterial (V-A) or veno-venous (V-V). The type of ECMO support is determined by the configuration of the cannulation and is tailored to the patient's clinical needs.

In V-A ECMO, blood is removed from the body via a venous cannula, oxygenated, and returned to an artery from where it is circulated around the body, reducing the stress on the heart and lungs. In V-V ECMO, there is no direct support for the heart. Blood is taken from a vein, oxygen is added, CO2 is removed, and blood is returned via a vein from where the patient's heart can pump oxygen-rich blood around the body. It allows the lungs to rest.

Table 8 describes what cardiorespiratory support can be supplied by various ECMO configurations, highlighting the indications for use in lung transplantation.[24] Intraoperatively, central V-A (right atrium to aorta) is most common as it negates Harlequin Syndrome.[1]

Table 8. ECMO configurations in lung transplantation

ECMO configuration	Support	Indication	Use in lung transplant
V-V: peripheral cannula in superior vena cava (SVC), internal jugular (IJV) or femoral vein	respiratory	hypoxaemia	BTT post-op respiratory support
V-A: can be peripheral, (femoral and subclavian arteries) or central (right atrium to aorta).	respiratory and circulatory	hypoxaemia and cardiac failure	BTT intraoperative mechanical support
VV-A as per V-V plus an additional cannula in the subclavian or femoral artery	respiratory and circulatory	severe right heart dysfunction with hypoxaemia	BTT intraoperative mechanical support is possible but unusual post-op respiratory support

ECMO pre-surgery: A bridge to transplant

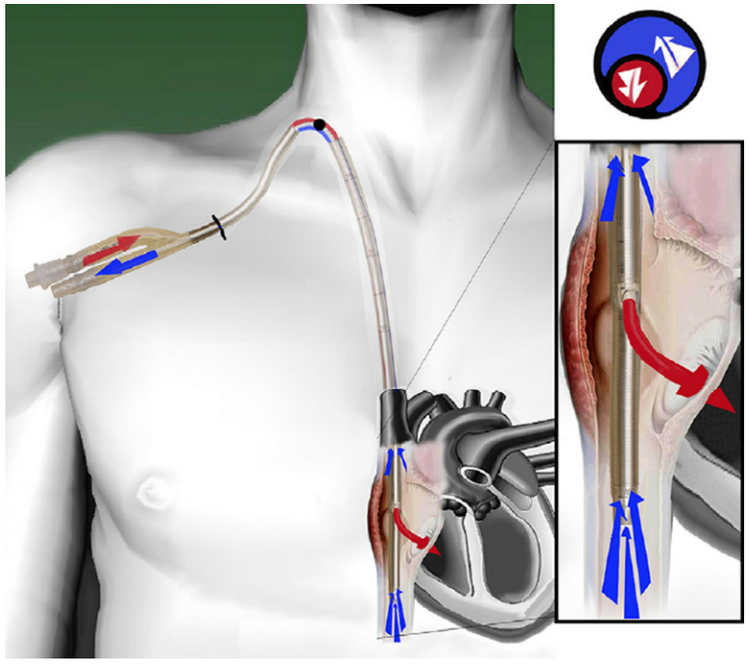
Traditionally, mechanical ventilation and sedation were the only options to bridge a patient in terminal respiratory failure to transplant. Prolonged sedation and artificial ventilation render the patient bed-bound, leading to profound deconditioning. Mechanical ventilation is associated with significant risks such as airway complications, pneumonia, and sepsis, all of which impact post-transplant outcomes and result in a decreasing probability of successful transplantation. Today, in a select group of patients, ECMO can be utilised as a BTT to improve pre-transplant stability whilst a suitable donor is found. ECMO as a BTT should only be considered for those patients who have acutely decompensated and have otherwise good rehabilitation potential. This usually means they have had a short duration of severe illness.

V-V ECMO is the method of choice as a BTT for isolated respiratory failure.[52] Indications for V-A ECMO in BTT are severe pulmonary hypertension, right ventricular dysfunction, and those decompensating on V-V ECMO. These individuals have worse outcomes following lung transplant than patients with other indications,[52] as V-A ECMO is more invasive and carries higher risk. The outflow cannula being directly in the arterial circulation means the patient requires an increased amount of heparin for anticoagulation, and there is a higher rate of embolic events, stroke, and limb complications. In comparison, V-V ECMO has a lower rate of vascular and neurological complications.[24]

V-V ECMO can be in a femoral-femoral configuration, or most recently, it has been deployed using a single-site veno-venous device. The Avalon cannula is a bi-caval, dual-lumen catheter with a single insertion site in the IJV. Deoxygenated venous blood is simultaneously drained from the SVC and inferior vena cava (IVC), and oxygenated blood is returned to the heart via a delivery port in the right atrium.

Figure 3 demonstrates the Avalon cannula in-situ. Inflow to the ECMO circuit is from the tip of the cannula, located in the IVC, along with fenestrations in the middle of the cannula at the SVC-right atrial junction. The outflow is directed towards the tricuspid valve.

Figure 3. Positioning of an Avalon bi-caval dual-lumen catheter



This system has only a single insertion point in the IJV. It simulates normal physiological blood flow by removing deoxygenated blood from both the SVC and IVC and returning oxygenated blood to the right atrium.

Regardless of the configuration, the key to ultimate success in ECMO as a BTT is to have a patient established on ECMO, awake and not intubated, who is mobilising, thus preventing deconditioning. While the upper-extremity-only circuit spares the need to access a patient's femoral vessels,[25] physiotherapy and prehabilitation are well-established practices in patients with femoral cannulation. The means to prevent deconditioning while a patient waits for their donor lungs has allowed a successful lung transplant to be performed after a patient has been on ECMO, in some cases for several months.[52]

Transplantation: Preoperative considerations

Once a donor has been identified, two distinct teams are mobilised. The first team will assess the donor lungs for suitability. Team two will remain at the transplant centre, where they will contact the potential recipient and prepare them for imminent surgery.

Donor evaluation: Explanation assessment

Evaluation of the donor lung can begin many hours or days before the explant process. After confirmation of consent, verification of brainstem death (in DBD), and assessment of ABO compatibility, a comprehensive history is taken from the donor's family.

Fibreoptic bronchoscopy is performed on the donor,[21] allowing inspection of the airway anatomy and the extent of secretions. The proceduralist will also acquire bronchial washings to guide the perioperative antimicrobial regimen. On surgical explantation, the lungs are assessed for their ability to be recruited.

Donor evaluation: Explantation and dissection

If the donor is DCD, the chest is rapidly opened after bronchoscopy, and the cross-clamp is applied to the aorta and SVC.

If donation is via DBD, once the chest is opened a deflation test is performed followed by full recruitment. The FiO_2 is increased to 1, and arterial blood gases are taken. Lung protective ventilation is commenced with a FiO_2 approximating 0.5 and PEEP 5-8cmH_20. The gases are communicated to the implant centre, and once the implant team accepts the lungs, a decision is made as to when to apply the cross-clamp. The lungs are re-recruited before being transported (inflated) and on ice.

Ex-vivo lung perfusion

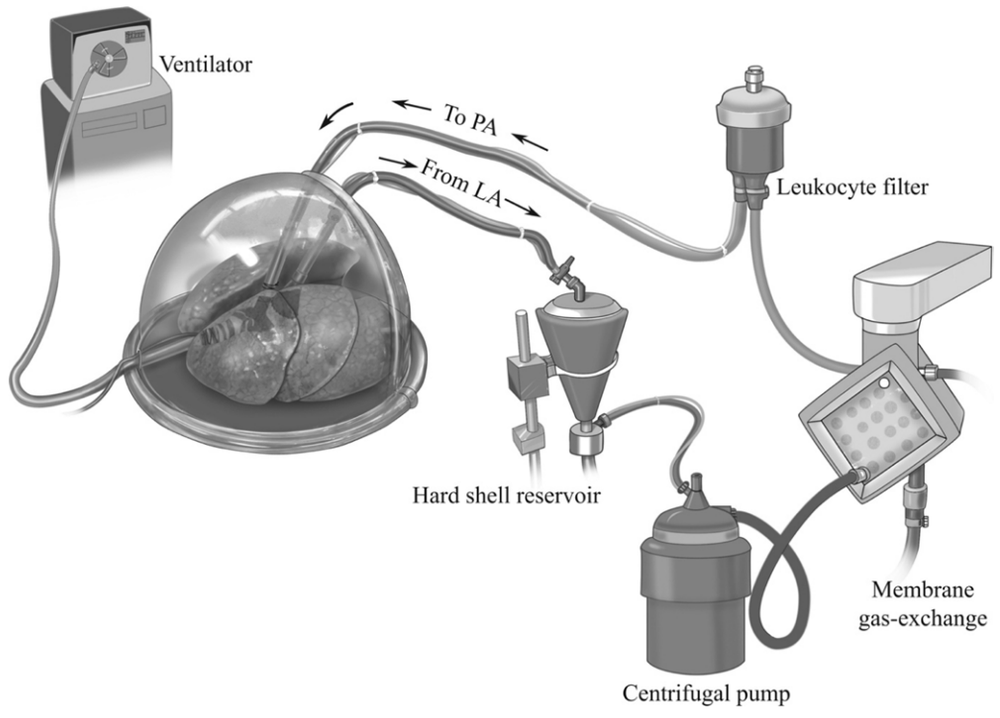
The lungs are one of the most precarious organs during the transplantation process. Events surrounding brain death subject the lungs to various mechanisms of injury, including ventilator-acquired pneumonia, neurogenic or hydrostatic pulmonary oedema, and barotrauma. Unfortunately, this means that many potential donor lungs are rejected. Data from the 2019 Organ Procurement and Transplantation Network (OPTN) reports that 6.4% of lungs recovered for transplant were not transplanted.[17] Consequently, recent strategies to optimise the viability of potential donor organs have gained much traction.

Ex-vivo lung perfusion (EVLP)[26] has made the expansion of the donor pool possible. EVLP has emerged as a modern preservation technique that allows more accurate lung assessment and improves lung function. An example is presented in Figure 4.

EVLP involves 4-6 hours of reconditioning via perfusion and ventilation of the lungs under an EVLP dome. There are four distinct phases encapsulated with EVLP[27]:

1. gradual rewarming to a state of normothermia
2. gradual increase in vascular flow as the lungs are rewarmed, targeting 40% of the donor-predicted cardiac output (CO)
3. protective lung ventilation
4. acellular perfusate with increased colloid osmotic pressure.

Figure 4. Lungs awaiting transplantation, in steady state under an EVLP dome[55]



Donor and recipient compatibility

The two most crucial features in matching a donor to a recipient are ABO blood group compatibility and size compatibility.[51] The latter can be fraught and is mainly based on comparing the donor and recipient heights and estimating lung volumes. The underlying condition of the recipient also affects the size of the lungs they require. Emphysematous lungs have larger thoracic cavities, while ILD is associated with smaller thoracic cavities.

AB blood group recipients are more likely to be matched, whereas patients with the O blood group remain on the wait list for much longer. Data from the NHSBT between 2018 and 2021 calculated the median time for AB and O at 345 days and 1177 days, respectively.[53] Table 9 demonstrates the criteria for allocation of donor lungs to recipients.

Table 9. Patient allocation criteria for lung transplantation

1. ABO compatibility
2. Size compatibility based on CXR measurements and total lung capacity values
3. Absence of a positive T-cell crossmatch and acceptable anti-HLA antibody profile on Luminex testing
Where more than one potential recipient meets the above criteria, the first choice will be determined by the following process
4. Clinical urgency and logistics
5. Long-term outcome/benefit
6. CMV status of donor and recipient
7. Recipient waiting time (if all other factors are equal)

Preoperative anaesthesia assessment

By the time the recipient arrives on their surgery day, they have undergone extensive anaesthetic review. On arrival, the case anaesthetist performs a targeted assessment, ascertains the need for premedication, and constructs a robust airway strategy. This is especially necessary for patients whose primary condition may render their airway more challenging to manage, such as those with connective tissue disease.

The presence of right ventricular impairment and/or pulmonary hypertension should be reviewed to allow the anaesthetist to risk stratify the potential for perioperative cardiac decompensation. Given the need to protect central veins if ECMO cannulation is required, a strategy for vascular access should be carefully considered.

Transplantation: Intraoperative management

The retrieval team will provide an estimated time of arrival for the donor lungs, at which point the anaesthetist and transplant coordinator will liaise to ensure meticulous timing of arrival of the recipient into the operating theatre. Initiation of anaesthesia must only be commenced after the call to confirm the donor lungs are officially accepted. This ensures graft ischaemic time is minimised. It also limits unnecessary time under anaesthesia for the recipient who, once intubated, may be very difficult, if impossible, to extubate given the extent of their end-stage lung disease.

Ischaemic time

The total ischaemic time is the difference between the donor cross-clamp and recipient reperfusion. By convention, the limit of acceptable ischaemic time for lungs was six hours. Data from ISHLT show that ischaemic times carry much less significance provided the lungs are preserved at 4 degrees centigrade on ice. Today, lung allografts with ischaemic times of 8-10 hours are associated with acceptable perioperative outcomes and post-transplant survival.[28]

Anaesthetic management

Typically, 1 hour is allocated for anaesthesia and 1 hour for preimplantation surgery. Full monitoring,

including a right-sided radial arterial line, is applied, and large IV access is established. Anaesthesia is induced and maintained with either volatile anaesthesia or total intravenous anaesthesia (TIVA) if ECMO is being utilised.

Induction of anaesthesia can be fraught in this patient demographic with profound hypotension or complete cardiovascular collapse. Having the surgeon and perfusionist in the OT during induction is prudent.

Meticulous essential airway management is paramount. Avoid aggressive bag-mask ventilation but ensure adequate ventilation to avoid hypoxaemia or hypercarbia both of which will increase pulmonary vascular resistance. Avoid aggressive bag-mask ventilation but ensure adequate ventilation to avoid hypoxaemia or hypercarbia, which will increase pulmonary vascular resistance (PVR). The convention is to place a left sided double lumen tube (DLT) if the transplant is off-pump or on ECMO and a single-lumen ETT if on CPB. The convention is to place a left-sided double-lumen tube (DLT) if the transplant is off-pump or ECMO and a single-lumen ETT if on CPB.

A quad lumen central line and vascular sheath are sited, and ideally, a pulmonary artery catheter (PAC) is floated. The tip of the PAC is withdrawn to the proximal PA before pneumonectomy of the recipient's native, diseased lungs to avoid it being included in the suture line. The position is confirmed using transoesophageal echo (TOE).

Cerebral monitoring, often consisting of processed EEG and/or cerebral oximetry, is more commonly used as a marker of brain oxygenation.

Meticulous attention should be paid to maintaining normothermia through a forced air patient warming device and fluid warmer, especially if the operation is carried out on ECMO or without CPB.

Patient blood management

Blood products should be readily available at the time of incision. These include packed red blood cells and fresh frozen plasma. Cell savers are utilised from the start. A rapid volume transfuser, such as a level 1, should be available from the beginning. Patient blood management (PBM) also includes point-of-care testing to guide the judicious use of blood products through TEG or ROTEM.

Immunological considerations

Antibiotics are delivered 30 minutes before skin incision. The regimen is based on the institution's antimicrobial policy and the patient's pre-existing colonisation. A dose of 10mg/kg of methylprednisolone is delivered before reperfusion and three doses post-operatively in the intensive care unit (ICU). However, institutional practice may vary and should be clarified at each new location.

Transoesophageal Echo (TOE)

TOE is utilised throughout the surgery for haemodynamic monitoring, including RV and pulmonary venous and pulmonary artery anastomosis assessments. The TOE also guides the vasculature de-airing during the anastomoses' final stages.

Transplant surgical access

Bilateral lung transplantation can be performed via clamshell incision, sternotomy, or bilateral anterior thoracotomies. The latter is more prevalent in off-pump techniques.

Circulation strategies for lung transplantation

Lung transplantation can be performed off-pump, via sequential one-lung ventilation, or using ECLS via CPB or ECMO. The circulation strategy employed may influence lung transplantation outcomes including the development of one of the most feared outcomes: Primary Graft Dysfunction (PGD). PGD is a particular type of acute respiratory distress syndrome (ARDS), primarily due to ischaemia-reperfusion syndrome.

Retrospective data analysis from the international ECLS registry demonstrates that severe PGD at 48-72hours is greater when lung transplantation is performed using CPB (43%) when compared to V-A ECMO (29%) and off-pump techniques (12%).[29]

While there are indications that off-pump techniques may be associated with better outcomes; it is only

sometimes feasible to utilise this approach. The growing global trend is towards intraoperative ECMO for lung transplantation, which allows extension of ECLS into the postoperative period, if it is required.[30] For those patients where off-pump surgery is instituted in the first instance, there must be a robust strategy in place to evaluate the need for intraoperative ECMO during the clamping of each PA as a backup strategy. Table 10 describes each strategy's key advantages and disadvantages.[31]

Table 10. Comparison of strategies for intraoperative mechanical circulatory support for lung transplantation

Modality	Advantages	Disadvantages
Off-pump	no anticoagulation, minimal bleeding, shorter operation times, minimal inflammatory cascade	cardiac compression can cause haemodynamic instability, operative visualisation less optimum
CPB	use of pump sucker, open heart anastomosis is possible, cardiac decompression with less hemodynamic instability	full heparinization, higher bleeding risk and more blood products transfused, greater inflammatory cascade
ECMO	less heparinisation less bleeding and less requirement for blood product replacement stable oxygenation and removal of carbon dioxide, decreased pulmonary hypertension stable haemodynamics with cardiac compression	risks of air embolism risks of vascular complications associated with cannulation

Off-pump lung transplant surgery

In bilateral sequential lung transplants, the first newly implanted lung supports the body, while the second lung is implanted. If both lungs are adequate, implanting the right lung first is preferable because it provides a larger vascular bed to receive the total cardiac output immediately after implantation. Also, the left lung is usually implanted faster.

If there is a discrepancy in function between the lungs, then the least functional lung is usually dissected first, and a trial of PA clamping is performed. This is a critical time for the anaesthetist, during which the patient's haemodynamic and respiratory function are continuously monitored clinically and using TOE. Cardiopulmonary conditions must be optimised during this brief but compromised timeframe. Indication for emergent ECMO is assessed using the following criteria:[30]

1. Hypercapnia
2. Decrease in arterial saturation to <90%
3. Cardiac index of <2 litre/min/m^2
4. Increase in PA pressure to supra-systemic values.

Hypoxia or acidosis is very concerning and may herald the need for emergent V-A ECMO.

Once the surgical anastomoses are completed, the lung can be re-perfused. Before releasing the PA clamp, the anaesthetist must inspect the lung using bronchoscopy. Bronchoscopy allows direct assessment of the bronchial anastomoses and meticulous suctioning of secretions.

The PA clamp should be released very slowly as the reperfusion time is extremely high risk and may result in profound hypotension. Pulmonary oedema heralds allograft injury. This is a critical time for the anaesthetist, who must deploy strategies for ventilation and circulation with meticulous precision.

From the ventilation perspective, the FiO2 is set at 0.21 at the time of reperfusion, and protective ventilation is targeted with low tidal volume, low minute ventilation, and the application of positive end-expiratory pressure (PEEP). The PAC is utilised throughout to monitor and assess mean pulmonary artery pressure. When performed off-pump or when weaning from ECLS, full protective ventilation is employed on low FiO_2.[54]

Before removing the cross-clamp, vasoactive infusions are increased.

At this point in the process, blood pressure is supported with boluses of intravenous fluid, 5-10 microgram boluses of adrenaline, and intravenous calcium administration.

On-pump lung transplant surgery

On-pump surgery utilises a traditional CPB circuit, which carries a higher risk than ECMO. Firstly, CPB is an independent risk factor for PGD.[31] Unlike ECMO, CPB is an open system that requires full heparinisation, exposing the patient to significant bleeding complications. The blood-circuit interface causes the induction of inflammatory mediators, which can contribute to coagulopathy.

ECMO for lung transplant surgery

The global trend is to perform lung transplantation on V-A ECMO. V-V ECMO can be used intraoperatively but provides no haemodynamic support. It is prudent to ensure that anaesthetic monitoring includes temperature and cerebral oximetry. Defibrillator pads should be attached from the start. Total intravenous anaesthesia is utilised when on ECMO.

Once surgical dissection is satisfactory, heparin is given to maintain an ACT between 180-220 seconds. Cannulation in a V-A configuration is performed, ideally intraoperatively.

The anaesthetic goals of maintaining a patient on V-A ECMO for lung transplantation are:

1. Maintain heart contractility, promoting blood flow into the lungs
2. Maintain a MAP of 60-65mmHg for coronary perfusion
3. Monitor cerebral oximetry as a marker of brain perfusion
4. Maintain a temperature of >36 degrees Celsius using a forced air patient warming device, warmed fluids, and the heater/cooler on the ECMO circuit
5. Manage significant fluid shifts with the careful administration of intravenous fluid (there are no pump suckers or reservoir, making volume management, maintenance of ECMO flow and haemodynamics very challenging).

While ECMO has a more favourable risk profile in many senses, one of its major drawbacks is that there is no safety margin for air embolus.

Numerous specific targets for ECMO management exist. ECMO is established with a flow of 50% of the cardiac output. Flow is adjusted according to haemodynamic demands and gas exchange and confirmed as pulsatile flow over the PA. Systolic PA pressures should be maintained below 40mmHg. The transplanted lung is re-perfused and reinflated, and perfusion is confirmed with an $etCO_2$ over 20mmHg. Lung perfusion may be associated with a drop in ECMO flow, requiring vasoconstrictor administration to support the blood pressure.

Meticulous bronchoscopy and lavage are performed. Once the lung is fully inflated, a PA systolic pressure of 10 – 15mmHg is targeted. This ensures good pulmonary blood flow. The TOE is used to confirm good flow from the pulmonary veins.

Once the second lung has been implanted, the ECMO flow can be reduced to 1L, and the arterial and venous lines cross-clamped. The lungs are assessed, and provided the set criteria are met, the ECMO cannulae can be removed.

Criteria for weaning from ECMO:

1. PaO_2:FiO_2>100mmHg
2. mPAP/mSAP <2/3
3. stable cardiopulmonary conditions between the measurements.

If these criteria are not met, ECMO is continued in the ICU in the post-operative phase, although the configuration of the cannulation may be changed depending on the circumstances.

Transplantation: Post-operative management

The immediate post-operative phase is crucial in determining short- and long-term survival.

Immunosuppression

Acute rejection complicates 50% of lung transplants and is a risk factor for chronic allograft dysfunction.[32] The acute post-transplant immunosuppression regimen varies between centres and should be tailored to individual patients. It may consist of induction therapy (such as alemtuzumab) and triple drug immunosuppression consisting of a calcineurin inhibitor (cyclosporine or tacrolimus), a cell inhibitor (azathioprine or mycophenolate mofetil), and a corticosteroid.[33]

Commencement of the nephrotoxic drug cyclosporine often complicates the postoperative period with acute kidney injury (AKI), especially in those recipients who are older or have pre-existing kidney injury. Cyclosporine-induced acute nephrotoxicity is caused by constriction of the afferent arterioles,[34] and the associated AKI significantly hampers post-operative recovery, with higher incidences of ventilated days, more tracheostomies, and administration of vasoactive medication for more extended periods compared to those without.[35]

Infection

Post-operative infections are common. They contribute to accelerated graft failure. Infection risk is assessed in terms of risk posed by the donor (having any pre-existing infections/colonisation) and risk posed by bacterial presence in the pre-transplant recipient, as well as post-operative hospital-acquired infections in the recipient post-transplant. Broncho-alveolar lavage samples are sent for C&S for both the donor and the recipient. In the immediate postoperative period, donor-derived pathogens account for most infections and empirical antibiotic prophylaxis reflects this with cover for broad-spectrum microbes such as methicillin-resistant Staphylococcus aureus (MRSA), Pseudomonas, and Enterobacter.[36]

Bacterial infections can present as pneumonia, parapneumonic effusions and empyema, mediastinitis, anastomotic leaks, and surgical wound dehiscence. Pneumonia being the most common bacterial infection, recipients are often commenced on prophylaxis with trimethoprim-sulfamethoxazole, given the risk of pneumocystis jirovecji and its potential to cause life-threatening lung infection.[37] Multi-drug resistant infections are usually an issue in this patient demographic, and knowledge of the recipient's pre-transplant cultures helps to tailor the appropriate antimicrobial therapy.

CMV status of the donor and recipient must be known. Lung transplantation recipients who are CMV-negative and receive CMV-positive donor lungs have the highest risk of developing severe life-threatening diseases.[38] Prophylaxis should be started immediately in all lung transplant recipients and generally consists of intravenous ganciclovir followed by oral valganciclovir or acyclovir.

Invasive fungal infections in lung transplantation are associated with high morbidity and mortality.[39] The most common organisms are Aspergillus and Candida. Risk factors include fungal colonisation, idiopathic pulmonary fibrosis, advancing age, increased BMI, airway ischaemia, and (interestingly) the presence of significant construction projects around the transplant centre.[39]

Post-operative complications

Potential complications following a lung transplant are summarised in Table 11. The most significant being PGD.

Table 11. Summary of post-transplant complications

Causes of respiratory failure
PGD
donor associated pneumonia
ventilator associated pneumonia
acute rejection
cardiogenic pulmonary oedema
pulmonary embolus
pulmonary vein anastomotic obstruction from thrombosis or dissection
transposition of the donor vessel
lung or lobar torsion
phrenic nerve injury leading to diaphragmatic injury
haemothorax
Airway complications
bronchial stenosis
bronchial anastomotic dehiscence
exophytic excessive granulation tissue formation
tracheobronchomalacia
bronchial fistulas
Other
bleeding
cardiogenic shock
tamponade
infection and or sepsis
arrhythmias
pericarditis
GORD
bowel ischaemia
immunosuppression side effects
CNS complications
critical illness myopathy

Primary graft dysfunction

PGD can be seen immediately on allograft perfusion. It occurs in 20-30% of recipients and is a type of ARDS precipitated by prolonged ischaemia time, reperfusion injury, and innate immune responses.

The ISHLT proposed a validated grading system to quantify PGD based on the onset of changes in partial pressure of oxygen (PaO_2:FiO_2) and chest radiography at specific epochs of time after reperfusion (0, 24, 48 and 72 hours).[40] Oedema is a crucial hallmark of the onset of PGD, with progressively declining PaO_2:FiO_2 ratios delineating the proportional severity of dysfunction. The grading classification is described in Table 12.

Grade 3 PGD is associated with morbidity in both the short and long term and can carry mortality as high as 50%.[41]

Table 12. ISHLT grading system of PGD

Grade	CXR findings	PaO_2:FiO_2
PGD 0	No oedema	Any
PGD 1	Oedema	>300
PGD 2	Oedema	200-300
PGD 3	Oedema	<200

Risk factors for PGD

The anatomical functionality of the lungs is not entirely restored after transplantation. Donor lungs lack bronchial circulation, which may affect parenchymal oxygen delivery. The bronchial anastomosis lacks innervation, leading to abnormal cough reflexes or hypoxic pulmonary vasoconstriction (HPV). Disruption of lymphatics also impairs the drainage of interstitial fluid.

The type of lung donor is associated with varying physiological challenges. Lungs retrieved via DBD are exposed to a substantial inflammatory response; in DCD, the donor may have had a prolonged period of mechanical ventilation.

The physical size of the donor lungs is also an important consideration, which can create mismatches with the recipient and varying associated issues. Donor lungs that are small relative to the recipient can create reduced pulmonary vasculature that may lead to pulmonary hypertension. Lungs larger than the recipient's chest cavity can lead to restrictive lung function patterns.

Recipient comorbidities, specifically obese recipients and those with sarcoidosis, IPF, or pulmonary hypertension,[33] are associated with a greater risk of PGD.

Intraoperative factors, such as CPB use, fat embolism or venous thrombosis, prolonged ischaemia time, a large volume of blood transfusions, or high FiO_2, all increase the incidence of PGD.[42] Aside from the radiological and gas exchange findings, which are used as diagnostic criteria for PGD, physiologically, PGD is characterised by increased PVR, decreased pulmonary compliance, and intrapulmonary shunts. The management of PGD is mainly supportive. However, post-transplant ECMO has been shown to improve survival if instituted early on, with a one-year survival of 64%.[41,33]

Transplantation: ICU management

A comprehensive discussion of post-op ICU management is outside the scope of this article, but mechanical ventilation and haemodynamic management will be considered.

Ventilatory considerations

The goals in the immediate post-operative phase are:

- adequate gas exchange
- monitoring lung allograft function
- early weaning of mechanical ventilation to minimise ventilator-induced lung injury to the graft.

Protective lung ventilation is instituted with targets of[43]:

- tidal volume 6ml/kg of *donor* predicted body weight
- plateau pressure <30cmH_2O
- pH>7.25
- oxygen sats > 90% and PaO2> 60mmHg (8kPa).

Tidal volume targets are based on donor rather than recipient body weight.[44] Inspired oxygen is minimised to reduce oxidative stress.[45] Once gas exchange is adequate (aligned with a pH>7.25 and PaO_2:FiO_2>200mmHg), mechanical ventilation and sedation can be weaned.

Mobilisation and chest physio are crucial to facilitate bronchial hygiene and avoid atelectasis. This is particularly important in transplanted lungs, where normal lung innervation and bronchial circulation are disrupted.[33]

Uncontrolled pain after lung transplantation inhibits coughing, reduces pulmonary toilet, and compromises graft expansion. Thoracic epidural analgesia (TEA) is commonly employed as part of a multimodal analgesia regime, but the exact timing of placement remains contentious.[49]

Given the risk of vertebral canal haematoma associated with preoperative placement and subsequent anticoagulation for intraoperative mechanical circulatory support, post-operative placement is more commonplace. A case series of over 100 lung transplant patients who had post-operative TEA demonstrated optimum analgesia with minimal complication rate.[50] Bilateral thoracic paravertebral block catheters are considered a good alternative that is increasingly utilised. Sternotomies usually won't need either.

Most transplanted lungs will incur uncomplicated pleural effusions, which mostly resolve within two weeks. Pleural complications include haemothorax, chylothorax, pneumothorax, and empyema. Air leaks complicate up to 35% of lung transplants.[45] Risk factors include donor-recipient size mismatch, bronchopleural fistulas, dehiscence of bronchial anastomoses, infection, rejection and/or ischaemia.

Diaphragmatic function can be compromised secondary to injury of the phrenic nerve either mechanically during surgery or because of myelin dysfunction associated with the transplant processes. Both mechanisms are associated with an increased incidence of PGD and mortality.[38]

Haemodynamic considerations

The goals in the immediate postoperative phase focus on maintaining adequate end-organ perfusion using the lowest possible CO to reduce the risk of exacerbating lung oedema from reperfusion injury.

End organ perfusion is monitored using surrogates such as lactate, urine output, and mixed venous oxygen saturations.

A PA catheter guides haemodynamic management by allowing assessment of cardiac preload (CVP and wedge pressure), systemic and PA pressure, systemic and peripheral vascular resistance, CO and mixed venous saturations.[33] Neutral fluid balance is targeted as sedation is weaned, and CO and lung perfusion increase. Any decline in the graft function, such as deterioration in gas exchange or lung compliance, may signal the development of PGD and prompt the weaning process to be slowed down. After that, early postoperative CXR and daily CXRs are part of PGD monitoring and diagnosis.

Typical haemodynamic targets are:

- CVP<7mmHg
- MAP 65-75 mmHg
- CI 2.2-2.5L · min^{-1} · m^{-2}

Cardiovascular complications include dysrhythmias, with atrial fibrillation (AF), supraventricular tachycardias, and atrial flutter, presenting an incidence of 25-35%.[38] Risk factors for AF include pre-transplant IPF, left atrial enlargement, diastolic dysfunction, and pre-existing coronary artery disease.

CONCLUSIONS

The perioperative care for lung transplantation is complex. It requires an MDT approach that commences long before the day of surgery and extends well into the post-operative phase. Intraoperative anaesthetic management is both highly challenging and extremely rewarding. For the anaesthetist, it allows execution of a highly honed skill set to a meticulous standard. For the lung transplant recipient, it represents the potential to regain quantity and quality of life.

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The emergency laparotomy patient

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BACKGROUND

In Australia and New Zealand, emergency laparotomies are one of the most common emergency procedures performed across all surgical specialties.[1] These are high-risk procedures that are performed on high-risk patients and are associated with significant rates of morbidity and mortality as well as substantial healthcare costs.[2] It is estimated that reducing the length of stay of emergency laparotomy patients by one day will likely save $34 million per annum.[3]

Definition

The term “emergency laparotomy patient” is broadly defined in the literature and has come to encompass a wide variety of clinical presentations, pathologies and procedures. Typically, it refers to a patient who undergoes an unscheduled operation for an acute abdomen via an open midline abdominal incision. The term “laparotomy”, however, now incorporates patients who undergo laparoscopic or laparoscopic-assisted procedures that were traditionally performed in an open manner.[4] The Australian and New Zealand Emergency Laparotomy Audit (ANZELA) defines emergency laparotomies as open or laparoscopic abdominal procedures involving the stomach, bowel or rectum. It includes adults over the age of 18 booked to undergo an abdominal procedure where the urgency for surgical intervention is under 24 hours.[5]

An estimated 13,500 to 15,500 emergency laparotomies are performed in Australia alone each year. The median age of emergency laparotomy patients is 66 years of age, with the majority of these patients (94.6%) admitted via the emergency department and a small proportion of patients (5.4%) presenting post-elective procedures.[6] Indications for emergency laparotomy include bowel obstruction, perforation, infection, abscess, ischemia and bleeding.[3,5] Of these, bowel obstruction and perforation are the most common pathologies.[7] Common conditions excluded from most definitions of emergency laparotomy include laparoscopic appendicectomies, laparoscopic cholecystectomy, and laparoscopic gynaecological or obstetric surgeries.[3]

Morbidity, mortality and long-term outcomes

There are high rates of mortality among emergency laparotomy patients due to their risk profile and the nature of the procedure. Recent studies have identified a 30-day mortality ranging between 5% and 20%.[6–8] The latest ANZELA reports a 30-day mortality rate as low as 5.2%. Australian emergency laparotomy mortality figures are notably lower than in other parts of the world, including the UK, which most recently

reported mortality of 9.3%.[9,10] This was observed even before recent nation-wide quality improvement projects, including ANZELA-QI, with the 2016 Perth Emergency Laparotomy Audit reporting a mortality rate of 5.4% across Western Australia.[11] Studies have suggested that this difference may be attributable to the Australian and New Zealand Audit of Surgical Mortality (ANZASM) and its focus on avoiding futile or non-beneficial surgery.[9] To date, ANZASM is the only national surgical mortality audit worldwide, a process where surgical patient deaths are independently peer-reviewed.

Despite lower 30-day mortality, Australia has relatively higher mortality figures two weeks post-operation, suggestive of poor compliance with perioperative care standards as compared to the UK.[9] In addition, Australia has lower rates of ICU admission for high-risk patients compared to the UK (64.2% as compared to 87.6%), despite this being an ANZELA standard of care.[6]

Regarding longer-term outcomes, a systematic review of 15 studies totalling 48,023 patients found that one-year mortality ranged from 15–47%, increasing to 30–47% in elderly patients.[12] A Danish study of 4346 patients undergoing emergency abdominal surgery showed that 14% had surgical complications and 23% had medical complications.[13] There is a gap in research on the long-term outcomes of emergency laparotomy patients in Australia and New Zealand.

Table 1. Preoperative risk factors for mortality after emergency laparotomy

Patient characteristics	Age, ASA status, frailty, preoperative sepsis, functional dependency status, presence of comorbidities.
Acute physiological derangements	Anaemia, coagulopathy, elevated creatinine, elevated lactate and hypotension.
Surgical factors	Delay, emergency category, indication and type of procedure.

Information sourced from Barazanchi et al. (2020),[14] Ahmed et al. (2020),[15] Kao et al. (2020),[16] and Price et al. (2025).[17]

Many of these risk factors have been incorporated into the risk assessment tools for 30-day mortality post-emergency laparotomy listed below. Further research is needed to determine which of these risk factors is most significant.

AUDITS

Over the past decade, there has been an increasing focus on determining patient outcomes following emergency laparotomy and establishing national standards to promote quality improvement measures. Several national audits and quality improvement projects have been established, most notably the National Emergency Laparotomy Audit (NELA) in England and Wales and the subsequent Australia and New Zealand Emergency Laparotomy Audit – Quality Improvement (ANZELA-QI).[3,18] Since the inception of these audits, there have been substantial improvements in patient outcomes at participating hospitals, including reductions in 30-day mortality and length of stay.[6,10]

NELA

NELA released its first report in 2015 and is now in its tenth year. The audit was established in response to a prospective, multicentre study published by the UK Emergency Laparotomy Network, which found a mortality rate of 14.9% across 35 NHS hospitals and identified significant inter-hospital variability in the care of emergency laparotomy patients.[19] NELA aimed to collect and publish high-quality, comparative data across hospitals in the UK, driving quality improvements in care and patient outcomes by auditing the provision of care against a set of national standards.[18] Data collection commenced in December 2012, with the first report published in 2015, which included data on 20,000 emergency laparotomy cases across 190 hospitals. The key takeaway from the first NELA report was the critical role of risk assessment in delivering care. It found that those with a documented risk assessment were far more likely to receive a level of care that met standards compared to those who had no documented risk assessment.[18,20] Since 2015, eight additional annual NELA reports have been published, with the most recent one released in October 2024. Currently, inpatient mortality rates have improved from 11% to 9%.[10,18] Table 1 outlines the current nine key standards and key process measures.

Table 2. NELA key standard and process measures

Workstream	Standard benchmarked by NELA
Computerised tomography (CT) scanning and reporting	Proportion of patients requiring immediate surgery who had a CT scan that was reported by senior radiologist within one hour and communicated with the surgical team before surgery.
Infection management	Proportion of patients with suspected infection or sepsis who had antibiotic administration within the correct clinical timeframe.
Timeliness to theatre	Proportion of patients with a "Royal College of Surgeons (RSC) immediate" pathology arriving in theatres within six hours of arrival at the hospital/ emergency department.
Risk assessment	Proportion of patients in whom a risk assessment was documented preoperatively *and* postoperatively.
Consultant-delivered care	Proportion of high-risk patients (risk of death of ≥ 5%) with consultant surgeon and consultant anaesthetist present in theatre.
Critical care	Proportion of high-risk patients admitted directly to critical care postoperatively.
Elderly care	Proportion of patients aged greater than 65 and frail, or aged greater than 80, who receive postoperative assessment and management by a member of a perioperative team with expertise in comprehensive geriatric assessment.
Data quality/completeness	Case ascertainment.
Outcomes	Mortality and length of stay.

Information sourced from the Ninth Patient Report of the National Emergency Laparotomy Audit (2024)[10]

ANZELA

ANZELA-QI was preceded by single-centre laparotomy audits in Perth, Victoria, New South Wales and Auckland, which were published in response to the UK NELA audit.[8,11,21] In 2016, the Perth Emergency Laparotomy Audit was first published, marking the first Australian prospective multicentre study of emergency laparotomy patients. The study found markedly higher mortality rates in patients who did not receive preoperative risk assessment (9.5%) compared to those who did (5.2%).[11] This audit, along with several additional local studies, served as the impetus for the establishment of the ANZELA-QI Working Party, which was established in 2017 and commenced data collection in July 2018. ANZELA aimed to determine the current standard of emergency laparotomies in Australia and New Zealand and to monitor compliance of participating hospitals with a set of ANZELA-QI key performance indicators (see Table 2).[3]

The first ANZELA-QI report presented data from June 2018 to June 2020, encompassing 24 Australian hospitals, and found an inpatient mortality rate of 7.1%.[3] The second and most recent ANZELA-QI report from January 2020 to December 2021 showed a reduction in mortality to 6.2%.[6] While suggesting that participating hospitals were improving patient outcomes through adherence to national guidelines, a large proportion of emergency laparotomies (approximately 89%) remains unreported and therefore not included in this ongoing audit.[6] Additionally, in keeping with the findings from NELA, there was marked inter-hospital variation in patient care and outcomes, suggesting further scope for improvement.

Table 3. ANZELA-QI key performance indicators

Preoperative	Intraoperative	Postoperative
Proportion of all emergency laparotomy patients who received a preoperative CT scan, which was reported on by a consultant radiologist preoperatively. Lactate level available to the surgeon at the time of surgical referral for patients admitted via the emergency department. Proportion of patients with risk assessment documented preoperatively. Preoperative frailty assessment performed for patients aged ≥ 65 years. Proportion of patients arriving in theatre within a time appropriate for the urgency of surgery (documented urgency 24 hours or less).	Consultant input during surgery: a) Proportion of patients with a calculated preoperative risk of death ≥ 5% for whom both a consultant surgeon and consultant anaesthetist were present in theatre. b) Proportion of patients with a calculated preoperative risk of death ≥ 5% for whom a consultant surgeon was present in theatre. c) Proportion of patients with a calculated preoperative risk of death ≥ 5% for whom a consultant anaesthetist was present in theatre.	Proportion of patients with a preoperative risk of death ≥ 10% who were directly admitted to critical care postoperatively. Proportion of patients aged ≥ 65 years who were assessed by a specialist in geriatric medicine.

Information sourced from the Second ANZELA-QI Program Summary Report (2022)[6]

CARE PATHWAYS

The preoperative assessment and optimisation of emergency laparotomy patients is difficult as the urgency of surgical intervention often limits it. Many emergency laparotomy patients present out of hours, where preoperative care and decision-making are often limited by time and resources.[22,23] Anaesthetic assessment and input, therefore, usually comes relatively late in a patient's presentation, and relies heavily on pre-assessment and management from emergency medicine and general surgery teams. As such, there appears to be a clear benefit in adopting standardised care pathways or bundles of care that have been recognised as effective ways to simplify, streamline and ensure greater consistency of patient care.[24,25] Multiple care pathways and recommendations for emergency laparotomy patients have been proposed in the literature, with considerable overlap, and have resulted in significant reductions in morbidity and length of stay.[22,26–28]

ERAS

Since 2021, Enhanced Recovery After Surgery (ERAS) has published a three-part series of recommended guidelines for patients undergoing an emergency laparotomy.[26,30] Strong recommendations from parts 1 and 2 of the ERAS guidelines are summarised in Table 4.[26,30]

ELPQuiC

The Emergency Laparotomy Pathway Quality Improvement Care (ELPQuiC) bundle was first introduced in 2014 through a study originating in England,[24,31] and shares most of its recommendations with ERAS protocols and ANZELA standards of care. It differs in that it mandates ICU admission and intraoperative goal-directed fluid therapy for all emergency laparotomy patients, even those who are not high-risk. The inclusion of mandatory ICU admission may be a factor contributing to the higher ICU admission rate in the UK compared to Australia and New Zealand.

ISCR

In the United States, the Improving Surgical Care and Recovery (ISCR) program is an enhanced recovery pathway project that has been operational since 2017, initially focusing on elective patients. In 2020, the ISCR extended its scope to include emergency general surgery patients, with results from the study yet to be published.

Table 4. Summary of strong recommendations from parts 1 and 2 of the ERAS emergency laparotomy guidelines

Preoperative	Intraoperative	Postoperative
Assess physiological derangement with early warning scoring systems and resuscitate and correct derangements early. Screen for sepsis with validated sepsis scores, administer antibiotics early and monitor lactate. Surgery within six hours if septic. Surgery within three hours if septic shock. Early contrast CT imaging, surgery, and source control of sepsis. Risk assess all patients using a validated risk score. For patients >65 years of age, assess frailty using a validated frailty score. If time permits, a cognitive assessment, delirium screen and physician assessment should be performed. Consider reversal of antithrombotic medications. Assess venous thromboembolism risk with a validated tool. Commence multimodal opioid-sparing analgesia and avoid sedative medications. Consider preoperative nasogastric intubation for patients at risk of aspiration and gastric distension. Patients and families should be part of shared decision-making surrounding surgery.	Rapid sequence induction with fast-acting muscle relaxant and cricoid pressure. Consider depth of anaesthesia monitoring for patients >60 years of age. Multimodal postoperative nausea and vomiting (PONV) reduction for all patients. Measure core temperature and utilise warming devices and warmed fluid to maintain normothermia. Use low tidal volume (6-8 mL/kg) and positive end-expiratory pressure (PEEP) ≥ 5cm H_2O. Utilise neuromuscular block monitoring and reverse with selective relaxant binding agent. Intravenous fluid and electrolyte replacement and consider arterial/central venous catheters early for delivery of vasopressors and fluids. Consider goal-directed haemodynamic therapy (GDHT) in high-risk patients. Aim MAP 60-65 mmHg and cardiac index >2.2 L/min/m^2 using vasopressors and inotropes as needed. Monitor blood glucose, aiming for 7.7-10 mmol/L using variable rate insulin infusion. Restrictive blood product replacement if required. Multimodal systemic analgesia. Assess suitability for endotracheal extubation.	Prevention of postoperative pulmonary complications including respiratory physiotherapy. Consider admission to the intensive care unit (ICU) or higher level of care postoperatively. Postoperative delirium screening and prevention. Ongoing venous thromboembolism risk assessment and treatment. Early urinary catheter removal. Early removal of nasogastric tube. Postoperative nutrition optimisation and early feeding. Postoperative ileus minimisation through fluid optimisation, opioid-sparing analgesia, early mobilisation, early oral intake, laxative use, and early removal of nasogastric tubes. Early mobilisation.

Information sourced from Peden et al. (2021)[26] and Scott et al. (2023).[30]

PREOPERATIVE CONSIDERATIONS

There are several patient, physiological and surgical factors that should be thoughtfully examined and addressed to enable rapid and safe perioperative management of emergency laparotomy patients, as outlined by the evidence-based ERAS guidelines, NELA key standards, and ANZELA-QI key performance indicators.[6,10,26] We incorporate these guidelines into the preoperative recommendations listed below.

1) Early identification and management of physiological derangement
   a) Resuscitation and correction of physiological derangement should begin immediately and continue during the diagnostic phase.
   b) An early warning scoring system should be used for rapid assessment of the patient for physiological derangements, and abnormal scores should trigger escalation to senior clinicians.

2) Screen and monitor for sepsis
   a) Use a validated sepsis score as early as possible and repeat at appropriate intervals.
   b) If systemic inflammatory response syndrome (SIRS), sepsis or septic shock is diagnosed, treatment should begin immediately.
   c) Prompt antibiotic administration should occur in line with existing guidelines, when sepsis is present or when surgical pathology makes the patient at high risk of infection (patients with peritonitis or hollow viscus perforation).
   d) Monitor blood lactate as a marker of risk and response to resuscitation.[26]

3) Early imaging
   a) Consider a preoperative CT scan for all patients who are candidates for emergency laparotomy. A consultant radiologist should ideally report this before surgery.
   b) Acquiring a CT scan should not cause a delay in urgent surgery.
   c) The incidence of contrast-induced nephropathy (CIN) after intravenous contrast administration is high in patients with normal renal function, and appears to be as high as 25% in patients with pre-existing renal impairment or in the presence of risk factors such as diabetes, advanced age and concurrent nephrotoxic medication.[32]
      i) Referring physicians should be familiar with the risk factors for renal disease, CIN and preventative measures.

4) Early surgery and source control of sepsis
   a) Delay in surgery increases mortality. Patients with septic shock should receive source control surgery within three hours.
   b) Patients with sepsis without shock should receive source control within six hours.

5) Risk assessment
   a) A risk assessment should be performed and documented prior to surgery. This enables the identification of high-risk patients, allowing their care to be appropriately escalated, and facilitates discussions regarding ceilings and goals of care.
   b) The use of a validated risk scoring tool is both an ANZELA and NELA key standard of care and is a fundamental part of preoperative assessment; however, it is currently underutilised.[6,18] There are presently many risk scoring tools, including the Surgical Outcome Risk Tool (SORT), Portsmouth Physiological and Operative Severity Score for the enUmeration of morbidity and Mortality (P-POSSUM), National Surgical Quality Improvement Program (NSQIP), Acute Physiology and Chronic Health Evaluation (APACHE-II), nzRISK and NELA score.[6,33,34] All estimate the risk of patient mortality within 30 days following surgery. Table 5 summarises the strengths and limitations of these tools.
   c) The NELA risk assessment score is considered most appropriate for Australia.[6]

6) Age-related evaluation of frailty and cognition
   a) Approximately 65% of emergency laparotomy patients are 70 years or older.[7] Elderly patients undergoing emergency laparotomy, particularly those over the age of 80, have an increased risk of postoperative complications and death.[7] Frailty is considered a significant determinant of outcomes in these patients.

b) A formal frailty assessment should be performed preoperatively for all patients aged 65 or older using validated scoring systems such as the Clinical Frailty Scale (CFS).

c) A validated assessment of cognitive function should be considered for all patients aged 65 years or older to identify those at risk of developing delirium. Efforts should be made to keep at-risk patients oriented, and to deprescribe potentially inappropriate medications listed in the American Geriatrics Society's Beer's criteria.

d) Patients over the age of 65 should be assessed by a geriatrician preoperatively if possible, and evidence-based, elder-friendly practices should be employed. Geriatrician involvement in the care of elderly emergency laparotomy patients has been associated with substantial morbidity reduction through increased recognition of complications such as delirium, acute kidney injury (AKI), urinary tract infection, and arrhythmia, and is associated with reduced medical emergency team/rapid system response (RSS) calls and length of stay.[35,36]

7) Reversal of antithrombotic medications

a) Patients are at high risk of both perioperative bleeding and thrombosis. Bleeding may be attributed to intra-abdominal surgery itself or patients presenting with haemorrhage, while coagulopathy is often secondary to sepsis and systemic inflammation.[37]

b) Reversal of anticoagulation or cessation of antiplatelet medications is a highly individualised process. It must consider the risks of bleeding from surgery, the risks of thromboembolism and the urgency of surgery.

c) Check:

i) Full blood count.

ii) Kidney and liver function, and electrolytes (including calcium).

iii) Relevant coagulation screen based on the anticoagulant and the time of its last administration.[37]

d) Determine how to proceed after seeking expert advice regarding test results.

e) In critical situations, consider a reversal agent (if available) before results are known. Consider platelet infusion in patients taking antiplatelet therapy when the planned procedural bleeding risk is high.

f) Where surgery cannot be delayed, cross-match blood and consult with haematology regarding measures to control bleeding both before and during surgery.

8) Assessment of venous thromboembolism risk

a) Risk should be determined using validated VTE risk assessment tools on admission, and reassessment should occur daily postoperatively.

b) If pharmaceutical prophylaxis is not possible, consider mechanical prophylaxis.

9) Pre-anaesthetic medication – anxiolysis and analgesia

a) Sedative medication should be avoided preoperatively to avoid the risk of micro-aspiration, hypoventilation and delirium.

b) Analgesia should be given to alleviate the patient's pain and stress.

c) Consider multi-modal opioid sparing agents to maximise comfort and minimise side effects.

10) Preoperative glucose, fluid and electrolyte management

a) Hyperglycaemia and hypoglycaemia are risk factors for poor outcomes.

b) Preoperatively, glucose levels should be maintained at 8–10 mmol/L. In diabetic patients, consider an insulin infusion to maintain blood glucose level within this range with appropriate monitoring of point-of-care blood glucose in accordance with local protocols.

11) Preoperative nasogastric intubation

a) Consider the need for a nasogastric tube based on pathology and patient factors (risk of aspiration).

12) Patient and family education and shared decision-making

a) Patients and families should have the opportunity to discuss the risk of surgery with a senior physician before surgery. When appropriate, treatment escalation plans and advance care plans should be discussed and documented.

Table 5. Commonly used scores for the prediction of mortality in emergency laparotomy patients

Risk assessment tool	Area under the receiver operating characteristic curve (AUROC)	Strengths	Limitations
NELA risk model	0.861 in internal validation study.	Primary risk tool used in ANZELA and NELA audits. Data from > 70,000 emergency laparotomy patients. Validated for Australian and New Zealand emergency laparotomy patients, with several studies showing it compares favourably to other risk scores.[38] Accessible online and on smartphone app. Thirteen variables required.	Like other risk scores does not factor in frailty.
P-POSSUM	0.65 to 0.82 for unplanned abdominal surgery.	Used in NELA audit prior to development of NELA score. Validated for Australian emergency laparotomy patients. Accessible online.	Can only be used to predict postoperative risk. Overpredicts mortality in young patients. Underpredicts mortality in elderly and emergency patients. Developed in 1998 from 2500 patients at a single UK centre undergoing elective and emergency surgery.
ACS NSQIP emergency laparotomy models	0.87-0.88 in internal validation study.	Predicts postoperative complications as well as mortality. Developed from 874 American hospitals with data from over 5 million operations across all surgical specialties. Provides surgery specific risk assessment. Accessible online.	Twenty-one variables required. Not developed for the Australian or New Zealand population. Predictive equations are not publicly released and hence cannot facilitate external validation.[39]
SORT	No data for emergency laparotomy patients; designed for non-cardiac, non-neurologic surgery.	Ten variables required. Accounts for emergency surgery status. Accessible online and on smartphone app.	Not explicitly studied in emergency laparotomy patients.

APACHE-II	Not originally developed on emergency laparotomy population but shows good discrimination consistently in studies done on emergency laparotomy patients, AUROC 0.74 to 0.98.	Uses routinely available clinical data. Twelve variables required. Accessible online and on smartphone app.	Not specifically designed for surgical patients, initially designed for critically ill ICU patients. Does not reflect severity of surgical procedure.
nzRISK	No data for emergency laparotomy, designed for non-cardiac surgery.	Developed and validated for the New Zealand population from data from over 270,000 patients.	Not explicitly studied in emergency laparotomy patients nor Australian patients.

No-Lap

Due to the high-risk nature of an emergency laparotomy, there will be a cohort of patients who will likely not benefit from surgery. These patients are typically higher-risk, elderly and frail and have been termed the "No-Lap" population – defined as patients who do not proceed to emergency laparotomy despite having an indication for it.

The decision not to proceed with surgery may be driven by either the patient, their family, or the treating anaesthetist or surgeon after careful evaluation. The decision not to operate on a patient is extremely difficult, particularly in time-limited emergencies. There must be a careful and thorough assessment of a patient's comorbidities, premorbid functional status, risk of death and, perhaps most importantly, a thorough discussion of their wishes.[40]

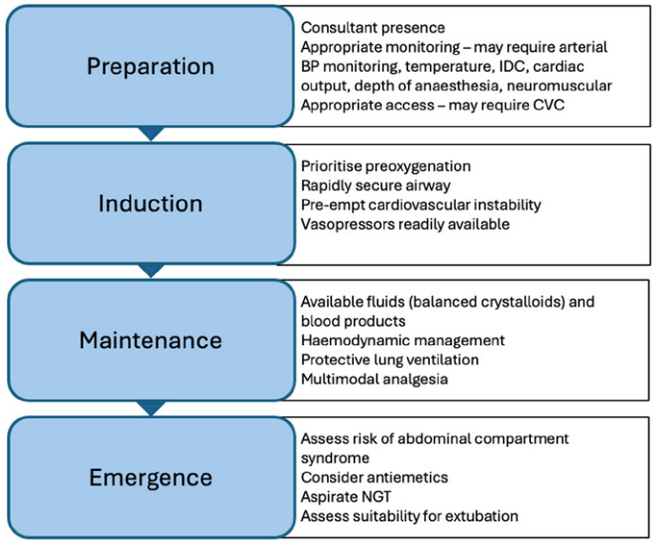
In situations where surgery is not undertaken, a multidisciplinary discussion is critical to ensure that all patient and family wishes and concerns are adequately addressed and that the patient has been thoroughly informed of the risks and benefits of surgery.[41] Involvement of palliative care physicians when appropriate is strongly recommended, as these discussions will inevitably surround end-of-life, comfort measures, and symptom management. A decision not to proceed to emergency laparotomy does not necessarily preclude patients from alternative interventions with palliative intent.

Notably, studies have found that many of these patients who do not proceed to emergency surgery do not die in the hospital and can be discharged to a palliative facility or to their pre-hospital residence, where attention may focus on supporting quality of life rather than life-prolonging therapy.

There is increasing interest in characterising the No-Lap population and its outcomes. Since April 2024, NELA has expanded its audit to include No-Lap patients and has established specific standards, which include documentation of risk assessment, frailty assessment, advance care plans and end-of-life care plans, as well as involvement of palliative care physicians.[42] ANZELA has yet to update its audit to study No-Lap patients separately, and to date, there are only a handful of local studies reporting on No-Lap in Australia,[9,11] highlighting the scope for further characterisation of these patients in Australia and New Zealand.

INTRAOPERATIVE CARE

Figure 1. Summary of intraoperative considerations



Once a decision to proceed with surgery has been made and preoperative optimisation has commenced, attention should turn to intraoperative planning of the emergency laparotomy patient. The presence of both a consultant anaesthetist and surgeon during surgery is recommended for high-risk patients and is a key standard of ANZELA-QI.[3] General anaesthesia is the standard method of anaesthesia provided in emergency laparotomy.[43,44]

Monitoring and venous access

To maximise the chances of haemodynamic stability, patients should be appropriately monitored and have appropriate peripheral and/or central venous access. For high-risk patients, especially those presenting with sepsis, bowel ischaemia and haemorrhage, invasive arterial blood pressure monitoring and large-bore IV access should be established prior to induction.[45] A central venous catheter (CVC) may be required for the infusion of vasopressors and inotropes, and is also helpful for administering electrolytes and postoperative parenteral nutrition.[46] Noradrenaline is the vasopressor of choice for septic patients. This is traditionally administered via a CVC but has been shown to be efficacious through peripheral administration temporarily in time-pressured situations, with a low incidence of adverse events that were predominantly related to drug extravasation.[47] Peripheral adrenaline or dobutamine may be preferred in patients with low cardiac output.[45,48] Insertion of an indwelling urinary catheter allows accurate monitoring of urine output. The Royal College of Anaesthetists in the UK recommends that cardiac output monitoring, such as pulse contour analysis, be readily available during all emergency abdominal surgeries.[41] In general, an 8-10% improvement in a measured parameter, such as stroke volume, is indicative of improvement in haemodynamic performance following a fluid bolus.[49]

Temperature monitoring and management are highly recommended in these patients. Normothermia should be maintained to minimise coagulopathy and altered drug pharmacokinetics.[45]

Induction and maintenance

A key goal of induction is to rapidly secure the airway to minimise the risk of aspiration. Emergency laparotomy patients inherently exhibit several risk factors for aspiration, including patient factors (inadequate fasting time, gastrointestinal obstruction, delayed gastric emptying from opioids and systemic diseases) and surgical factors (pneumoperitoneum).[50] Preoxygenation should be prioritised, and drugs

should be chosen to allow for rapid onset of anaesthesia and neuromuscular blockade, ideal conditions for tracheal intubation, and haemodynamic stability.[45,48] Succinylcholine remains the muscle relaxant of choice for RSI; however, the use of rocuronium 1.2 mg/kg has gained popularity due to the increased availability of sugammadex and lower rates of adverse effects.[48] Cricoid pressure and suctioning the nasogastric tube, if one is present, may be considered to further minimise the risk of aspiration.

Cardiovascular instability is the most common adverse event after intubation.[51] Pre-induction administration of an appropriate crystalloid bolus and early initiation of a vasopressor infusion has been shown to offer some benefit in preventing instability; however, evidence remains limited.[52,53]

Prophylactic antibiotics should be administered as per local therapeutic guidelines. Generally, the choice of empirical antibiotics depends on the indication, whether entry into the bowel is expected, if peritoneal soiling is likely to be present, and if protection against enterococcal endocarditis is required for patients with specific cardiac conditions. For small intestine and colorectal surgery, cefazolin plus metronidazole intravenously may be appropriate.[54] Suggested intraoperative redosing intervals for these agents, assuming normal renal function, are four hours and 12 hours, respectively.[54]

Maintenance of anaesthesia can be through volatile agents or total intravenous anaesthesia and is operator-dependent. Depth of anaesthesia monitoring should be considered in all patients. Ventilation may be challenging due to elevated intra-abdominal pressures, which can lead to increased airway pressures. Furthermore, protective lung ventilation, achieved through PEEP titration and low tidal volumes, is recommended in patients who may have acute respiratory distress syndrome. Lung-protective ventilation has been shown to reduce major pulmonary complications such as pneumonia and respiratory failure.[55]

Communication with the surgeons, recovery staff and intensive care should be maintained at appropriate stages of the case. If there is a significant deterioration in the patient's status whereby ICU support may be required or increased at the end of the case, this should be communicated early.

Fluids and haemodynamic management

Balanced crystalloids are the mainstay of intraoperative fluid therapy and should be adequately given but not in excess.[48] There should be ongoing fluid assessment and implementation of fluid resuscitation to correct hypovolemia. Fluid balance is essential for renal perfusion and prevention of AKI, particularly in patients with sepsis and abdominal pathologies such as bowel obstruction.[56]we included patients undergoing major emergency abdominal surgery at the Department of Surgery, Zealand University Hospital, Denmark, from 2010 to 2016. The primary outcome was the occurrence of AKI within postoperative day seven (POD7 Goal-directed haemodynamic therapy (GDHT), which utilises cardiac output monitoring to guide fluid and vasopressor administration, is not yet routinely recommended over conventional fluid administration despite being advocated by the Emergency Laparotomy Collective.[48] Maintaining a MAP of 60-65 mmHg and a cardiac index of greater than 2.2 L/min/m^2 is recommended as part of GDHT. Other measures that can guide fluid therapy include serial lactate levels and base excess.[29,48,57] In addition to fluids, blood products should be readily available to address coagulopathies, anaemia (Hb < 70 g/L) or thrombocytopenia. Tranexamic acid is a useful adjunct in cases of excessive bleeding.[48]

Intraoperative analgesia

Opioids are generally the first-line intravenous agents in the emergency laparotomy patient; however, they are associated with postoperative complications such as delirium, respiratory depression and gastrointestinal ileus.[57] Opioid use may be minimised with regional techniques, including transversus abdominis plane (TAP) blocks, rectus sheath blocks, and thoracic epidurals, which have shown reduced incidence of ileus.[48] However, neuraxial strategies may be relatively contraindicated in patients with sepsis, hypovolaemia or coagulopathy.

Other opioid sparing strategies include the intraoperative use of paracetamol, intravenous lignocaine, ketamine and magnesium.[48] Non-steroidal anti-inflammatory drugs (NSAIDs) should be avoided in elderly patients and those with hypovolaemia or reduced renal function. There has been controversy surrounding NSAID use in patients with intestinal anastomosis due to a proposed increased risk of anastomotic leak;[58] however, a 2020 systematic review in colorectal cancer surgery has shown no relationship.[50]

Emergence

At the time of closure, the risk of abdominal compartment syndrome should be assessed. High ventilatory pressures (>30 cmH_20) with hypoxia are concerning for abdominal compartment syndrome and should be discussed with the surgeon and intensivists postoperatively, as laparostomy may be required.[33]

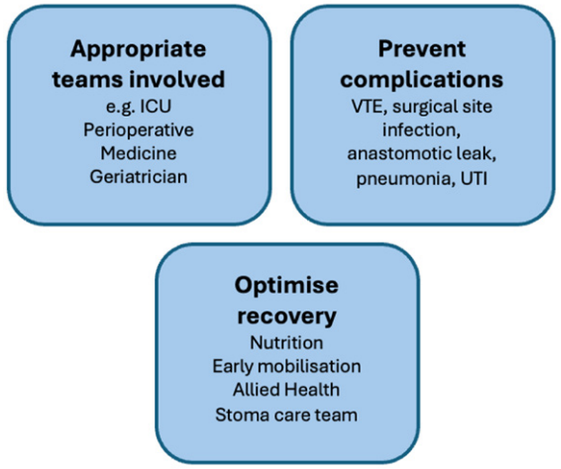
Antiemetics should be administered based on risk in patients who are planned to be extubated at the end of the case. Fluid status and vasopressor requirement should be assessed, and an appropriate postoperative plan should be made.

At the end of the procedure, not all patients will be suitable for tracheal extubation, as some may require a period of ongoing intubation and postoperative ventilation in the ICU. Factors influencing suitability for extubation include intraoperative oxygen and vasopressor requirements, acid-base status, temperature, and coexisting pulmonary complications such as atelectasis, pneumonia or effusion.[48,51] Extubation for emergency laparotomy patients carries a higher risk of pulmonary aspiration. Efforts to mitigate this risk include aspiration of any indwelling nasogastric tubes, suctioning of the pharynx and extubation when the patient is awake with the return of protective airway reflexes.[48]

There should be a strong consideration for neuromuscular monitoring both during the operation to optimise surgical conditions, and to facilitate optimal extubation considerations. Elderly patients have an increased risk of residual neuromuscular blockade after reversal due to age-related pharmacokinetic changes, associated with increased postoperative pulmonary complications and airway obstruction.[46,59]

POSTOPERATIVE CARE

Figure 2. Summary of postoperative considerations



The immediate postoperative assessment should focus on identifying signs of organ dysfunction.[45] High-risk patients are at risk of reintubation and postoperative pulmonary complications for several days following surgery. They are likely to require monitoring and management of acidosis, hypothermia, fluid shifts and vasopressors.[46]

ICU involvement

There should be strong consideration of ICU/HDU in high-risk patients, especially elderly patients and those with high frailty scores. Direct admission to the ICU/HDU for patients with an estimated risk of death exceeding 10% is an ANZELA standard of care, whereas NELA uses a lower cut-off of ≥ 5% for its standard of care for ICU admission, reinforcing the importance of preoperative risk assessment.[6,10] If an ICU/HDU bed is unavailable, it is recommended that high-risk patients be kept in recovery for a period of ongoing observation.[33] Patients with an open abdomen or awaiting a planned relook operation may be best managed sedated and ventilated in the ICU.[49]

Physician involvement

Postoperative review by a perioperative physician is recommended for patients at high risk. Specialist geriatrician involvement, in particular, is recommended for elderly and frail patients and has proven to reduce morbidity, mortality, and length of stay.[35,36] Further research is needed to determine the outcome improvements that perioperative physician involvement provides post an emergency laparotomy.

Postoperative analgesia

Poorly managed pain after laparotomy is strongly associated with postoperative complications, prolonged length of stay and mortality.[48,57] Pain after laparotomy may be visceral pain from stretch and inflammation of the peritoneum, which resolves more rapidly, and somatic pain from surgical incision. Management of this somatic pain, allowing the patient to breathe deeply, cough, and mobilise, should be the goal of analgesia.[48]

In addition to opioid sparing intraoperative strategies mentioned above, multimodal analgesia is the recommended approach to post emergency laparotomy pain management.[58] Gabapentinoids are not routinely recommended due to conflicting evidence in the literature.[58] Early involvement of an acute pain service (APS) is recommended. Use of patient-controlled analgesia (PCA) has been associated with reduced postoperative complications and length of stay in hospital for emergency laparotomy patients.[60]

Preventing postoperative complications

Other postoperative considerations include VTE risk assessment and prophylaxis, early recognition and treatment of postoperative complications, including surgical site infections, anastomotic leak, pneumonia and urinary tract infection.[7,45] Hyperglycaemia and electrolyte derangement should be avoided. Involvement of a stoma care team has been shown to reduce stoma-related complications, which are markedly higher in emergency surgeries as compared to their elective counterparts.[51]

There is great importance in optimising nutrition, as sepsis and the surgical stress response are hypercatabolic states.[48] There should be regular assessment of nutritional status and early commencement of parenteral nutrition in patients who are unable to meet their nutritional requirements enterally.[58]

Early mobilisation with physiotherapists or nursing staff is a core principle of the ERAS protocols. It is associated with decreased pulmonary complications, reduced loss of skeletal muscle strength, fewer thromboembolic complications, and a lower likelihood of insulin resistance.[26,40]

The development of a postoperative bundle of care has been proposed as a possible method of further reducing morbidity and mortality by simplifying and standardising expected management in the postoperative period.[58]

DISCHARGE AND FOLLOW-UP

It is estimated that more than 30% of patients who undergo emergency laparotomy are not discharged to their pre-hospital residence.[61] Routine follow-up provides an opportunity to ensure that patients are recovering well and to update morbidity and mortality data, which is invaluable when assessing long-term outcomes of surgery.

CONCLUSION

Significant progress has been made in the care and understanding of emergency laparotomy patients both in Australasia and abroad. Patient outcomes have markedly improved since the introduction of national audits, such as NELA and ANZELA-QI, through the development of key standards of care and the measurement of adherence to these.[63]

In Australia and New Zealand, there appears to be ongoing under-reporting of risk assessment, which is an underutilised and undervalued component of the preoperative assessment. There also appears to be a need for greater standardisation of care through the development of validated and nationally adopted preoperative and postoperative care bundles. We await the release of the next ANZELA report to see if outcomes have improved for emergency laparotomy patients in Australia and New Zealand since 2021. In the meantime, ongoing quality improvement through compliance with care standards and multidisciplinary optimisation of care remains as important as ever in improving the outcomes of these high-risk surgical patients.

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Post-craniotomy pain: Analgesia and scalp blocks

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INTRODUCTION

There is a historical and widespread belief that patients have minimal pain post-craniotomy.[1–4] However, studies show that post-craniotomy analgesia is frequently suboptimal, with pain often not assessed and, therefore, inadequate analgesia achieved in 30-60% of patients.[2–5] This is due to the common belief that craniotomy surgery is not painful, the reluctance of healthcare providers to use opioid analgesia secondary to concerns that any associated sedation may impede neurologic assessment, and concerns over respiratory depression and hypercarbia leading to raised intracranial pressure.[4] Moreover, altered neurological status after craniotomy can hinder appropriate pain assessment.[6] In fact, when assessed, patients often have significant acute post-craniotomy pain, with up to two-thirds of patients reporting moderate to severe pain and 10-25% reporting severe pain postoperatively.[2–5]

Besides patient discomfort, uncontrolled post-craniotomy pain can increase the risk of acute complications such as hypertension, agitation and vomiting, delayed recovery, increased length of hospital stay, increased mortality, and healthcare costs.[2,5,7] Some of these symptoms can be particularly deleterious in neurosurgical patients as they can mimic, obscure, and increase the risk of neurosurgical complications, like raised intracranial pressure and intracranial haemorrhage.[1–3]

PATHOPHYSIOLOGY

Post-craniotomy pain is often described as superficial and commonly presents as a generalised headache with pounding or pulsating qualities and is most significant in the first 48 hours post-surgery.[8] It is thought to arise from the dissection of the richly innervated scalp, pericranial muscles, surrounding soft tissues and dura mater. The brain tissue itself does not contribute significantly to postoperative pain. Suboccipital, retrosigmoid, and subtemporal operative approaches are associated with a greater frequency and severity of pain, likely related to the associated surgical dissection and reflection of major muscle tissues like the temporalis, splenium capitis and splenius cervicis muscles.[5,6,9]

CHRONIC POST-CRANIOTOMY PAIN

There is a 7-30% risk of chronic post-craniotomy headache, with 25% of these patients having severe pain.[2,4] Chronic post-craniotomy headache is debilitating and difficult to treat, can significantly impair quality of life and social functioning, and impede return to employment.[2,4] A consistent predictor for the development of *chronic* postsurgical pain is the severity and duration of *acute* postoperative pain.[4] Chronic headaches are common post-head injury, and patients having surgery for primary head injury are at higher risk for the development of chronic post-traumatic headaches.[6] Although there is limited data on the efficacy of interventions to prevent chronic post-craniotomy headache, evidence supports that severity and duration of acute postoperative headache may play a role in central sensitisation and that interventions aimed at reducing acute pain may be beneficial in reducing the risk of chronic post-craniotomy headache.[2,3]

Mitigating acute post-craniotomy pain may help diminish the possibility of chronic post-craniotomy pain, as demonstrated in studies showing that scalp infiltration with ropivacaine reduced the incidence of both persistent and neuropathic pain two months post-craniotomy.[7,10] Further studies on locoregional techniques and prevention of chronic post-craniotomy pain are still required. However, evidence from wider surgical populations suggests locoregional techniques may play an essential role in achieving effective analgesia, compared to conventional systemic treatments, in reducing the incidence of chronic postoperative pain.[2]

Risk factors for severe acute post-craniotomy pain

Patient factors that are independent predictors of more severe postoperative pain include younger age, female gender, level of preoperative pain, anxiety, and depression.[7] Specific to post-craniotomy pain, younger age and level of preoperative pain were associated with more significant postoperative pain; however, there is limited and conflicting evidence to demonstrate an association with gender and greater postoperative pain.[8] With regard to surgical risk factors, the amount of postoperative pain may be related to the extent of peri-cranial muscle dissection and reflection in the operative approach. Additionally, infratentorial procedures have been shown to have more pain than supratentorial approaches, with subtemporal and suboccipital routes yielding the highest incidence of postoperative pain.[8,11] Conversely, frontal craniotomy is associated with lower pain scores and opioid consumption.[5–7,9]

Risk factors for chronic post-craniotomy pain

Chronic pain following craniotomy is more common in patients with pre-existing pain, psychological vulnerability (e.g. catastrophising), anxiety, female gender, younger adults, worker's compensation-related claims, and opioid requirements. Severity and incidence are greater after infratentorial procedures compared to supratentorial procedures.[4,7]

POST-CRANIOTOMY ANALGESIA

The traditional approach to post-craniotomy analgesia via the use of low-dose opioids is often inadequate and can have side effects that are concerning in this patient population. Multimodal opioid-sparing approaches have proven beneficial in terms of better pain relief, less opioid administered, and subsequently fewer opioid-related side effects.[2,12] Opioid-sparing multimodal analgesia is increasingly important for enhanced recovery after surgery (ERAS) for craniotomy and is associated with benefits in postoperative analgesia, length of hospital stay and cost reduction in patients undergoing craniotomy.[13,14]

Pre-emptive analgesia is important to consider as it may ameliorate the mechanisms involved in developing both acute and chronic postoperative pain. Pre-emptive analgesia is particularly beneficial in neurosurgery, as the nature of the surgery may impede the patient's initial ability to report pain and thus achieve adequate postoperative analgesia. The need for accurate postoperative neurological assessment is often a factor credited with decisions to limit postoperative analgesic options.

The PROSPECT (Procedure Specific Postoperative Pain Management) Working Group of the European Society of Regional Anaesthesia and Pain Therapy (ESRA) recommend a multimodal analgesic regimen for craniotomy which consists of paracetamol, nonsteroidal anti-inflammatory drugs (NSAIDs), intravenous dexmedetomidine infusion and a regional analgesic technique, with opioids reserved as rescue analgesia.[5]

The following is a compendium of common analgesic modalities that are considered in targeting post-craniotomy pain.

Paracetamol

Paracetamol provides modest pain relief, is superior to placebo for reducing postoperative pain scores but not opioid consumption, and is recommended preoperatively and postoperatively.[5,12,15] However, paracetamol alone is ineffective as an adequate analgesic regimen.[2,4]

Nonsteroidal anti-inflammatory drugs (NSAIDs)

There is high-quality evidence that NSAIDs reduce pain up to 24 hours postoperatively.[2,5] They also reduce opioid requirements and postoperative nausea and vomiting.[2,5] NSAIDs are superior to placebo and paracetamol for analgesia and reducing opioid requirements. However, there has been a reluctance to include them in a craniotomy analgesic regimen due to a single-centre retrospective cohort study that identified an association between the development of postoperative haematoma and the use of aspirin or non-selective NSAIDs.[4] A systematic review and meta-analysis found that NSAIDs provided satisfactory analgesia and were not associated with clinically meaningful bleeding, with results being consistent across various types of NSAIDs and surgical procedures.[16]

Parecoxib has shown benefits in improving the level of sedation and analgesia, but no opioid-sparing effect.[17,18] Another study using rofecoxib (withdrawn from the market in 2004) demonstrated better analgesia, reduced opioid adverse effects, earlier mobilisation, reduced length of stay and reduced total hospitalisation costs.[19]

While postoperative administration of NSAIDs may still be considered controversial, there are reasonable studies showing no adverse effect of postoperative administration.[5,7,20,21] There are protocols at some centres that choose to administer them selectively, such as in uncomplicated cases with no coagulopathy or waiting 6-24 hours postoperatively. The PROSPECT guidelines recommend paracetamol and NSAIDs as basic analgesia after craniotomy.[5]

Opioids

Opioids form a mainstay in the management of moderate to severe pain in craniotomy despite concerns surrounding adverse effects of respiratory depression, sedation, hypercarbia, and raised intracranial pressure.[6] They are associated with increased rates of postoperative nausea and vomiting after craniotomy.[20] The PROSPECT guidelines have, therefore, recommended that opioids be reserved as rescue analgesia for severe pain in the postoperative period.[5]

Codeine

Codeine was historically and is still widely used. However, it has been shown to be inadequate in the management of post-craniotomy pain. It should be considered less effective or predictable than morphine and other opioids due to genetic variability in metabolism and has a risk of potential respiratory depression and sedation.[7]

Tramadol

Tramadol has less potential for respiratory depression and dependence compared to other opioids. However, it has a greater risk of nausea and vomiting and a rare incidence of seizures. Although it has been used successfully in craniotomies, its analgesic efficacy is inferior to morphine, and its side effects limit its use.[7,22] When added to a multimodal regime of paracetamol and other opioids rather than as a sole agent, tramadol may reduce pain scores, opioid requirements,[5] hospitalisation costs, and length of stay while also leading to earlier mobilisation.[22,23]

Alpha-2 agonists

Intraoperative dexmedetomidine provides superior analgesia compared to placebo and reduces postoperative opioid requirements for up to 12 hours, with the added benefit of reduced emergence tachycardia and hypertension.[2,5] There is conflicting evidence on the risk of delayed recovery and emergence, with 1 RCT supporting delayed emergence and sedation,[24] 1 RCT reporting lower postoperative Ramsay sedation scores[25] and 2 RCTs reporting no significant differences in emergence time or postoperative sedation.[26,27] There is inconclusive evidence on the effects on postoperative nausea and vomiting (PONV).[2,4,5,12,25–27] Clonidine has not been shown to significantly improve analgesia after supratentorial craniotomy.[4] The PROSPECT guidelines recommend the use of dexmedetomidine for analgesia after craniotomy with the caveat that it may cause delayed recovery and emergence.[5] If an intraoperative dexmedetomidine infusion is used, one must consider discontinuing it early enough to avoid delayed emergence.

Ketamine

Ketamine has inconsistent effects on cerebral physiology, with some studies showing increases in cerebral blood flow, metabolic rate, and intracranial pressure, while others report no change or a decrease in these parameters, especially when administered with other anaesthetics. It may also cause hallucinations that may confound neurological assessment and, therefore, should be used with caution in craniotomy surgery and in patients with raised intracranial pressure.[7,22]

Pregabalin and gabapentin

Both pregabalin and gabapentin improve early pain scores at 6-12 hours and reduce the incidence of nausea and vomiting.[2] Pregabalin demonstrates opioid-sparing effects while gabapentin does not.[5] However, their use is also associated with increased sedation and delayed extubation.[4,28]

Steroids

The use of preoperative steroids is associated with reduced post-craniotomy pain, likely due to an anti-inflammatory effect.[8,29]

Local infiltration

Local anaesthetic infiltration provides early analgesia post-craniotomy. It reduces opioid requirements, with preoperative infiltration improving pain scores for up to 8 hours postoperatively and postprocedural infiltration improving pain scores for up to 12 hours postoperatively.[2] Scalp blocks and local infiltration are also technically easier and more tolerable for the patient when performed after induction, under general anaesthesia.

Non-pharmacological

Non-pharmacological analgesic strategies include the application of heat and cold, massage therapy, aromatherapy, guided imagery, music therapy, and hypnosis. Music therapy, with patient-preferred music, has been shown to decrease stress and anxiety, but not analgesic requirements post-craniotomy.[7] Discomfort may also be related to the tightness of circumferential headdressings.[7] Transcutaneous electrical acupuncture stimulation may improve analgesia and reduce opioid requirements; however, studies are of poor quality with a high risk of bias.[4] Cold packs improve analgesia, eyelid oedema, and facial ecchymosis post-craniotomy.[4] Cold therapy has been shown to reduce pain 3 days post-craniotomy rather than in the immediate postoperative period.[22] Acupuncture has shown an analgesic effect, with one study demonstrating an opioid-sparing effect.[5] However none of these studies included the use of basic analgesics, and the use of acupuncture may be impractical and carry a risk of infection.

BENEFITS OF SCALP BLOCKS FOR CRANIOTOMY ANALGESIA

Haemodynamic stability

Skull pinning is a brief, sudden, painful stimulus comparable to an incision or laryngoscopy, often inducing hypertension and tachycardia. This can increase cerebral blood flow and intracranial pressure, especially in patients with impaired cerebral autoregulation where small increases in systemic blood pressure can cause larger changes in cerebral blood flow and intracranial pressure.[30] Alternative medications to attenuate the haemodynamic response (like opioids, propofol, and antihypertensives) can lead to inadvertent periods of hypotension after the stimulus is over.

The use of a scalp block prior to skull pinning improves haemodynamic stability from incision to dural opening.[31] Compared to placebo, patients who receive scalp blocks have lower intraoperative heart rates and mean arterial pressure.[32] It is superior to local infiltration and opioids for haemodynamic stability during pining and incision, with some studies showing no haemodynamic change with pinning.[30,31,33] Additionally, scalp blocks reduce the requirements for postoperative antihypertensive agents.[4]

Post-craniotomy pain

Scalp blocks are recommended by the PROSPECT Working Group of ESRA as part of an optimal multimodal pain management regimen after craniotomy.[5] A systematic review and meta-analysis concluded that scalp blocks with ropivacaine were likely the most efficacious method for pain control and reduction of opioid consumption and suggested scalp blocks should be included in craniotomy ERAS protocols due to this.[13] Scalp blocks have been demonstrated to reduce post-craniotomy pain for up to 48 hours, with the greatest effect in the first 12 hours, and decrease opioid and additional analgesia requirements.[2,3,5,13,28,33] They lower pain scores in both adult and paediatric patients and reduce additional analgesia requirements and time to first analgesic request.[2,5,13,32,34,35]

Reduced opioid requirement and adverse effects

Scalp blocks reduce opioid requirements within the first 24 hours after surgery when compared with placebo.[1,3,5,13,32,36,37] PONV is also reduced when scalp blocks are used.[2,5,35] To date, no studies address sedation as an outcome, although this potential could be extrapolated secondary to reduced opioid requirement.

Chronic post-craniotomy pain

There is some evidence that the incidence of chronic pain is lower with scalp blocks, with one study demonstrating less persistent pain at 2 months postoperatively after scalp infiltration with ropivacaine.[10] Another study demonstrated reduced pain at 14 days post surgery with pre-emptive scalp blocks.[38] Patients also had a lower likelihood of neuropathic symptoms if scalp blocks were used when compared with placebo.[10,31]

Compared to local infiltration

Infiltration of local anaesthetic at the surgical site doesn't block nociception to deeper tissues, such as temporalis muscles, which are often divided and reflected as part of a myocutaneous flap. Scalp blocks, on the other hand, target both superficial and deep tissue layers.[3] Scalp blocks are superior to infiltration for haemodynamic stability during pins and incision,[3] yielding improved pain scores and reduced opioid consumption.[5,13,28,37] In addition the efficacy and duration action for local infiltration was variable especially when compared with scalp blocks, which are longer lasting, thus providing superior analgesia.[5,13,39]

Adjuvants added to the local anaesthetic mixture

One RCT showed that the addition of dexamethasone to the local anaesthetic mixture prolonged its analgesic effect.[40] Intravenous dexamethasone is often administered during craniotomy to reduce tumour-associated oedema and for antiemesis, and can reduce postoperative pain and opioid consumption.[41–44] However, given that the effect of analgesic prolongation with dexamethasone is similar whether or not it is given perineurally or systemically, we recommend dexamethasone be administered systemically, especially if access to preservative-free dexamethasone is limited.

The addition of adrenaline to the local anaesthetic solution did not reduce postoperative 24-hour pain scores.[13]

The addition of dexmedetomidine to the local anaesthetic mixture improved the analgesic effect of both local infiltration and scalp block, with a greater effect when added to scalp blocks over local infiltration.[45] However, this study also showed there was a degree of systemic absorption of dexmedetomidine, resulting in slightly higher postoperative Ramsay sedation scores. As there is minimal evidence for benefit, the addition of adjuvants to local anaesthetic mixtures is not recommended.[5]

ANATOMY

The scalp is innervated by the trigeminal nerve anteriorly (supraorbital, supratrochlear, zygomaticotemporal, auriculotemporal), and cervical nerve roots C2 and 3 posteriorly (lesser and greater occipital) (see Figure 1).[37]

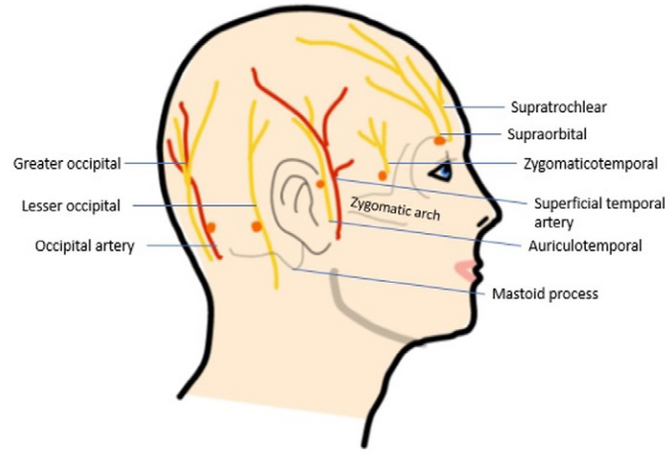


Figure 1. Scalp block nerves and injection sites (orange dots)

TECHNIQUE FOR SCALP BLOCKS

Landmark techniques are time efficient and allow for judicious use of local anaesthetic compared to a haphazard field or ring block. In practice, scalp blocks can be easily performed with the patient supine, post-intubation, during the additional routine preparations taking place prior to shaving and establishing the surgical site. Local anaesthetic concentration of at least 0.5% has the most consistent benefit.[31] Some of the anatomical landmarks are assisted by visualising the closed or open eye. As such, ensure any taping of the eyes (if the blocks are conducted after induction of general anaesthesia) does not interfere with needle insertion or distort the orbital/periorbital anatomy. Key considerations for each block are summarised in Table 1.

Supraorbital nerve block

Palpate the supraorbital notch, which usually lies at the medial one-third of the supraorbital ridge or at the medial edge of the iris. Insert the needle perpendicularly to the skin, 0.5cm above the supraorbital rim, till bone is contacted. Injection of 0.5ml of local anaesthetic is sufficient to block the nerve. Maintain the needle under the skin at the conclusion of the block, which can be redirected for the supratrochlear nerve block.

Supratrochlear nerve block

Positioning for this block is the same as for the supraorbital block. As such, it is ergonomically efficient to perform this block after the supraorbital block. The supratrochlear nerve runs parallel and roughly 1cm medial to the supraorbital nerve. Using the same puncture site as the supraorbital nerve block, redirect the needle medially under the skin by about 1cm and inject 0.5ml of local anaesthetic.

Zygomaticotemporal nerve block

Approaching the patient's head from its profile, identify the corner between the lateral orbital rim and zygomatic arch at the level of the lateral canthus of the eye. Insert the needle to contact bone (temporal surface of the greater wing of the sphenoid bone), withdraw slightly, and inject 2ml of local anaesthetic below the temporalis fascia. This nerve branches extensively as it pierces the temporalis fascia, so superficial and deep injections are required, which involves withdrawing the needle for a second injection of 2ml, above the fascia. Even then, blockade is sometimes incomplete and may require surgical supplementation in awake craniotomy.[1,30,31]

Auriculotemporal nerve block

This nerve is traditionally blocked with an injection near the superficial temporal artery at the tragus. However, there is a risk of also blocking the facial nerve adjacent to it. To decrease the risk of inadvertent transient facial nerve palsy, inject posterior to the superficial temporal artery, 1cm cephalad to the tragus, and limit the injectate volume to 2ml below the temporalis fascia and 1ml superficial to fascia as the needle is withdrawn.

If a facial nerve palsy is detected postoperatively, the presence of *forehead sparing* can differentiate peripheral and central nerve palsy. Forehead sparing is a sign of central palsy, whereas forehead paresis is a sign of peripheral or inadvertent facial nerve block. Central facial palsy is often associated with other focal deficits like tongue or upper limb paresis, while peripheral facial nerve palsy is usually isolated.

Greater and lesser occipital nerve block

These nerves are located by dividing an imaginary line between the occipital protuberance and mastoid process into thirds. The lesser occipital nerve is often situated at the point of the lateral third, while the greater occipital nerve sits at the point of the medial third (or adjacent to the occipital artery). It is ergonomically easier in a supine patient to turn the head and infiltrate along the superior nuchal line between the occipital protuberance and mastoid process. As this block is done by linear infiltration, it often requires 2-3ml on each side.

Table 1. Summary of scalp block nerves, technique, and considerations

Nerve	Location	LA vol	Special considerations
Supraorbital	Supraorbital notch 0.5cm from upper margin of supraorbital rim, 3cm from midline	0.5-1ml	Caution to prevent orbital injury
Supratrochlear	1cm medial to supraorbital or 1.5cm from midline below upper margin of supraorbital rim	0.5-1ml	Caution to prevent orbital injury
Auriculotemporal	1cm superior to tragus, posterior to superficial temporal artery	1-2ml below temporalis fascia, 1ml superficial to fascia	Superior to tragus, low vol to prevent inadvertent facial nerve palsy
Zygomaticotemporal	Corner between lateral orbital rim and zygomatic arch near lateral canthus of eye	2ml below temporalis fascia, 2ml above temporalis fascia	Frequently incomplete and challenging block due to extensive and early nerve branching
Lesser occipital	Lateral 1/3 distance along nuchal ridge between occipital protuberance and mastoid process, or 2.5cm lateral to greater occipital	2-3ml	Consider superficial wheal along nuchal ridge for both occipital nerves
Greater occipital	Half to medial 1/3 distance along nuchal ridge between occipital protuberance and mastoid process, or inject just medial to occipital artery	2-3ml	Caution injury to occipital artery Consider superficial wheal along nuchal ridge for both occipital nerves

Practical tips

Coordinate the timing and extent of the block with the surgical team. Anaesthetists should consider the site of surgery and the use and positioning of pins, as not all nerves may need to be blocked in an asleep craniotomy, especially if not using pins. Scalp blocks are most useful in craniotomies where muscle, like the temporalis, is manipulated or cut for surgery in the temporal or parietal area and for cranioplasties.

Consider performing the block preoperatively, especially if the bone flap is not being replaced, due to the risk of accidental intracranial injection. In an asleep craniotomy, scalp blocks can be performed post-intubation and before surgical incision so as not to cause a delay. It is important to limit the volume of local anaesthetic injected, to not excessively distort facial anatomy, as this may interfere with surgical stealth navigation. The application of some gentle pressure on injection sites with gauze helps to reduce bleeding from injection sites and reduce the extent of swelling from the local anaesthetic injection. Performing scalp blocks in asleep craniotomies increases the volume of practice for these blocks, increasing familiarity with the technique, which is beneficial for awake craniotomies, where block success is important.

Complications

Complications from scalp blocks are rare.[3] Potential complications include inadvertent transient facial nerve palsy, local anaesthetic toxicity, haematoma, infection, and allergic reactions. The auriculotemporal nerve block can cause transient facial nerve palsy, which is self-limiting and should resolve as the block wears off. Scalp nerves are superficial terminal sensory branches, so the risk of permanent nerve damage is low.[31] The scalp is vascular, so systemic absorption is quick, and peak plasma concentrations occur in 16 minutes following local anaesthetic injection.[31] There are no published reports of proven local anaesthetic systemic toxicity from scalp block despite some doses in studies being above the recommended total local dose. It is advisable, however, to use ropivacaine due to its better safety profile compared to bupivacaine.[31] Caution should be exercised in skull defects, where bone has not been replaced, to avoid inadvertent subarachnoid injection.

ULTRASOUND GUIDED GREATER OCCIPITAL NERVE BLOCK AT C2

Greater occipital nerve blocks are beneficial for the treatment of refractory migraines, occipital neuralgia, cervicogenic headache, cluster headache, and post-dural puncture headaches.[46] These blocks have also been shown to provide a benefit in posterior fossa operations. Compared to standard care with systemic medication, they provide superior quality and duration of analgesia and a better haemodynamic profile for posterior fossa surgery.[47]

Infratentorial surgical approaches are associated with a higher risk of severe pain and a greater incidence of severe chronic post-craniotomy pain compared to supratentorial procedures.[7,9]

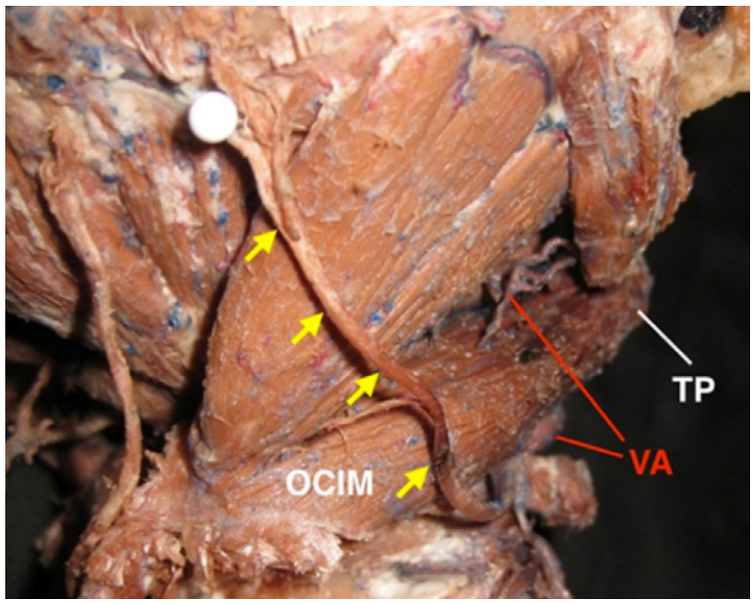
A randomised controlled trial comparing ultrasound-guided greater occipital block versus control in children undergoing elective posterior fossa craniotomy showed a clinical improvement in pain scores, significantly longer time (13.4 hours compared with 1.8 hours) to first analgesic request, reduced opioid consumption, and lower systolic blood pressure intraoperatively and postoperatively, with no block related complications.[47]

Complications of greater occipital nerve blocks are rare, especially if ultrasound-guided. Only one complication has been reported, involving inadvertent subarachnoid injection in a patient with previous posterior fossa surgery. The injection was not ultrasound-guided and resulted in a coma, but the patient made a full recovery shortly afterwards.[48]

Anatomy

The greater occipital nerve is a sensory branch of the C2 spinal nerve and, together with the lesser occipital nerve, innervates the sensation of the occipital region up to the vertex.[46] The greater occipital nerve leaves C2 posterior to the lateral atlantoaxial joint and travels laterally to emerge at the inferior border of the obliquus capitis inferior muscle (OCIM) (see Figure 2a). The nerve then ascends while sandwiched between the OCIM and the semispinalis capitis muscle (SsCM), pierces SsCM and terminates as a superficial nerve, where it lies adjacent to the occipital artery, usually medial (see Figure 2b). There is high variability (1.5-7.5cm) of its position when it becomes superficial along the line between the mastoid process and external occipital protuberance. Because of its variability and branching at this superficial location, successful landmark techniques requiring higher volumes and ultrasound identification at this location are more difficult. The nerve position is most consistent at the OCIM, which is, therefore, an important muscular landmark.[46] The OCIM connects the spinous process of C2/axis medially to the transverse process of C1/atlas laterally.

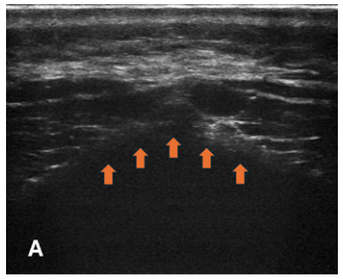
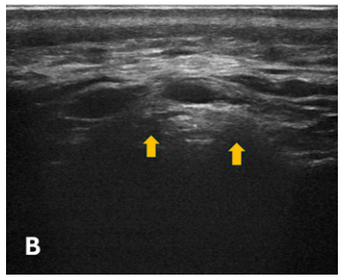
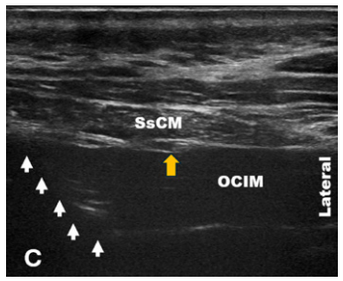
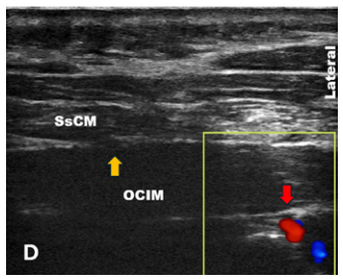
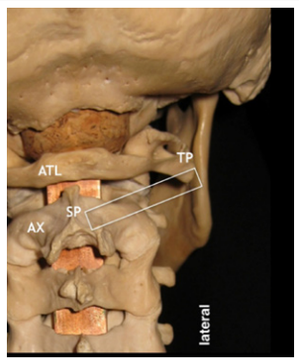
Figure 2. The greater occipital nerve shown on the posterior surface of OCIM (yellow arrows). The vertebral artery (VA in red) is located anterior and deep to the OCIM close to its attachment at the transverse process of C1/atlas (TP in white). (Reproduced with permission from USRA.ca)[49]



Ultrasound technique and practical tips

This can be performed prone, sitting, or in the lateral decubitus position. In posterior fossa surgery, it is easily performed after induction, with the patient in the prone position, after the hair has been removed for surgical exposure. A high-frequency linear transducer is used along with a 50mm echogenic needle and 3-5ml of long-acting local anaesthetic, such as ropivacaine 0.5% per side (see Figure 3).

Figure 3. Ultrasound scanning technique.[49]

	A: The probe is initially placed midline on the occiput and moved inferiorly where the surface of the posterior arch of C1/atlas (orange arrows) is seen. Note that it has no spinous process.
	B: moving the transducer caudally visualises the bifid C2/axis spinous process (orange arrows), which is an important osseous landmark to locate OCIM.
	C: translating the transducer laterally visualises the OCIM and SsCM. The best images are obtained if the transducer is rotated obliquely such that its lateral end is shifted superiorly towards the transverse process of C1, and tilted slightly cephalad to enhance visualisation of fascia and the nerve. The OCIM is typically hypoechoic relative to the overlying SsCM and sandwiches the greater occipital nerve (orange arrow). The lamina of C2 is visible deep to OCIM (white arrows).
	D: the vertebral artery (red arrow with colour doppler) can be seen laterally, near the transverse process of C1/atlas and deep to OCIM when the probe is moved laterally. Note that the greater occipital nerve (orange arrow) is a safe distance from the artery.
 Reproduced with permission from USRA.ca	Final position of the transducer: rotated obliquely between the spinous process of C2 and the transverse process of C1. ATL: atlas AX: axis SP: spinous process of C2/axis TP: transverse process of C1/atlas White rectangle: outline of transducer position

Analgesia and enhanced recovery for craniotomy

Enhanced recovery protocols include interventions to optimise patients for surgery. Preoperatively this can include education, risk assessment, and medication management. Intraoperative measures include minimally invasive surgical approaches, selection of anaesthesia, and multimodal analgesia techniques. Postoperative measures include pain service consultation, where required, rehabilitation and return to normal diet and activity. Pain assessment and effective analgesia are key.[7]

Preoperatively, identification of high-risk patients may improve pain management by establishing multidisciplinary communication about pain expectations and outcomes, referral for pain consultation, or psychological cognitive intervention.[7] Patients are concerned about pain and value education and communication about the perioperative journey, thus education material about expected pain and its multimodal management may improve their experience. This is a recommended component of enhanced recovery for oncological craniotomy.[7]

Postoperatively, the goal should be to provide consistent pain assessment, analgesia, side effect attenuation, minimisation of breakthrough pain, and early initiation of oral medications.[7] Adequate multimodal therapies improve analgesia while minimising opioid adverse effects and may allow earlier mobilisation, decreased length of stay, and decreased hospitalisation costs.[19] Scalp blocks have been recommended in some systematic reviews as part of a multimodal analgesic regimen for enhanced recovery after craniotomy.[14]

CONCLUSION

Significant post-craniotomy pain is common, and analgesia is often suboptimal secondary to concerns of confounding neurological assessments. A multimodal analgesic approach throughout the perioperative period reduces opioid requirements and opioid-related adverse effects, improves patient experience, and facilitates earlier mobilisation and return to normal function. Mitigation of severe acute post-craniotomy pain may reduce progression to chronic post-craniotomy headache.

Scalp blocks are recommended by the PROSPECT Working Group of the European Society of Regional Anaesthesia and Pain Therapy (ESRA) as part of an optimal multimodal pain management regimen after craniotomy.[5] Scalp blocks improve haemodynamic stability during pining, incision, and closure and are superior to local infiltration or isolated treatment with opioids. They significantly reduce opioid requirements and are thus a good opioid-sparing analgesic option to consider implementing more frequently. Scalp blocks are simple to perform with minimal risk of adverse outcomes.

Ultrasound-guided greater occipital nerve blocks at the level of C2 may be beneficial for infratentorial procedures, which are often more painful. It is important to assess and consider patient and surgical factors when formulating an individualised perioperative analgesic approach to facilitate improved post-craniotomy recovery.

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Opioid and related health consequences in East Asian communities with high population density: An empirical case of Hong Kong

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INTRODUCTION

The use of opioids has a global impact on health risk. In 2019, a review found that the prevalence of prescription opioids has been rising globally.[1] According to a 2022 longitudinal study, sales of opioid analgesics increased from 2015 to 2019.[2] They went from 27.52 milligrams of morphine equivalent per 1000 people per day (MME per 1000/day) in 2015 to 29.51 MME per 1000/day in 2019. Despite lower sales in North America and Oceania, this longitudinal analysis indicated increases in opioid analgesic sales in South America, Eastern Europe, Asia, and Western/Central Europe. These increases were influenced by country-level Human Development Index and cancer death rates.

On the extreme end of the spectrum, some countries are experiencing a serious epidemic of opioid misuse with numerous fatal cases (e.g. the United States and Canada).[3-5] The COVID-19 pandemic also altered the pattern of opioid use and its associated health impacts. It significantly increased overdose mortality in the United States, particularly in suburban White communities with wealthier residents as well as urban districts with poorer subpopulations (e.g. Black and Hispanic communities).[6] Understanding opioid usage, problems and associated health effects is crucial for medical treatment and reducing risk because of the inequity of opioid consumption and access globally. Notably, cultural norms and therapeutic approaches differ significantly in East Asian communities with dense populations (such as Hong Kong) from those in European and American countries. Opioid issues and their effects on health risks among these East Asian communities are typically underreported. As a result, this study uses the particular situation in Hong Kong as a case for global comparison.

OPIOID CONSUMPTION IN HONG KONG

In comparison to other areas, Hong Kong has a decreased risk of opioid abuse due to its tight drug consumption legislation. Oxycodone, an opioid pain medication, was not registered as a medicine appropriate for medical treatment until 13 May 2010.[7] As of 14 April 2023, there were only 455 registered

opioid-containing pain medications in Hong Kong, including seven products containing buprenorphine, 356 products containing codeine, 16 products containing fentanyl, 16 products containing morphine, 18 products containing oxycodone, and 42 products containing tramadol. These are pharmaceutical products that can only be obtained with a prescription and are sold under strict control. There are no registered medications containing hydrocodone, hydromorphone, or oxymorphone in Hong Kong.

Hong Kong has minimal opioid consumption not only in comparison to European and American countries, but also in comparison to adjacent East Asian communities. A recent study analysed trends in opioid use for pain in six adjacent communities (South Korea, Japan, Taiwan, Singapore, Hong Kong, and China) using World Health Organization (WHO) data from 2015 to 2017.[8] Hong Kong had the second-lowest opioid consumption rate of the six communities, with just 218 defined daily doses for statistical purposes (S-DDDs) per million inhabitants per day (S-DDD/m/d) for six types of opioids (fentanyl, morphine, oxycodone, hydromorphone, codeine and pethidine). This is critical because daily opioid intake in Hong Kong was just 9.4% of the intake recorded for South Korea and 15.9% compared to Japan. Daily consumption in Hong Kong was 1.8% of that in North America (12,255 S-DDD/m/d), 2.6% of that in Oceania (8246 S-DDD/m/d), and 3.3% of that in South America (6648 S-DDD/m/d) between 2015 and 2017.

Despite its low opioid usage, Hong Kong's opioid consumption trends differed slightly from those of the other areas. Fentanyl was the most often used opioid across most regions between 2015 and 2017, followed by oxycodone. However, morphine (94 S-DDD/m/d) had the largest local usage per day in Hong Kong, followed by fentanyl (76 S-DDD/m/d). Despite 356 recognised pharmaceutical items containing codeine for pain relief in Hong Kong, daily codeine intake was just 1 S-DDD/m/d. Interestingly, this daily codeine intake in Hong Kong was believed to be used primarily for cough treatment, rather than for pain reduction. This pattern of opioid intake had an impact on health outcomes and medical treatment strategies in Hong Kong.

OPIOID UTILISATION PATTERNS IN HONG KONG

Due to differences in opioid consumption trends between Hong Kong and other locations, a 2018 study evaluated opioid utilisation patterns, in terms of opioid order, after head and neck procedures in the United States and Hong Kong.[9] Based on 253 cases from a representative hospital in Hong Kong and 567 cases from a representative hospital in the United States, it was found that the hospital in the United States used a substantially greater opioid order the day before surgery (PRE1), postoperative day 6 (POD6), and postoperative day 14 (POD14) (see Table 1).

The orders of acetaminophen or paracetamol, NSAIDs, and anxiolytics did not differ significantly between hospitals in the United States and Hong Kong.

Table 1. Frequency of opioid and tramadol orders in US and Hong Kong hospitals

	Frequency of opioid orders in US hospital	Frequency of opioid orders in Hong Kong hospital	Frequency of tramadol orders in US hospital	Frequency of tramadol orders in Hong Kong hospital
PRE1	15.3%	1.6%	0.4%	4.7%
POD6	86.8%	0.4%	0.9%	13.4%
POD14	71.4%	0.8%	4.0%	9.5%

Using data from Li et al. (2018)[9]

A comparative study in 2019 also discovered a difference in opioid intake owing to cultural background and healthcare setting.[10] This research studied patients who underwent major abdominal surgery and were given patient-controlled analgesia with intravenous morphine for postoperative pain treatment, comparing patients in Hong Kong with those from surrounding regions. Educational attainment, place of residence, and ability to understand English were used to define the level of Western cultural influences. One hundred and twenty-eight Chinese patients in rural China and 134 patients in Hong Kong with a high influence from Western culture were compared, based on a total opioid requirement up to 48 hours after surgery as the primary endpoint. Postoperative opioid requirements were substantially higher among patients in Hong Kong. Estimated by morphine equivalent, the average cumulative opioid demand among patients in Hong

Kong was 42.0 mg ([CI: 38.3–45.6], p-value < 0.0001), whereas patients in rural China required just 18.8 mg (CI: 15.7–22.0). More notably, ethnicity was a significant influence on opioid requirement in addition to operation duration and severity of pain upon admission to the post-anaesthetic care unit. These findings confirmed the causes for regional differences in opioid consumption, with an underlying assumption regarding the potential influences of regional socioeconomic status, cost of healthcare, and utilisation.

Another notable example is the use of opioids for palliative care in Hong Kong, particularly among cancer patients. Opioid medication for chronic non-cancer pain is uncommon and lacks established regulatory/practice guidelines in Hong Kong.[11] Specifically, guidelines are published in Hong Kong, but medical doctors are not required to follow them. Interestingly, opioids are widely utilised among cancer patients, particularly those whose situations are deteriorating. A retrospective study conducted in Hong Kong in the early 2000s discovered high usage of opioids among patients receiving palliative care.[12] This study included 494 cancer deaths to examine the utilisation of public healthcare by advanced cancer patients in their last six months of life and their end-of-life process within the last two weeks of life. This cohort included 247 patients who received palliative care and died in palliative care units (PCS-PCD), 86 patients who received palliative care but died in non-palliative care wards (PCS-NPCD), and 161 patients who did not receive palliative care (NPCS-NPCD).

Although all groups received a similar amount of mild opioids during the last two weeks of life, individuals in PCS-PCD received much more fentanyl and morphine than the other groups. The difference between groups was not significant for fentanyl; however, it was for morphine (p-value = 0.001). Patients in PCS-PCD received significantly more morphine than patients in PCS-NPCD, while PCS-NPCD patients received significantly more morphine than patients in NPCS-NPCD. Although opioid usage patterns in Hong Kong have evolved lately, these traditions of using morphine for palliative care have remained notable.

MORTALITY RISK FROM OPIOID USE IN HONG KONG

A recent analysis for drug poisoning deaths (2001–2016) in Hong Kong indicated a considerable decline in mortality from other opioids (codeine or morphine) between 2001 and 2004, and a stable declining trend between 2005 and 2010,[7] owing to rigorous drug registration laws and specific patterns of opioid use. However, as with prescription opioid difficulties in other countries, the number of deaths has steadily climbed since 2011, shortly after the certification of prescription opioids for medicinal purposes (e.g. oxycodone). A population-based retrospective cohort study for opioid-naive individuals who underwent surgical operations between 1 January 2000 and 30 November 2020, found similar evidence.[20] Based on a month as the median follow-up period, 15,112 (3.45%) of 438,128 patients had persistent opioid use. The use of prescription opioids after discharge also increased 30-day all-cause mortality, with an OR of 1.68 (1.53–1.86).

The fatal risk directly induced by opioids is not a significant issue in Hong Kong, with a very small number of deaths when compared to other leading causes of mortality, such as malignant neoplasms and pneumonia. In total, there were roughly 113.3 deaths (range: 96–130, SD: 15.2) directly from other opioids (codeine or morphine) in Hong Kong every year between 2001 and 2004, 33.2 deaths (range: 17–59, SD: 15.5) between 2005 and 2010, and 32.0 deaths (range: 19–48, SD: 9.6) between 2011 and 2016.[7] Middle-aged, young-old (aged between 55 and 70), and divorced people were more likely to die from other opioids (codeine or morphine). Since 2011, a significant demographic shift in mortality patterns has occurred, with a 6.5-fold increase in deaths from other opioids (codeine or morphine) in people aged 60 compared to the 2001-2010 period (OR: 6.50 [3.97, 10.65]). Opioid-related deaths have also shifted to regions with less neighbourhood deprivation, more highly educated citizens, and a mix of private and public housing residents.[8]

Although opioid use may not directly increase the risk of death, it may indirectly cause deaths due to factors such as self-harm and suicide. In 2022, a population-cohort study used the Hong Kong Hospital Authority's Clinical Data Analysis and Reporting System (CDARS) to examine connections between specific drug-related disorders and the risk of self-harm or suicide in Hong Kong.[13] This study identified 8270 relevant CDARS cases between 2004 and 2016, who were aged 10 or older and had visited the accident and emergency department of a representative hospital for one of the following drug-related disorders: 1) opioid, 2) ketamine, 3) methamphetamine, 4) sedative, hypnotic, or anxiolytic, 5) amphetamine or related stimulant, 6) cocaine, 7) cannabis, 8) hallucinogen, and 10) polydrug.

The most prevalent group, opioid use disorder, was represented by 2523 cases (30.51%). When compared to the other drug-related disorders, opioid use disorder had the highest risk of self-harm or suicide, with an

adjusted hazard ratio (aHR) of 27.323 [95% CI: 19.71–38.32; p-value < 0.0001] controlled for gender and age. The aHR was 15.97 [95% CI: 10.73–23.23; p-value < 0.0001] for the best model defined by this study, which adjusted for gender, age, self-harm diagnosis, concurrent self-harm diagnosis, drug use disorder diagnosis, and any psychiatric disorder (comprising depression, bipolar disorder, alcohol and tobacco abuse disorder, personality disorder, anxiety disorder, and schizophrenia) and any physical illness (comprising asthma, diabetes, epilepsy, HIV, cancer, and dermatitis or eczema) diagnosis before or on the index date. The above findings consistently show that opioid consumption in Hong Kong is associated with a high fatal risk due to indirect and underlying causes of death, even though the level of consumption itself is not high.

NON-FATAL HEALTH CONSEQUENCES FROM OPIOID USE IN HONG KONG

Non-fatal health consequences in Hong Kong as a result of opioid use should also be noted. There are several significant consequences of opioid use: 1) substance abuse, 2) mental distress, and 3) side effects on physical health and healthy behaviours. According to a population-cohort study conducted in 2022, people with opioid use disorder had a high prevalence of comorbidity with psychiatric disorders.[13] About 424 of the 2523 opioid use disorder cases (16.81%) had some type of psychiatric disorder, 125 cases (4.95%) had depression, 110 cases (4.36%) had schizophrenia, and 84 cases (3.33%) had personality disorders. Approximately 134 cases (5.31%) had an alcohol and tobacco use disorder. Additionally, other than people with cancer (85 cases, 3.37%), comorbidities related to physical illness and conditions among opioid use disorder cases included 72 cases (2.8%) of asthma, 57 cases (2.26%) of epilepsy, 42 cases (1.66%) of diabetes, and 34 cases (1.35%) of dermatitis or eczema.

Comorbidities may also exacerbate issues of substance abuse or mental distress, as well as the side effects on physical conditions or healthy behaviours. In another population-based cohort based on CDARS data, Wei et al. (2021) compared people with and without substance use disorders.[14] After matching, individuals with substance use disorders had a much higher percentage of decedents from non-heroin opioid poisoning than those without disorders (4.2% vs 0.5%). According to related studies, opioids were the most abused substance in the accident and emergency (A&E) department of Hong Kong's public hospitals (27.1%) between 2004 and 2016.[15,16] Opioids in particular were one of the major substances causing patients with substance abuse to return to the hospital. According to a recent population-based study, prescribing opioids on discharge was linked to an increased risk of developing persistent opioid use (OR: 2.30 [2.19-2.40]), 30-day emergency department visits (OR: 1.28 [1.23-1.33]), and 30-day readmission (OR: 1.17 [1.13-1.20]).[20] For the first three and a half months of 2023, the Hong Kong Department of Health had received 28 reports of adverse drug reactions as follows: four from codeine, three from fentanyl, ten from morphine, four from oxycodone, and seven from tramadol. The prevalence of opioid-related side effects in Hong Kong, such as nausea, drowsiness, itching, and dizziness, has yet to be determined.

Thus, a better public health surveillance system is essential, partially due to changes in social behaviours/health awareness among the Hong Kong population. A population-based study found that fewer people were taking medications for chronic pain in 2013 compared with data from 1999 (34.9% in 2013 vs 47.6% in 1999, p-value = 0.019).[17] The proportion of people taking analgesics (opioids) as oral pain medication dropped from 0.9% to 0.09%, although the result was statistically insignificant. Fewer people used pharmaceutical analgesics by injection in 2013 (1.6% in 2013 vs 10.3% in 1999, p-value < 0.0001). Furthermore, improved public health concern is critical, owing in part to changes in social behaviours and health awareness among the Hong Kong population. A population-based study discovered that fewer people were taking chronic pain medications in 2013 than in 1999 (34.9% in 2013 vs 47.6% in 1999, p-value = 0.019).[17] The number of people using addictive analgesics (opioids) for oral pain relief decreased from 0.9% to 0.09%, though the difference was statistically insignificant. Pharmaceutical analgesics by injection were used by fewer people in 2013 (1.6% in 2013 vs 10.3% in 1999, p-value = 0.0001). Furthermore, another population-based study found the following:

1. Chronic pain patients with neuropathic characteristics were less likely to receive prescribed oral medication, including both additive and non-additive analgesics (e.g. NSAIDs) (p-value = 0.0226).
2. Oral analgesics were less useful (p-value = 0.0215).[18] This could be due to apprehension about using opioids.

Notably, the above differences were not statistically significant. In addition, the above study indicated a higher percentage of individuals using additive analgesics (opioids) among chronic pain patients with neuropathic characteristics compared to those without neuropathic characteristics (3.8% vs 1%), but a lower percentage of chronic pain patients with neuropathic characteristics using NSAIDs (1.3% vs 2.4%).[18] According to another Hong Kong study, individuals with cancer pain may have fatalistic beliefs, posing a barrier to optimising pain control.[19] Because 79% of respondents believed that medications could not relieve cancer pain, they identified pain as an unavoidable component of hospitalisation. About 52% of respondents expressed concern about becoming addicted to opioid analgesics. Approximately half of those polled thought opioid analgesics should only be used as a last resort.

HEALTH POLICY IMPLICATIONS

Overall, our empirical case of Hong Kong indicates a low risk of opioid-related mortality. However, the risk of side effects and morbidity cannot be overlooked. Concerns about social behaviours and health awareness, as well as a lack of policies and protocols addressing local opioid use, can be issues. This evidence may be useful for global comparison, as "relatively low-risk" does not always imply "always" good. It is critical to understand how to create a "no one left behind" framework to support local citizens, especially in high-risk areas due to high levels of dependence and addiction to opioids.

However, whether there are relevant policies to target opioid risk is always a question. Using Hong Kong as an empirical case, the local government established the "Steering Committee on Primary Healthcare Development" in November 2017 to improve primary healthcare services. In December 2022, the Hong Kong government's official policy framework, known as the "Primary Healthcare Blueprint" was released. This policy framework established four domains of healthcare strategy to improve the overall health of the Hong Kong population: 1) prevention-oriented healthcare services, 2) community-based healthcare systems, 3) family-centric healthcare support, and 4) early detection with timely intervention. In addition, the Hong Kong government released a policy-oriented action plan in 2018, titled "Towards 2025: Strategy and Action Plan to Prevent and Control NCD in Hong Kong," with nine targets for health actions to: 1) reduce premature mortality from noncommunicable diseases, 2) reduce harmful alcohol use, 3) reduce physical inactivity, 4) reduce salt intake, 5) reduce tobacco use, 6) contain the prevalence of raised blood pressure, 7) halt the rise in diabetes and obesity, 8) apply drug therapy and counselling to prevent heart attacks and strokes, and 9) increase the availability of affordable basic technologies and essential medicines to treat major noncommunicable diseases. All of these targets, however, were not directly related to the risk of opioid use.

This situation is similar to that in most cities in East Asia. Particularly, the most significant social and health concern among East Asian cities is population ageing. Therefore, most healthcare protocols (similar to Hong Kong's blueprint noted previously) target chronic illnesses, which are more relevant to the direct causes affecting the ageing population. For opioid risk, it progressively becomes a serious issue because it more notably affects the indirect health effects of ageing individuals, such as side effects in pain patients after treatments. There are many social and health issues due to a lack of "knowledge, attitude, and practice" (KAP) secondary to a low health awareness among these patients in East Asian cities. A recent example of non-prescription drug use is seen in Japan. As in China, there are Japanese individuals who adopt the use of traditional (or herbal) medicine. This has led to a "bloom" of traditional medicine used for pain relief in Japan, which is not only being sold to locals but also to visitors. However, it has recently been found that such traditional medicine-based pain relievers contain an excessive amount of codeine. As a result, Japan may benefit from setting emergency policies that restrict visitors from buying these pain relievers in order to reduce the overuse of these drugs due to the lack of transparency and awareness surrounding the potential presence and side effects of opioids.

Thus, patients need to be informed about the benefits and drawbacks of using opioid analgesics to reduce misconceptions and concerns. Furthermore, it is critical to develop guidelines and protocols for the use of opioids in various treatments, as this can reduce adverse health risks (e.g. mortality risk, substance abuse) among the local population. Finally, more population-based studies should be conducted in different cities to clarify the associations between opioid use and side effects on both mental and physical conditions.

CONCLUSION

Understanding opioid usage/challenges and health-related implications is vital for risk reduction because disparities due to opioid consumption/access are documented globally. Medical treatment strategies and cultural practices in Asian areas with high population density differ greatly from those in Westernised countries, and opioid risk usage/challenges in these Asian populations has been underreported. Hong Kong was chosen as our study location for a worldwide comparison, as it is representative of the East Asian community. In general, opioid consumption in Hong Kong is modest in comparison to European/

American countries and neighbouring regions. However, patterns of opioid utilisation in Hong Kong differ from those found elsewhere. Although the risk of death from opioid consumption is relatively low, death counts have steadily climbed since 2011, shortly after the registration of prescription opioids for medical applications (e.g. oxycodone). Furthermore, the demographic pattern for deaths from other opioids (codeine or morphine) has migrated toward the middle-aged, young-old, and divorced, and decedents lived in areas with low neighbourhood deprivation, which could be influenced by social behaviours, cultural practices, and health awareness. In Hong Kong, opioid usage is also linked to additional comorbidities with tragic outcomes (e.g. self-harm, suicide) and adverse health consequences (e.g. substance abuse, mental distress, side effects on physical conditions/health behaviours). These are risk factors that can further induce high levels of dependence and addiction to opioids. Furthermore, the Hong Kong government has established several health policy frameworks, such as the "Primary Healthcare Blueprint" and “Towards 2025: Strategy and Action Plan to Prevent and Control NCD in Hong Kong”; however, none of these frameworks explicitly address opioid usage hazards. Thus, the central question is how to improve location-specific solutions to reduce opioid hazards. Our findings suggested that “relatively low-risk” may not always be “good.” Creating a “no one left behind” framework to support local communities is thus critical, particularly in areas with high opioid risk.

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GLP-1 receptor agonists – an evolving paradigm in perioperative medication management

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INTRODUCTION

The 20th century saw a profound shift in global health, with a dramatic rise in metabolic diseases. In high-income countries, including Australia, rates of obesity and type 2 diabetes have surged. Current estimates are that 66% of Australians are overweight or obese[1] and 5.3% are living with diabetes.[2] Obesity is a risk factor for type 2 diabetes and both conditions greatly increase the risk of stroke and cardiovascular disease.[3]

Many interventions have been trialled to halt the rise of metabolic disease. These include dietary interventions, physical exercise programs, behavioural interventions, appetite suppressants, absorption inhibitors, bariatric surgery and public health measures aimed at reducing the availability of highly dense caloric ingredients such as high fructose corn syrup.[4] However, most of these interventions have limited efficacy, can cause significant rebound weight gain, or are invasive surgical treatments.

Glucagon like peptide-1 receptor agonists (GLP-1 RA) are a new class of medication that has recently emerged. GLP-1 RA are being prescribed to an increasing number of patients for the treatment of diabetes and/or obesity. The market for GLP-1 RA was estimated to be worth $US10.8 billion in 2023 and is projected to grow at a compound annual growth rate of 7.8% to reach $US21.2 billion by 2032.[5] In Australia, among non-insulin glucose lowering drugs, the proportion of GLP-1 RA being used has increased from 1.7% in 2013 to 11.7% in 2023. In 2023, it was estimated that GLP-1 RA were being used by 192,000 people. GLP-1 RAs were also the most expensive drug class, costing $308 million in 2023, representing 11.7% of utilisation but 35% of overall spending on non-insulin glucose-lowering drugs.[6] Due to the sharp rise in popularity, anaesthetists are increasingly encountering patients taking these drugs perioperatively.

This article explores the history of GLP-1 RA development, current perioperative management guidelines, controversies and future directions. Additionally, it discusses how the medical community recognises and adapts to the evolving landscape of perioperative medication management, and the current status of GLP-1 RA in this journey.

DEVELOPMENT OF GLP-1 RA

During the mid-to-late 20th century, it was observed that intestinal extracts could reduce blood glucose levels. Furthermore, it was discovered that injecting glucose into the intestinal lumen triggered the production of more insulin than injecting it into a vein. These discoveries led to the search for incretin hormones, released from the intestine (predominantly the small bowel) to stimulate pancreatic insulin secretion. In the 1970s the first incretin hormone, known as glucose-dependent insulinotropic polypeptide (GIP) was identified, and later another hormone glucagon-like peptide-1 (GLP-1) was characterised.[7]

GLP-1 is an endogenous incretin hormone released mainly from the ileum that lowers blood glucose levels by promoting insulin release from pancreatic beta cells and decreasing glucagon secretion from alpha cells.[8] Importantly, studies demonstrated that the effect of GLP-1 on insulin secretion was glucose-dependent and, therefore, did not cause hypoglycaemia.[8] By the early 1990s, GLP-1 was identified as a promising diabetes drug.

However, GLP-1 has an ultrashort half-life, being rapidly degraded by dipeptidyl peptidase-4 (DPP-4) and cleared by the kidneys, which created major challenges utilising it as a drug.[9] The key intervention that allowed GLP-1 RA to be viable as medications were various structural modifications which markedly extended the half-life.[10]

In 2005, exenatide (Byetta), was the first injectable GLP-1 RA medication worldwide to receive United States (US) Food and Drug Administration (FDA) approval for the treatment of type 2 diabetes. Exenatide had a modified amino acid sequence making it resistant to dipeptidyl peptidase-4 (DPP-4) degradation,[6] with a half-life of 2-4 hours making it suitable for twice-daily administration subcutaneously.

In 2009, liraglutide (Victoza) from Novo Nordisk was granted approval by the European Medicines Agency (EMA), followed by US FDA approval in January 2010, for managing type 2 diabetes. Liraglutide had an acylated fatty acid which further increased its half-life to 13 hours, allowing once daily injectable dosing and making it more convenient for patients.[7]

Eli Lilly introduced dulaglutide as a further improvement using a fusion protein of GLP-1 bound to an immunoglobulin fragment which increased the half-life to 5 days. The US FDA approved dulaglutide in 2014 for treating type 2 diabetes, and it is administered once a week by injection. Dulaglutide was more appealing to patients due to its once-weekly injection dosing. It was also shown to have better glycaemic control that liraglutide.[11]

In 2017, Novo Nordisk launched semaglutide (Ozempic), which has a half-life of 7 days due to the addition of a fatty acid side-chain which binds to albumin, enabling weekly administration by injection. In addition, when semaglutide (Ozempic) was administered to patients with diabetes, it was discovered that 40% of them lost more than 10% of their body weight. Further clinical trials then investigated semaglutide as a treatment for obesity.[12] In 2019, the US FDA granted approval for a unique formulation of semaglutide (Rybelsus), which was the first oral GLP-1 analogue treatment for adults with type 2 diabetes administered once a day.[7] Rybelsus was preferred by some patients who are averse to self-injections and prefer oral formulations. In 2021, semaglutide (Wegovy) once weekly injection was approved by the FDA for chronic weight management in adults with obesity. The higher doses in Wegovy at 2.4 mg, as compared to Ozempic at 0.5 mg, showed a dose-dependent increase in weight loss.[13]

Eli Lilly unveiled tirzepatide (Mounjaro) in 2022, a new dual GLP-1/GIP receptor agonist. It is administered once a week via subcutaneous injection and activates both GLP-1 and GIP receptors. GIP can reduce body weight by curbing food intake and increasing energy consumption.[10] When combined with a GLP-1 RA, it may have a more significant impact on blood glucose levels and body weight.[7]

Newer generations of GLP-1 RAs were modified to increase their half-life, therefore reducing administration frequency and improving convenience for patients. The development of an oral formulation also benefited patients who are averse to injections. Newer generations of GLP-1 RA and new dual GLP-1/GIP receptor agonist also showed improved efficacy in glycaemic control and weight loss. Table 1 shows the GLP-1 RAs and dual GLP-1 and GIP co-agonists registered for use in Australia.

BENEFITS OF GLP-1 RAS AND GLP/GIP CO-AGONISTS

For patients with type 2 diabetes, GLP-1 RA has been shown to have better glucose-lowering effects than oral medications such as SGLT2 inhibitors, DPP-4 inhibitors, and sulphonylureas.[14] A systematic review

conducted in 2024 showed that GLP-1 RAs and GLP/GIP co-agonists effectively lowered HbA1c and fasting plasma glucose concentrations. Tirzepatide was the most successful medication for glycaemic management, causing the greatest decrease in HbA1c and fasting plasma glucose levels.[11] Additionally, it has been demonstrated that GLP-1 RAs significantly improve the ability of patients with type 2 diabetes to control their weight. In a study of semaglutide vs placebo for weight loss in patients with type 2 diabetes, semaglutide resulted in 6.2% mean weight loss vs placebo.[15] In addition to glycaemic control and weight loss, several trials have also demonstrated that GLP-1 RAs reduce the risk of major adverse cardiovascular events (MACE) compared to placebo in patients with type 2 diabetes.[16-18] The results of the cardiovascular outcome trial for tirzepatide are expected in late 2025.

For patients without diabetes and utilising GLP-1 RA for weight loss, a cohort study observed that semaglutide (-5.1%) was more effective than liraglutide (-2.2%). It also observed that patients utilising GLP-1 RA for obesity as a treatment indication (-5.9%) had more weight loss in one year as compared to patients utilising GLP-1 RA for type 2 diabetes as a treatment indication (-3.2%).[19]

Table 1. GLP-1 RAs and Dual GLP-1 and GIP co-agonists registered for use in Australia

Agent	Receptor agonism	Elimination half-life	Administration schedule and route of administration	Trade name	Status
Exenatide twice daily	GLP-1	3.3-4.0 hours	Twice daily Subcutaneous	Byetta	Withdrawn for commercial reasons, global discontinuation of drug
Liraglutide	GLP-1	12.6-14.3 hours	Once daily Subcutaneous	Victoza (up to 1.8 mg) Saxenda (up to 3.0 mg)	Not PBS listed
Exenatide once weekly	GLP-1	3.3-4.0 hours	Once weekly Subcutaneous	Bydureon	Withdrawn for commercial reasons, global discontinuation of drug
Dulaglutide	GLP-1	4.7-5.5 days	Once weekly Subcutaneous	Trulicity	PBS listed for type 2 diabetes
Semaglutide	GLP-1	5.7-6.7 days	Once weekly Subcutaneous, or once daily oral	Ozempic (up to 1 mg SC) Wegovy (up to 2.4 mg SC) Rybelsus (up to 14 mg daily orally)	Ozempic: PBS listed in 2020 for type 2 diabetes Wegovy: TGA approved but not yet PBS listed (as of 2024) Rybelsus: TGA approved
Tirzepatide	GLP-1 & GIP	4.2-6.1 days	Once weekly Subcutaneous	Mounjaro	Not yet PBS listed (as of 2024) Unavailable until 31 August 2025 due to global demand for GLP-1 RAs

GLP-1 = Glucagon like peptide 1, GIP = Glucose-dependent insulinotropic polypeptide, PBS = Pharmaceutical Benefits Scheme, SC= subcutaneous, TGA = Therapeutic Goods Administration Australia. Table adapted from Clinical Practice Recommendation on Periprocedural Use of GLP-1/GIP Receptor Agonists and reproduced with permission[20]

RISK OF HARM

The gastrointestinal adverse effects of GLP-1 RA include nausea, vomiting, and diarrhoea,[21] attributable to delayed gastric emptying and direct central effects of GLP-1 RA. It has been observed that GLP-1 RA do not significantly prolong gastric emptying further in patients with type 2 diabetes who already have diabetes-related gastroparesis.[12,22] The risk of aspiration linked with delayed gastric emptying is of particular concern to anaesthetists and has been reported recently in a number of case reports involving patients taking GLP-1 RA perioperatively for weight loss or type 2 diabetes indications.[23] More research is needed to delineate the risk period and return of gastric function after cessation of GLP-1 RA.

In early 2022, there was an unexpected increase in demand of semaglutide (Ozempic) due to off-label prescribing for weight loss.[24] In Australia, this was largely fueled by increased reporting and unlawful advertising on digital platforms including social media.[25] The result was a worldwide shortage of semaglutide, which also affected Australia. Certain Australian compounding pharmacies responded to this demand by producing replicas of Ozempic and Mounjaro. This sparked major concerns that the large-scale unregulated manufacture of these compounded products posed risks to human health. A Therapeutic Goods Administration (TGA) investigation into one of these laboratories revealed unsanitary conditions. There were also reports of alarming side effects from the use of these replica drugs.[26] In May 2024, compounding pharmacies in Australia were banned from producing replica versions of Ozempic and Mounjaro.[27]

Both Ozempic and Wegovy are expensive. Ozempic is listed on the PBS for type 2 diabetes only, costing approximately $10 per week. However, patients using Ozempic for weight loss need to pay the full price of approximately $45 per week. Costs are less for the indication if a patient has a concession card. Wegovy is currently not PBS listed and costs approximately $115 per week.[28]

EXISTING GUIDELINES

As of December 2024, there is no consensus among international guidelines regarding perioperative management of patients who take GLP-1 RA. For a drug to be completely cleared from the body, it should be withheld for three to five half-lives. Withholding GLP-1 RA for this period of time results in a washout period of more than four weeks. Withholding GLP-1 RAs in patients with diabetes causes worsening glycemic control. Additionally, patients often attend preoperative clinics only weeks prior to their procedures to receive medication advice. Therefore, withholding GLP-1 RA often results in delaying the procedure to allow washout.[29] In Australia, the Australian and New Zealand College of Anaesthetists (ANZCA) published a consensus clinical practice recommendation in June 2024 endorsed by the Australian Diabetes Society (ADS), National Association of Clinical Obesity Services (NACOS) and Gastroenterological Society of Australia (GESA) (Table 2).

Table 2. Guidelines for the perioperative management of GLP-1 RA

Organisation	Date	Recommendation
Australian and New Zealand College of Anaesthetists, Gastroenterological Society of Australia, National Association of Clinical Obesity Services, Australian Diabetes Society	2025	• Patients should be asked about the use of GLP-1 RAs and GLP-1/GIP RAs prior to anaesthesia or sedation for surgical and endoscopic procedures and be involved in discussion and planning regarding the risk of aspiration. • Elective preprocedural cessation of GLP-1 RAs and GLP-1 RA/GIP RAs is not recommended, and risks hyperglycaemia in people with diabetes and may compromise weight control where patients are taking GLP-1 RAs and GLP-1/GIP RAs for this indication. • Patients should be asked about the use of other medications and medical conditions which may exacerbate gastrointestinal symptoms and delay gastric emptying, such as, but not limited to bowel dysmotility, gastroparesis, and Parkinson's disease. • Preprocedural diet modification with 24-hour fluid diet, and then following recommended 6-hour fasting guidelines, should be recommended for all patients receiving GLP-1 RAs and GLP-1 RA/GIP RAs. • Risk mitigation options should be undertaken for those who have not withheld solids for 24 hours. These include detection of residual gastric contents, prokinetic agents, modification of anaesthesia, or deferral of procedure.[20]
American Society of Anesthesiologists, American Gastroenterological Association, American Society for Metabolic and Bariatric Surgery, International Society of Perioperative Care of Patients with Obesity, Society of American Gastrointestinal and Endoscopic Surgeons	October 2024	• GLP-1 RA therapy may be continued preoperatively in patients without elevated risk of delayed gastric emptying and aspiration. When an elevated risk of delayed gastric emptying and aspiration exist, withholding of GLP-1 RA should be balanced with the surgical and medical risk of inducing the potential for a hazardous, metabolic disease state, like hyperglycaemia. Further, bridging therapy off a GLP-1 RA may be resource-intensive, cost or insurance prohibitive, and risk other adverse side effects like hypoglycaemia. Finally, withholding GLP-1 RA perioperatively only for patients with the diseases of overweight and obesity, could constitute overweight and obesity bias, which should be avoided. • If the decision to hold GLP-1 RAs is indicated given an unacceptable safety profile following shared decision-making in the preoperative period, the duration to hold therapy is unknown. At this time, it is suggested to follow the original guidance of the American Society of Anesthesiologists, holding the day of surgery for daily formulations, and a week prior to surgery for weekly formulations. All patients should still be assessed on the day of procedure for symptoms suggestive of delayed gastric emptying. • Preoperative diet modification (preoperative liquid diet for at least 24 hours, as performed in patients undergoing colonoscopy and bariatric surgery) can be utilised in patients when there is concern for delayed gastric emptying based on clinical symptom review.

American Society of Anesthesiologists, American Gastroenterological Association, American Society for Metabolic and Bariatric Surgery, International Society of Perioperative Care of Patients with Obesity, Society of American Gastrointestinal and Endoscopic Surgeons	October 2024	• When clinical concern for retained gastric contents exists on the day of the procedure, point-of-care gastric ultrasound could be used to assess aspiration risk. This technology may be clinically limited based on institutional resources, inter-user variability, and credentialing requirements. • When clinical concern for retained gastric contents exists or is confirmed on the day of the procedure, providers should engage patients in a shared decision-making model and consider the benefits and risks of rapid sequence induction of general anesthesia for tracheal intubation to minimise aspiration risk versus procedure cancellation.[30]
Centre for Perioperative Care, United Kingdom	October 2023	Do not withhold GLP-1 RA.
Society for Perioperative Assessment and Quality Improvement, United States	March 2021	• Continue GLP-1 RA before the day of surgery unless heightened concern for postoperative nausea, vomiting or gut dysfunction (e.g. GI surgery). In these situations, consider holding 24 hours for once or twice daily preparations, and up to one week before surgery for weekly preparations (including holding dose within seven days before surgery). • Withhold GLP-1 agonists on the morning of surgery. • If a weekly dose is due on morning of surgery, delay taking until later in the day after surgery.[31]

GLP-1 = Glucagon-like peptide 1, GIP = Glucose-dependent insulinotropic polypeptide

Currently, none of the guidelines recommend different perioperative management strategies based on the indication of GLP-1 RA (weight management vs diabetes management). The American multi-society clinical practice guidance states that it could constitute obesity or overweight bias if only patients taking GLP-1 RA for weight management are asked to withhold GLP-1 RA perioperatively.[30] Both the Australian and American multi-society guidelines have suggested the use of point-of-care gastric ultrasound if there is a clinical concern for retained gastric contents.[30,20] It can be an accurate and reliable tool to assess gastric content and aspiration risk. The I-AIM (Indication, Acquisition, Interpretation and Medical Decision Making) framework is recommended as a standardised approach to minimise error.[32] However, this skill may be limited by inter-user variability, institutional resources and training requirements.

SAFETY CYCLE – THE REACTION TO NEW MEDICATION CLASSES

The desire to protect our patients from harm can paradoxically place them at risk when excessive caution is used. The medical profession as a whole, but in particular the field of anaesthesia, is replete with examples of evolving changes to management of new medications. There is a familiar cycle of introduction of a new class of medication, emergence of case reports of isolated harm, response to case reports with conservative guidelines and widespread appropriate caution, followed by large observational and/or randomised controlled trials often demonstrating different findings to the initial case reports, sometimes with evidence of harm from the initial conservative guidance. Sodium-glucose co-transporter-2 (SGLT2) inhibitors and direct oral anticoagulants (DOACs) provide two recent instructive examples.

SGLT-2 inhibitors

Sodium-glucose co-transporter-2 (SGLT2) inhibitors are anti-hyperglycemic agents that promote glucosuria by inhibiting renal glucose reabsorption.[33] As the number of patients taking SLGT2 inhibitors increased, case reports emerged of patients developing severe ketoacidosis with normal blood glucose levels requiring perioperative intensive care or high dependency unit admissions.[34] This resulted in widespread concern, advice to withhold SGLT2 inhibitors for all procedures in some cases up to two weeks prior to surgery,[31] and cancellation of any perioperative patient who had not ceased an SGLT2 inhibitor prior to surgery or even those who had ceased but had ketone levels above 1 mmol/L.[35]

After many studies were undertaken, predisposing factors for diabetic ketoacidosis in patients using SGLT-2 inhibitors were identified and updated evidence emerged with the current ANZCA guidance updated almost 10 years after the initial FDA approval for the first SGLT2 inhibitor.[36]

Direct oral anticoagulants

Direct oral anticoagulants (DOAC) are now commonly used in the treatment and prevention of venous thromboembolism and prevention of stroke in non-valvular atrial fibrillation.[37] When they were first used in 2010, there were no studies available to guide the timing of perioperative interruption and resumption of DOAC therapy. It was also unclear whether heparin bridging should be administered and if preoperative coagulation function testing was necessary. Patients of high thrombotic risk were often required to bridge with heparin when their DOAC was withheld, and patients having surgeries with high bleeding risk often needed APTT or thrombin time monitoring to ensure adequate drug elimination. This resulted in patients having coagulation testing as well as injectable anticoagulants[38] that were later found to be unnecessary.

The Perioperative Anticoagulant Use for Surgery Evaluation (PAUSE) study published in 2019 found that withholding DOACs perioperatively in patients with atrial fibrillation resulted in low rates of major bleeding and thromboembolic events. The PAUSE study provided a simple and safe perioperative DOAC management strategy that laid the foundation for the publication of future guidelines.[39] "Regional Anaesthesia in the Patient Receiving Antithrombotic or Thrombolytic Therapy" published by the American Society of Regional Anaesthesia and Pain Medicine (ASRA) in 2018 did not recommend routine bridging therapy for patients on DOAC therapy.[40] This recommendation is similar to the process Drummond suggests, including that clinicians consider the type of DOAC, whether it is a prophylactic or therapeutic dose, the type of procedure and the patient's renal function when deciding the duration for withholding the DOAC before the procedure.[37] With the advent of more evidence, there is now more consensus among various guidelines for the perioperative management of DOACs, including advice that bridging with heparin and coagulation profile testing are not recommended.

Given the history of evolving changes to perioperative medication management, it is incumbent on the profession to view the rise of GLP-1 RA in this context and ensure unrestrained safety advice without randomised controlled trial informed guidance does not result in unintended harms. For example, the current ANZCA guidelines recommend that "risk mitigation options should be undertaken for those who have not withheld solids for 24 hours" which would suggest conducting a rapid sequence intubation. If the procedure or predisposing patient factors does not require a muscle relaxant to be used, this recommendation exposes patients to the additional risk of anaphylaxis to muscle relaxants.

ISSUES TO CONSIDER WHEN MANAGING A PATIENT TAKING GLP-1 RA IN THE PERIOPERATIVE PERIOD

1. Perioperative management of GLP-1 RA should be based on shared decision making of the patient with a multidisciplinary team (anaesthetists, proceduralists and prescribing teams e.g. endocrinologists).[30]
2. Consider the individual patient's metabolic need for GLP-1 RA and risk profile.
    a. Escalation phase (when patients are given increasing doses of GLP-1 RA, typically lasting 4 to 8 weeks) vs maintenance phase is associated with higher risks of delayed gastric emptying.[41]
    b. The higher the dose of GLP-1 RA, the higher the risk of gastrointestinal side effects.[41]
    c. Weekly formulations are associated with increased gastrointestinal side effects compared to daily formulations.[42]
    d. Symptoms such as vomiting, nausea, dyspepsia, abdominal pain and constipation are suggestive of delayed gastric emptying.[43]
    e. Other pre-existing medical conditions that can also delay gastric emptying such as gastroparesis, bowel dysmotility and Parkinson's disease.[30]
3. When an increased risk of delayed gastric emptying and aspiration exist, withholding of GLP-1 RA should be balanced with the surgical and medical risk of inducing the potential for a dangerous metabolic disease state like hyperglycaemia.[30]
4. Consider preoperative diet modification (clear liquid diet for 24 hours) in patients with an increased risk of delayed gastric emptying.[43]
5. Consider point-of-care gastric ultrasound to assess aspiration risk on the day of the procedure if there is clinical concern of retained gastric contents.[44]
6. If clinical concern for retained gastric contents exists or is confirmed on the day of the procedure, multidisciplinary teams should engage in shared decision making with the patient and consider the risks vs benefits of rapid sequence induction to minimise aspiration risk vs cancellation of procedure.[30]

FUTURE DIRECTION OF GLP-1 RA

GLP-1 RA are an evolving class of drugs and continue to increase in public popularity for the treatment of obesity. It is likely that GLP-1 RA will be PBS listed for the treatment of obesity in the future in Australia. Recent advances in drug development have led to the combination of GLP-1 RA with other new bioactive peptides resulting in dual or triple agonists. CagriSema, a dual GLP-1 and amylin agonist, containing semaglutide and cagrinlintide, is in phase 3 trials. Similar to GLP-1, amylin also delays gastric emptying and reduces appetite, leading to glucose-lowering effects and weight loss.[45]

Advances in drug delivery systems can also improve the ease of administering GLP-1 RA. New orally-available preparations of GLP-1 RA are available which further lowers the barrier for patient adoption. Additionally, a recent report showed that incorporating GLP-1 RA in a new hydrogel enables a "sustained-release depot" of the drug that may require dosing only once every four months.[46]

Researchers are also investigating the use of GLP-1 RA beyond the indications of type 2 diabetes and obesity. GLP-1 RA have anti-inflammatory effects.[47] Areas of potential benefit include reduction of major adverse cardiovascular events, kidney disease, metabolic liver disease and even neuroprotection and addiction. We may see broader uses of GLP-1 RA in the future such as for the treatment of Alzheimer's disease and chronic kidney disease.[48]

CONCLUSION

Given the positive effects of GLP-1 RA on glycaemic control, weight loss and cardiovascular risk reduction, use of these medications in the community will rise over time. The perioperative conundrum of whether to withhold GLP-1 RA to reduce aspiration risk, or continue to mitigate hyperglycaemia and potentially cardiovascular disease risk will continue to stir debate until more definitive evidence emerges. As perioperative medicine specialists, we should carefully consider the best way to manage these novel agents during this phase before high-quality evidence emerges and reflect on how we should manage agents with a lack of perioperative evidence.

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Are you thirsty? Changing the liquid fasting paradigm – the "Sip Til Send" initiative

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Edited by Professor Alicia Dennis

INTRODUCTION

Preoperative fasting is a critical component of patient preparation for surgery, traditionally aimed at reducing the risk of pulmonary aspiration during anaesthesia. However, prolonged fasting can lead to patient discomfort, dehydration, and other complications. The "Sip Til Send" approach, an emerging practice in perioperative care, offers a promising alternative by allowing patients to sip approved clear liquids until called to theatre.

The "Sip Til Send" approach permits patients to consume small amounts of clear liquids, such as water, black tea or coffee, and electrolyte solutions, thereby reducing the duration of liquid fasting without an apparent increase in the risk of aspiration. This method has shown potential benefits, including decreased postoperative nausea and vomiting, improved hydration, and enhanced patient satisfaction.

This article aims to increase awareness among anaesthetists about the "Sip Til Send" approach, highlighting its benefits, implementation strategies, and the evidence supporting its safety and efficacy. Adopting this practice enhances patient experience and thereby improves perioperative care.

HISTORY OF PREOPERATIVE LIQUID FASTING – AN ANAESTHETIC DOGMA

Mid-late 19th century – The beginning

In the mid to late 19th century, anaesthesia transitioned from William Morton's ether to James Simpson's chloroform. Preoperative fasting was recommended to reduce nausea and vomiting, with operations ideally held before breakfast or the next meal.[1,2] In 1883, British surgeon Sir Joseph Lister introduced the first fasting guideline, distinguishing between solids and liquids. He suggested avoiding solid food but allowed certain liquids two hours before surgery, noting that prolonged fasting worsened exhaustion. This highlighted the negative impact of extended preoperative fasting for the first time.[1,2]

Mid-late 20th century – "Nil by mouth" (NBM) concept, gastric contents and aspiration risk

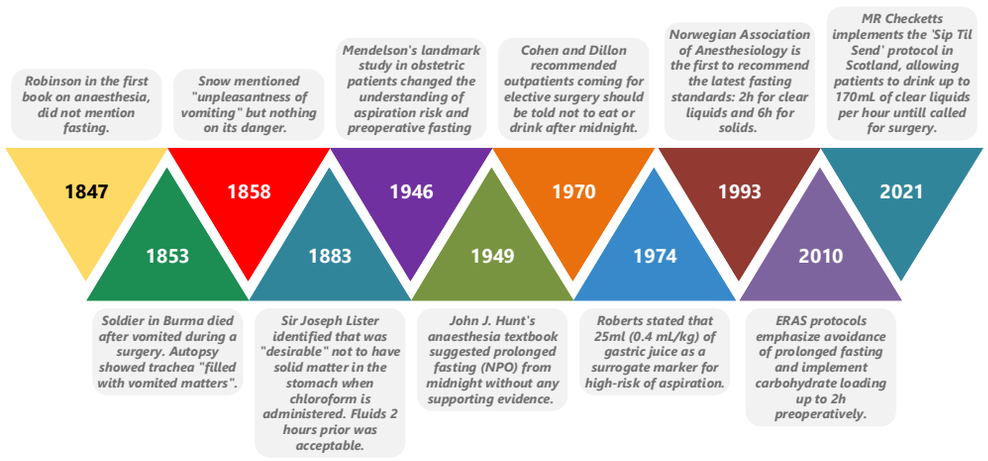
Preoperative fasting became widely accepted in the mid-20th century to reduce the risk of pulmonary aspiration without distinguishing between clear liquids and solids.[2-6] In 1946, American obstetrician and cardiologist Curtis Lester Mendelson described chemical pneumonitis caused by aspiration of gastric contents based on a retrospective study of 66 cases of aspiration during anaesthesia of 44,016 pregnant women from 1932 to 1945. Two patients died from airway obstruction by solids and 40 who aspirated liquids had short-lived asthma-like symptoms.[2-6] This condition is now known as Mendelson's syndrome, an eponym for aspiration pneumonitis.

Fearing the occurrence of Mendelson's syndrome in patients undergoing elective surgery, Cohen and Dillon developed the concept of "nil by mouth from midnight". They recommended that all patients fast after midnight regardless of their preoperative risk factors.[1-4]

MR Checketts, in his editorial in *Anaesthesia*, remarked that fasting for an "empty stomach" might be a prime example of medical sophistry. This conclusion seems logical but lacks supporting evidence and is essentially a fallacy.[3] Although it appears reasonable to believe that fluid fasting would ensure an empty stomach prior to the induction of anaesthesia, thereby reducing the risk and severity of aspiration, gastric ultrasound studies have indicated that fasting does not achieve an "empty stomach" in approximately 10% of patients.[7]

In 1974, Roberts found that around 25 mL (0.4 mL/kg) of gastric juice indicated a high risk of aspiration in monkeys.[1,4] Recent studies set the threshold for an empty stomach at 1.5 mL/kg, the 95th-97th percentile of gastric volume in fasting adults.[7] The body secretes about 2.5 L of gastric juice and saliva daily, increasing up to 600 mL/hr during the cephalic phase of digestion. Therefore, fasting may not ensure an entirely empty stomach.[2] The timeline of the development of concepts and fasting rules is shown in Figure 1.

Figure 1. The fasting timeline



Information sourced from Maltby (2006),[1] Ruggeberg et al. (2024),[2] Checketts (2023)[3] and Gan et al. (2024)[4]

The dogma in anaesthetic practice persists – Why do we need to challenge it?

Brady et al., in a 2003 Cochrane review, not only showed that there was no evidence to suggest that a shortened liquid fast was associated with increased aspiration risk, regurgitation, or related morbidity compared to a "fast from midnight" but also showed that allowing patients to drink water preoperatively resulted in significantly lower gastric volumes.[8] The recommendations arising from this study became central to subsequent fasting guidelines worldwide.

The current guidelines recommend a two-hour fast from clear liquids and a 6-hour fast from solids for adults.[3, 9-11] However, adults' typical fasting time from clear liquids is nine-12 hours.[11] There are many reasons why patients are inappropriately fasted, from the ease of writing "NPO" (nil per os) or "FFMN" (fast from midnight) to staff and patient anxiety regarding fear of aspiration, cancellations, inability to easily reschedule and the belief that it is safer.[2,3,10] Prolonged fasting is still a significant issue in many hospitals worldwide and does not come without harm.

Despite a paucity of evidence and theoretical pathophysiological basis for harm with clear liquid fasting shorter than two hours, previous institutional efforts to reduce fasting time have demonstrated limited or non-lasting efficacy.[12]

With a desire to reduce liquid fasting duration and increasing confidence that clear liquids empty rapidly from the stomach, more anaesthetists are adopting approaches like "Sip Til Send", "Drink Until Called", "Liberal clear liquids fasting" or "Unrestricted drinking before surgery".[2]

The latest update of the *PG07* 2024

Regarding our guidelines in Australia and New Zealand, the Australian and New Zealand College of Anaesthetists (ANZCA) recently updated the professional document *PG07 Guideline on pre-anaesthesia consultation and patient preparation 2024*.[13] The Appendix 1 refers to matters related to fasting guidelines. The recommendations for solid food were unchanged, but the approach for clear liquids has been updated to reflect the latest published evidence. The document's salient points are:

- Recognition of "Sip Til Send" as *"an emerging practice gaining increasing acceptance and has been shown to reduce fasting duration."*
- *"To date, strategies involving liberal clear liquids have not shown significant evidence for increased aspiration risk..."*
- Multifactorial risk factors contribute to delayed gastric emptying.
- Gastric ultrasound could be used as a tool to guide further management for the risk of aspiration.[13]

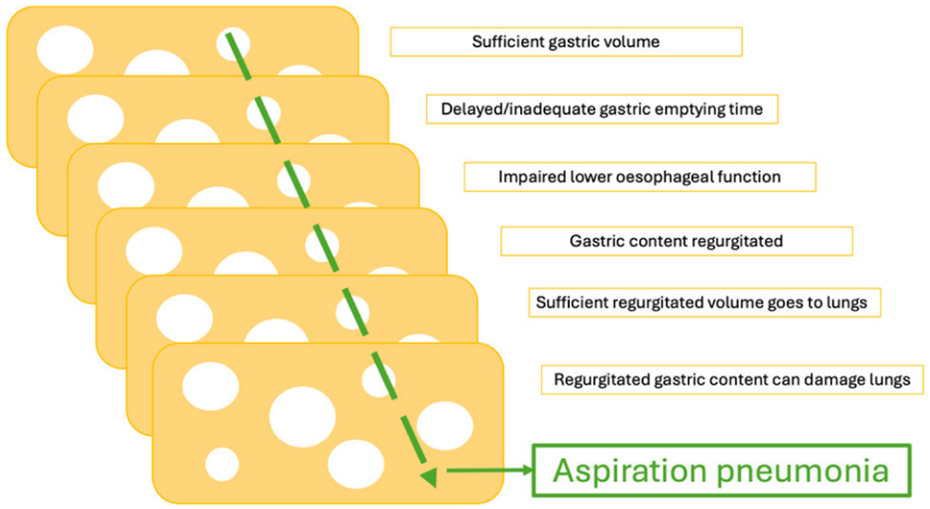
THE CHALLENGES IN DETERMINING ASPIRATION RISK

Perioperative aspiration – A rare event

The risk of aspiration following an elective procedure ranges from one in 900 to one in 10,000, whereas for an emergency tracheal intubation, it occurs in approximately one in 12 people.[7,10,14-16] Serious complications associated with aspiration are predominantly due to solids, while clear fluid aspiration rarely results in significant consequences.[2,4] There is currently no evidence indicating a correlation between drinking clear liquids and the risk of aspiration in elective surgery patients.[2] In severely ill adults, mortality from aspiration is typically caused by acute asphyxia resulting from complete airway obstruction by solids or particulate matter.[16]

A Swiss cheese model for aspiration pneumonia (Figure 2) illustrates how several factors need to align for aspiration pneumonia to occur in an elective setting, even with adherence to fasting recommendations. There must be enough gastric content present, which implies delayed gastric emptying and the lower oesophageal sphincter must be impaired, such as in patients with reflux disease or an inability to hold the gastric pressure caused by tracheal intubation reflexes secondary to inadequate anaesthesia.[2,17] The residual gastric content must then be regurgitated and reach the bronchi to cause pulmonary injury.[2] After the initial chemical pneumonitis resulting from the acidic nature of gastric contents, only a subset of these patients will develop pneumonia.

Figure 2. Aspiration pneumonia sequence of events

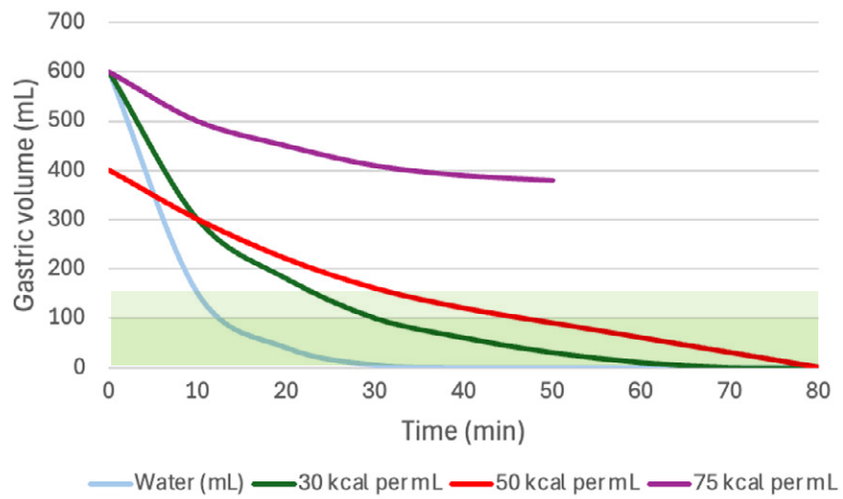


Adapted from Ruggeberg (2024)[2]

Variability of gastric emptying

Clear liquids (water/low calorie) have a half-life of 10-15 minutes, with the stomach emptying 500 mL of water in 20-30 minutes, though there is 30% inter-subject variability (Figure 3).[2,3,18,19] Gastric emptying of clear liquids follows first-order kinetics, in which an increase in fluid volumes in the stomach results in an increased rate of gastric emptying.[2,14] It is also proportional to the rate of filling; therefore, drinking clear liquids also speeds up the emptying of the stomach.[2,14] Whereas, gastric emptying times are slower with higher energy clear liquids as the receptors in the small intestines regulate gastric emptying to approximately 200 kcal/hr to prevent the intestine from receiving more nutrients than it can absorb.[2] With non-clear liquids, gastric emptying time depends on the calorie and nutrient content, whereby carbohydrates empty faster than proteins and fat.[2,19] It is also interesting to note that drinking tea or coffee with a dash of milk (up to 20% of the total volume or 50 mL) is comparable to drinking black coffee or tea.[2,20]

Figure 3. Gastric emptying after drinking water and clear carbohydrate liquids with three different calorie contents



The range of normal gastric residual volumes is indicated in green.

Glucagon-like peptide-1 receptor agonists (GLP-1 RA) and delayed gastric emptying

Emerging weight-loss strategies using novel drugs such as long-acting glucagon-like peptide-1 receptor agonists (GLP-1 RA) (e.g. semaglutide (Ozempic®)) are increasingly being used in the community. Those drugs are known to significantly delay gastric emptying for solids. Silveira et al. performed a retrospective analysis of patients undergoing elective upper endoscopy and the relationship between perioperative semaglutide and gastric content.[21] The study showed that perioperative semaglutide use was associated with an increased residual gastric volume in 24.2% of patients taking the drug compared with those who were not ($p<0.001$).[21] Solid content was present in 85.2% of the patients taking the drug.[21] Only four patients met the study criteria for an increased gastric fluid volume of >0.8 mL/kg, but this volume is considered by some to be below the threshold for increasing aspiration risk (baseline gastric secretions of >1.5 mL/kg).[21,22]

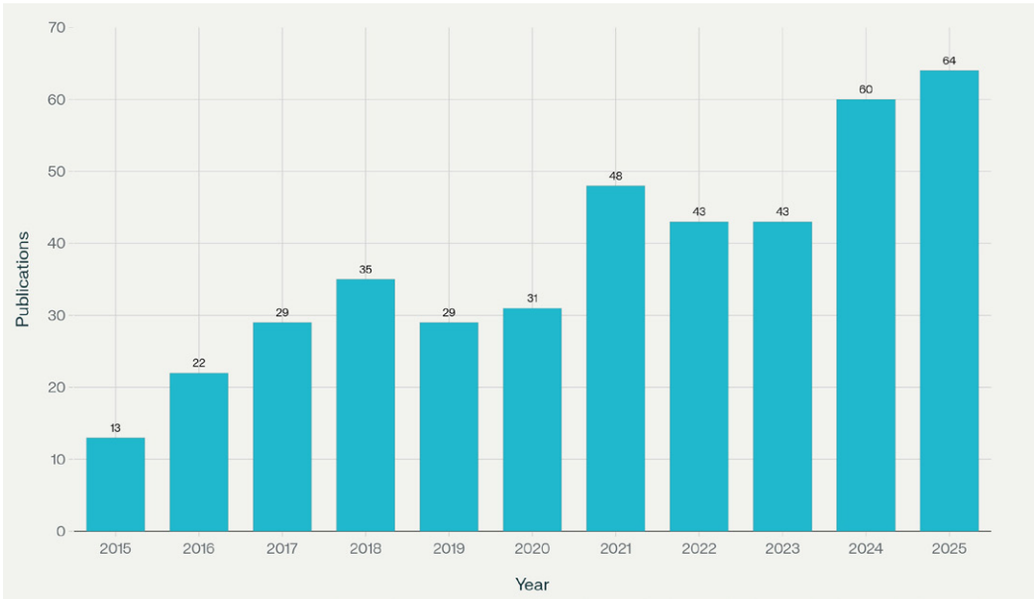
In 2024, Facciorusso published a large meta-analysis on the effects of GLP-1 RA on upper gastrointestinal endoscopy. The study also showed increased residual gastric contents and more frequent aborted procedures in patients using those medications.[23]

Several studies on perioperative management of GLP-1 RAs are currently being conducted worldwide. As of the time of writing of this article, there is still much controversy around the topic of withholding (and how long before surgery) or not. Numerous colleges and medical societies across the globe have released joint statements to address the issue, but at this stage, there is not enough evidence to reach a consensus.

Emergence of gastric ultrasound as a risk assessment tool

Given the widespread use of GLP-1 RA drugs and the move to a more liberal liquid fasting practice, there is an increased demand for an objective method to assess stomach content. According to PubMed data (Figure 4), interest in preoperative gastric ultrasound as a risk assessment tool has increased exponentially among anaesthetists and perioperative physicians, reflected by the number of publications in the last decade.

Figure 4. Number of perioperative gastric ultrasound publications in the last decade
Source: PubMed



Even though gastric ultrasound is known to be highly sensitive and specific, it is still operator dependent. What is quite reassuring is that according to a recent study from 2022, Tankul et al. demonstrated that many anaesthetists might have an advantage compared to others when learning gastric ultrasound.[24] Anaesthetists with experience in regional blocks required only nine scans after a teaching intervention in a

workshop to achieve 98.7% sensitivity and 93.8% specificity.[24] The learning process for anaesthetic trainees and non-anaesthetists to achieve success rates of 90 to 95% may take longer, even after attending a three-hour workshop and performing 24 to 33 scans with expert feedback.[25] The positive and negative predictive values are both important attributes of a test. But when it comes to gastric ultrasound, the negative predictive value is the most important one, given the implications of a true "empty" stomach finding for aspiration prevention.[22]

In *Australasian Anaesthesia* 2023 Sidhu and Pozaroszczyk published a comprehensive summary of gastric ultrasound to eliminate guesswork in perioperative medicine and provide guidance for interested anaesthetists. It also challenges the question "Do you feel hungry?" that is commonly asked in the pre-anaesthetic room or before induction of anaesthesia. The question is very subjective since 86% of patients feel hungry again before the completion of gastric emptying, and 30% of them feel hungry after a meal.[26]

Like any risk assessment tool, gastric ultrasound in elective patients should take into consideration other risk factors that will delay gastric emptying and increase aspiration risk when assessing those patients. It is important for anaesthetists wishing to incorporate gastric ultrasound into their practice that they receive formal training (e.g. a workshop) then further supervised scans to obtain competence.[26]

"SIP TIL SEND"

What is the "Sip Til Send" approach?

"Sip Til Send" is a pragmatic approach to clear liquid fasting, with the aim to reduce patient discomfort and the harmful effects of prolonged deprivation of water and energy.

Two hours of fasting from clear liquids is widely demonstrated to be safe and used in all major fasting guidelines worldwide.[13,27,28] However, it has repeatedly been demonstrated that when a strict one- or two-hour clear liquids fasting guideline is in place, patients fast significantly longer.[9,10,29-32] A policy of allowing clear liquid consumption until called to theatre significantly reduces both the median fasting times and variability in fasting times without a demonstrated increase in regurgitation or pulmonary aspiration risk.[2,30,32,33] The "Sip Til Send" approach is more straightforward for both staff and patients and, when coupled with education and reassurance, is both straightforward and effective.[3]

There are various implementations of "Sip Til Send", but the common key features are as follows:

- Solids and non-clear liquids stop six hours before anticipated arrival at theatre.
- Clear liquids may continue up until the time the patient is sent for the procedure.
- Children may consume human breast milk up until three hours before surgery, and those under 12 months may consume formula or non-human milk up to four hours prior. Children over 12 months must withhold formula and non-human milk for six hours.[13]
- Medications can be taken when due with water.
- Emergency cases can follow "Sip Til Send" unless otherwise advised by a surgeon or anaesthetist.
- Fluid restrictions for medical reasons (e.g. renal or cardiac failure) should be maintained.
- Oral intake restrictions for surgical or medical reasons should be maintained.
- If there is confusion regarding a patient's individual circumstances, the co-ordinating or treating anaesthetist should be consulted.
- Patients excluded from "Sip Til Send" should still be encouraged to consume clear liquids up until two hours preoperatively (where safe to do so).

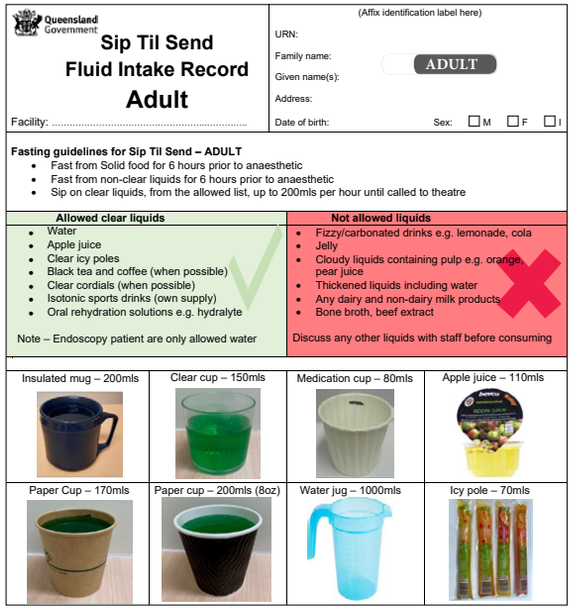
Variations in established protocols are mostly centred around the allowable amount of fluid intake; however, a safe maximum volume is not clearly defined.[2] Hospital-issue drinking cups are typically between 170 mL and 200 mL; therefore, most protocols specify an hourly volume allowed for adults. An amount of 3 mL/kg/hr is considered safe for children.[13,34]

As per traditional fasting recommendations, allowable liquids are those containing water and simple sugars. Liquids containing significant amounts of fat, protein, or fibrous material are excluded. This includes thickened fluids, and as such, patients requiring these due to pharyngeal dysfunction are excluded from "Sip Til Send". A small volume of milk in tea or coffee is typically allowed in the United Kingdom; indeed, this amount has not been shown to remain in the stomach longer than beverages without milk.[20,28] This practice is not common in Australian early adopters, given the lack of inclusion in our pre-existing guidelines.[13] Chewing gum and boiled candy must be removed before induction of anaesthesia due to the risk of inhalation. However, neither has been demonstrated to cause an increased risk of regurgitation or aspiration and consumption of these should not cause delay or cancellation of surgery.[13,28] Jelly is also not considered a clear liquid for "Sip Til Send" purposes; however, it has also been demonstrated to empty from the stomach like a liquid rather than a solid.[35] These equivocal items are often excluded from protocols mainly for the sake of simplicity (Table 1).

Table 1. Example of liquids allowed or not in "Sip Til Send" protocols

Allowable clear liquids	Not allowed
Water	Cloudy/pulpy juices
Clear juice without particulate matter	Thickened clear fluids
Cordial	Dairy/milk alternatives
Icy poles (if clear when liquid)	Bone broth/stock
Black tea or coffee	Protein drinks (even if clear)
Isotonic sports drinks	Carbonated beverages
Oral rehydration solutions	Jelly
Ice cubes	Lollies

Figure 5. "Sip Til Send" fluid intake record – Cairns Hospital


Queensland Government

Sip Til Send
Fluid Intake Record
Adult

Facility: .....

(Affix identification label here)

URN:

Family name:

Given name(s):

ADULT

Address:

Date of birth: Sex: ☐ M ☐ F ☐ I

Fasting guidelines for Sip Til Send – ADULT

- Fast from Solid food for 6 hours prior to anaesthetic
- Fast from non-clear liquids for 6 hours prior to anaesthetic
- Sip on clear liquids, from the allowed list, up to 200mls per hour until called to theatre

Allowed clear liquids

- Water
- Apple juice
- Clear icy poles
- Black tea and coffee (when possible)
- Clear cordials (when possible)
- Isotonic sports drinks (own supply)
- Oral rehydration solutions e.g. hydralyte

Note – Endoscopy patient are only allowed water

Not allowed liquids

- Fizzy/carbonated drinks e.g. lemonade, cola
- Jelly
- Cloudy liquids containing pulp e.g. orange, pear juice
- Thickened liquids including water
- Any dairy and non-dairy milk products
- Bone broth, beef extract

Discuss any other liquids with staff before consuming

Insulated mug – 200mls | Clear cup – 150mls | Medication cup – 80mls | Apple juice – 110mls

Paper Cup – 170mls | Paper cup – 200mls (8oz) | Water jug – 1000mls | Icy pole – 70mls

Most centres have abandoned patient exclusion criteria, due to the complexities in providing a list of specific contraindications. Furthermore, most conditions that impede gastric emptying slow the transit of solids significantly more than clear liquids.[2,21,36,37] A non-exhaustive list of conditions potentially impacting the safety of clear liquids consumption is included in Table 2, which should be evaluated in the individual patient with the same approach as the traditional assessment of fasting status. Pharyngeal dysfunction, achalasia, and gastro-oesophageal reflux do not alter gastric emptying of clear liquid and are thus not considered preclusions to the "Sip Til Send" approach.[2]

Table 2. Exclusion criteria for "Sip Til Send" and unclear considerations for inclusion

Exclusion criteria[10,11]	Considerations (unclear):
NBM for surgical reasons	Trauma[38] or GIT pathology[31]
NBM or thickened fluids for medical reasons (e.g. post stroke)	Pyloric stenosis[38] and other anatomical disorders[29]
Specific procedural fasting instructions (e.g. bowel preparation or radiographic studies)	Gastroparesis
If instructed by anaesthetist	GLP-1 receptor agonists
Patient refusal	Vagotomy[39]
	Prior bariatric or oesophageal surgery[13]
	High-dose opioids[13]
	Daily cannabis use[7]
	Severe Parkinson's disease[7]

NBM = nil by mouth, GIT = gastrointestinal, GLP-1 = glucagon-like peptide-1

The benefits of "Sip Til Send" and harms of extended liquid fasting

A 'Sip Til Send' approach benefits patients by reducing unnecessary dehydration and lack of carbohydrates caused by traditional fasting. With a two-hour clear fluid fasting rule, theatre schedules often lead to patients fasting longer than needed and delays due to "inadequate" fasting. Precise and consistent staff communication to provide constant updates about theatre timing must be enforced to achieve optimal fasting duration, although this is difficult to achieve in real-world practice.[9,33]

The concern regarding shortened fasting times is the potential for increased gastric volume and intraoperative regurgitation/aspiration. However, not only have these complications not been demonstrated by any of the early adopters, but the risk may even be reduced by ongoing consumption of carbohydrate-containing solutions.[3,10,29,31] Gastric pH is increased by the presence of dilute simple carbohydrate solutions, which increases gastric pH.[6] Solid fasting compliance may also be more likely with a more generous allowance of clear liquids.[29,40]

Patient and guardian experience is certainly improved with "Sip Til Send", with increased comfort and reduced hunger, anxiety, and fatigue.[2,3,10] In particular, it is undisputable that paediatric behaviour is improved with continued consumption of water and calories.[10,33,41] Nausea and vomiting are reduced both pre- and postoperatively, as are headaches from dehydration or caffeine withdrawal.[6,42-46] Postoperative delirium and related morbidity in the adult population also correlate with the duration of the liquid fast.[47] Finally, avoidance of dehydration may improve venous cannulation success.

Patient physiology and metabolism benefit from reduced water and sugar intake deprivation, particularly in the more vulnerable patients – small children and frail or medically complex patients.[48] Improved water intake reduces dehydration, hypovolaemia, hypotension, and renal impairment.[2,38,49] Perioperative blood sugar management is improved with reduced caloric deprivation, where prolonged fasting can contribute to decreased insulin sensitivity and subsequent elevated blood sugars postoperatively.[2,50,51] Ketosis and biochemical derangement are increased with prolonged fasting, as is the catabolism of muscle deleterious to patient strength and recovery.[41,51,52] Maintenance of preoperative oral intake may also promote early return of bowel function, which, alongside the reduction in postoperative nausea and vomiting, is beneficial to restoring early oral intake in accordance with "enhanced recovery after surgery" principles.[33]

It is logical that the benefits of a "Sip Til Send" approach and reduced fasting times for clear liquids may also improve health system resource utilisation and decrease expenditure. One would expect reduced antiemetic, intravenous (IV) fluids and vasopressor use, particularly in day-stay surgery.[10] The self-directed administration of liquids reduces staff workload by patients and the gains in efficiency resulting from this streamlined approach. There may also be improved theatre utilisation due to reduced delays when patients have fasted for fewer than two hours and decreased length of hospital stay resulting from postoperative complications.

Limitations of "Sip Til Send"

Thus far, it appears there are two primary limitations to the "Sip Til Send" approach to clear liquid fasting. The first is the potential for increased gastric volume, regurgitation, or aspiration in healthy and comorbid patients. The second is the institutional and cultural changes required to implement this strategy effectively.

As discussed, there has been no demonstrated increase in either regurgitation or aspiration in departments that have been early adopters of the "Sip Til Send" approach.[3,57] This is despite some centres reporting median liquid fasting times with "Sip Til Send" of less than two hours.[57] Events of regurgitation and aspiration are not correlated with clear liquid intake or timing but instead a variety of clinical factors, including inadequate anaesthesia, gastric hyperinflation, and emergency surgery.[7,31,32] Similarly, it appears that even when gastric transit is delayed, the residual fluid volume is not dissimilar when a two-hour versus "Sip Til Send" fast is deployed.[7,17,33] Although the issue still requires clarification, it appears that patients with potential delayed gastric emptying should be assessed and treated for aspiration risk using standard processes and may then, if deemed safe, participate in "Sip Til Send".

With regards to implementing a change to clear liquid fasting protocols, one can expect to encounter some resistance, as with any change to long-established practice. Bosse and colleagues discuss approaches to this, and local barriers should be identified and addressed where possible in the planning stages.[53] Reference to existing evidence-based care indicators and established practice in respected centres is essential, with widespread education and reassurance regarding the goals, benefits and safety before roll-out.[31] The process requires a multidisciplinary team with credible and committed leaders to champion the cause alongside an established route for stakeholders to direct concerns or questions.[54]

Implementation of "Sip Til Send" can be supported by easily accessible drink stations or beverages being handed out on patient admission, along with written instructions for patients and wall posters.[3,54] Examples of these are widely available from early-adopter health networks. The experience of patients and staff should be evaluated once these new fasting processes have been changed, and these results, alongside audit data regarding patient outcomes, should be used to further refine protocols. Demonstrating safe practice and improved patient and staff experience without increased complications will further improve buy-in and enthusiasm.

THE "SIP TIL SEND" INITIATIVE – SUCCESS STORIES

Early adopters

The recent surge of interest in "Sip Til Send" stemmed from work by the Scottish team led by MR Checketts in 2021 when they first coined the term and successfully introduced it in December of that year after months of planning and education.[3]

The "Sip Til Send" protocol adopted by Checketts allowed patients to sip one cup (170 mL) of clear liquid per hour until they were transported to theatre. The implementation successfully reduced median fluid fasting times from six hours to 17 minutes. To date, there has been no increase in reported adverse events through ongoing governance monitoring.[3] They subsequently supported many hospitals across the United Kingdom and internationally to launch their own programs.

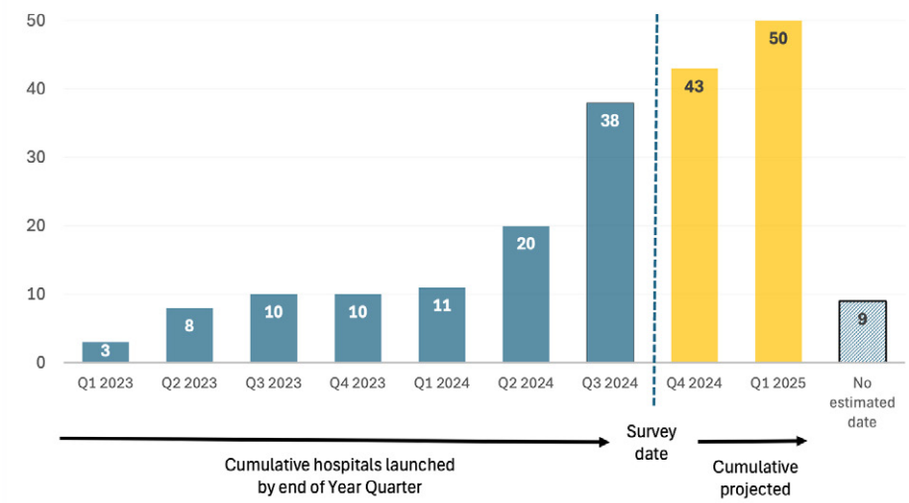
Growth of "Sip Til Send" in Australasia and formation of the Australasian Sip Til Send Network

The practice of allowing patients to drink until theatre to minimise fasting time is, in fact, not new. Some centres in Australia and abroad have been practising this for years.[55,56] "Sip Til Send" is simply a modern rebranding that came at the right time when anaesthesia practice was increasingly focused on improving perioperative care.

The Australasian Sip Til Send Network was established by one of the authors (PM) to promote "Sip Til Send" among the anaesthesia community and to form a local support base for hospitals wishing to adopt the program. One of the initial goals was to promote universal rules for "Sip Til Send" that can be applied to all hospitals, hoping to reduce the incidence of protocol breaches due to confusion arising from staff and patients moving between different hospitals. However, protocols must fit local needs, resulting in fine-tuning to accommodate each health service's idiosyncrasies. Some of the observed protocol variations stemmed from current controversies, such as how to manage preoperative fasting for patients on GLP-1 RA medications, with 31% of hospitals not allowing "Sip Til Send" for patients on these medications.[57]

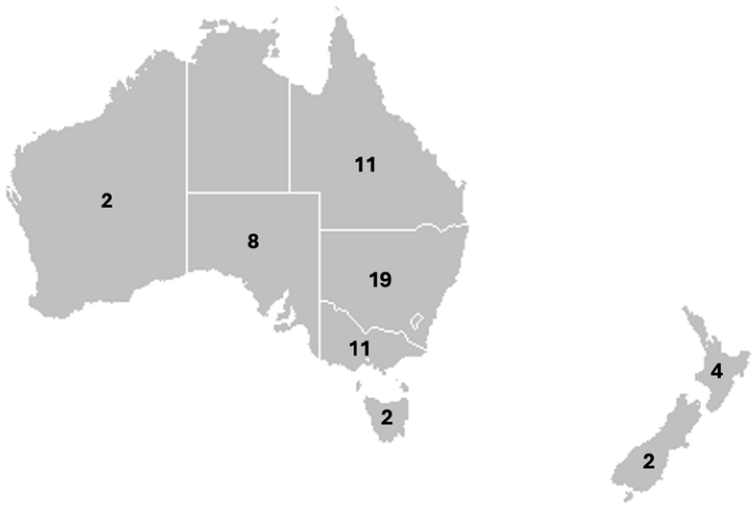
The collaboration of the Australasian Sip Til Send Network, the inclusion of "Sip Til Send" in ANZCA fasting guidelines, and a concurrent worldwide supply shortage of IV fluids, spurred the rapid growth of "Sip Til Send" in Australasia during 2023-2024. Data from an Australasian "Sip Til Send" implementation survey undertaken in late 2024 shows the rapid proliferation of "Sip Til Send" programs and their geographic distribution (Figures 6 and 7).[57]

Figure 6. Cumulative number of Australasian hospitals running "Sip Til Send"



Q = quarter; Y-axis is number of hospitals

Figure 7. Hospitals represented in Australasian "Sip Til Send" Implementation Survey, by region



"Sip Til Send" outcomes

In an unpublished audit of two weeks of theatre cases involving 619 patients after "Sip Til Send" was introduced, Cairns Hospital reported a median liquid fasting time of 1.8 hours. Of the 619 patients, 296 (48%) were booked for emergency surgery, and 52 (8%) were children. On subgroup analysis, median

liquid fasting times for emergency cases was 2.3 hours, for elective cases was 1.6 hours, for patients who participated in "Sip Til Send" (65% of all cases) was 1.5 hours, and for patients who did not participate in "Sip Til Send" was 2.9 hours. These were significant reductions from the hospital's audits prior to "Sip Til Send", where reported median times were 13 hours for adult inpatients, 5 hours for adult outpatients and 7.5 hours for outpatient children. Interestingly, with an active "Sip Til Send" program, even patients who did not participate in "Sip Til Send" had shorter fasting times compared to patients before the introduction of the program. As an example of the Hawthorne effect, it is thought that all patients may benefit when a hospital runs a "Sip Til Send" program, regardless of whether they participate.

Cairns Hospital has a QR-code-based system for reporting cases of regurgitation or suspected aspiration and frequently encourages staff to submit cases, which are later reviewed individually for diagnostic verification. It has reported no change in the incidence of aspiration in the periods before and after the introduction of "Sip Til Send" (Figure 8).

Figure 8. Aspiration and regurgitation audit from Cairns Hospital

	1st Feb to 14th July 2024		1st Aug to 31st Dec 2024	
	Pre-SipTilSend		SipTilSend	
	Regurg	**Aspiration**	**Regurg**	**Aspiration**
Frequency	33	7	23	7
Denominator	7368	7368	6829	6829
Risk	0.45%	0.10%	0.34%	0.10%
Probability	1 in 223	1 in 1053	1 : 297	1 : 976

Regurg = regurgitation

An Australasian "Sip Til Send" survey found that hospitals reported a reduction in liquid fasting times and no increase in aspiration rates.[57]

Role of multicentre studies

While single-centre audits have, to date, not reported a change in aspiration incidence, these are all underpowered. Adequately powered studies to compare such an event as rare as pulmonary aspiration require very large numbers of patients. Addressing this challenge, the Australasian Sip Til Send Network is conducting the Australasian Multicentre Aspiration Risk Study (MARS), a multicentre observational study assessing the risk of aspiration in hospitals practising "Sip Til Send", compared to those with more restrictive fasting programs.

CONCLUSION

"Sip Til Send" represents a potentially transformative approach in perioperative care that allows patients to safely consume approved clear liquids up until they are called to the operating theatre, thereby shortening their fasting period. This reduction in fasting time is associated with several benefits, such as more effective gastric emptying, decreased gastric residual volume, minimised physiological stress during anaesthesia, lower rates of postoperative nausea and vomiting (PONV), and enhanced patient comfort and satisfaction.

"Sip Til Send" may have the potential to have significant economic benefits due to its flexibility in adapting to changes in theatre scheduling and improving theatre utilisation times. It may be particularly valuable in reducing extended fasting periods for inpatients awaiting emergency surgery, where frequent delays due to theatre unavailability are common. Future studies may look at other benefits associated with "Sip Til Send", such as reducing the need for IV fluid therapy, hospital length of stay, and postoperative complications.

Until now, audited data from early adopters of "Sip Til Send" have not demonstrated significant evidence of increased aspiration risk compared to more conservative fasting guidelines, making "Sip Til Send" a promising and reassuring practice change to liquid fasting.

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Birth trauma and the anaesthetist

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Amy Dawes is the co-founder and CEO of the Australasian Birth Trauma Association (ABTA). Established in 2016, ABTA is a peer-led organisation helping to prevent, diagnose, and treat birth-related trauma. A firm believer in collaborative care, Amy has worked with parents and a wide range of health professionals involved in caring for birthing families to increase community understanding of birth-related trauma, provide support and education, conduct research, and advocate for change.

Edited by Professor Alicia Dennis

Consider the following fictional story that illustrates an example of psychological birth trauma:

Two weeks postpartum, Ms S remains impacted by her traumatic birth.

Hoping for some relief from the intense contractions that had been going on for hours, she requested an epidural. However, multiple insertion attempts were challenging, adding to her distress. As she struggled to remain still through contractions, the anaesthesia team worked to place it successfully. When it finally took effect, the initial relief was brief, soon replaced by sharp pain in her lower back and groin. She was reassured that this could be due to her baby's position and that the epidural was working as best as possible under the circumstances.

As hours passed, she heard the words: she was "failing to progress". The decision was made to proceed to an emergency caesarean section. Rushed to the operating theatre, she felt overwhelmed. Consent forms were presented, risks explained quickly in the urgency of the moment. Her partner held her hand tightly, his face pale with concern.

In the operating theatre, additional medication was administered through her epidural. She noticed she could still move her feet despite being told they would go weak. As the procedure began, she experienced intense pain. She cried out, panicked. The team acted quickly, placing a mask over her face to administer general anaesthesia. The last thing she saw was her partner's worried expression before everything faded to black.

She woke in the recovery room, groggy, with her baby and husband beside her. A brief explanation was given — she had been put under general anaesthesia. In the whirlwind of postpartum recovery, no further follow-up occurred of the events she experienced in labour and the operating theatre.

Now, the memories replay in her mind — the fear, the pain, the sudden general anaesthetic during her caesarean section and birth of her child. The experience weighs heavily on her, making it difficult to fully embrace these early days of motherhood. She longs for understanding, for closure, and for a way to heal.

INTRODUCTION

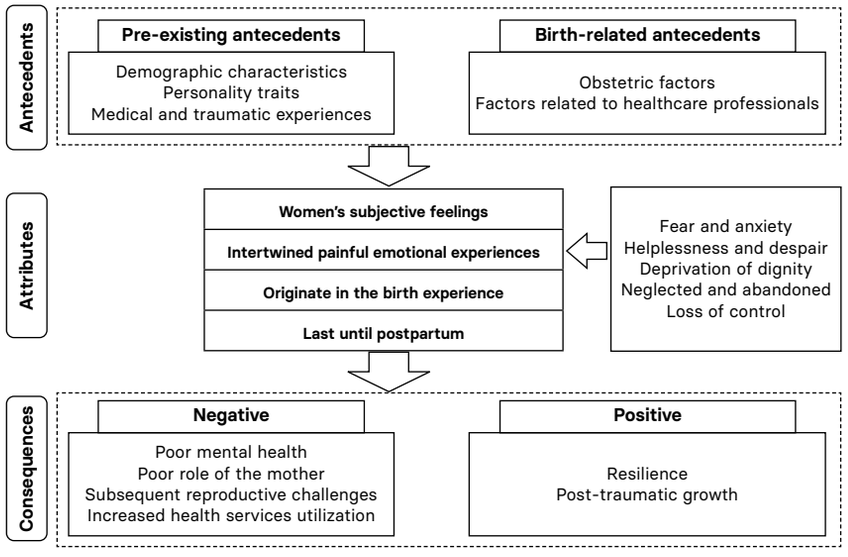
The birth of a baby is usually a memorable, emotionally charged and profoundly impactful moment in the lives of parents. Society perceives childbirth as an exciting and positive experience. However, research suggests that one in three pregnant people experience psychological trauma associated with birth.[1-6] Birth trauma has received increased recognition in Australia recently, particularly as a result of the NSW Parliament Legislative Council Select Committee on Birth Trauma Report released in May 2024.[7]

Prior to 2000, the terminology 'birth trauma' was exclusively used to refer to maternal or neonatal physical trauma after birth, such as pelvic floor dysfunction, neonatal cephalohaematoma, clavicular fracture or brachial plexus injury.[4] Since then, the concept has evolved significantly to include both physical and psychological components.[6,8] The Australasian Birth Trauma Association (ABTA) describes birth trauma as a person's experience of interactions and/or events related to childbirth that cause overwhelmingly distressing emotions or reactions, leading to short-and/or long-term negative impacts on a pregnant person's health and wellbeing.[2,8]

Birth trauma has a widespread impact on the birthing person and their partner or support person. Physical birth trauma now includes birth injuries such as perineal tears, pelvic floor trauma or ongoing symptoms such as incontinence, nerve damage, infective complications and persistent pain.[9-11] These processes are often linked with psychological birth trauma — the focus of this article — particularly if there is a delay in diagnosis and treatment. Psychological birth trauma is harder to define but has been noted to have four key attributes in the psychology literature:[6,8,12]

1. Subjective feelings
   a) Noting that childbirth appearing normal and straightforward to health professionals can be perceived as traumatic by the parturient, and not all patients with complications have traumatic experiences.
2. Painful emotional experiences
   a) Such as fear and anxiety, helplessness and despair, deprivation of dignity, feeling neglected and abandoned, and loss of control.
3. Originate in the birth process.
4. Persists in the postpartum period.

Figure 1. The concept of psychological birth trauma[6]



The negative effects of psychological birth trauma can be short-lived or long-lasting. They can impact the parent-infant relationship, the confidence to cope with the challenges of parenting, breastfeeding behaviour, partner relationships and future reproductive decisions.[4,6,13] Experiencing birth trauma increases the probability of postnatal depression by four to five times.[14] In addition, evidence suggests that 4-6% of postpartum patients in the community meet diagnostic criteria for postpartum post-traumatic stress disorder (PTSD) following a traumatic birth experience.[15]

Psychological birth trauma is often preventable and treatable if anticipated and proactively managed.[7] Genuine, compassionate care and shared decision-making, coupled with heightened awareness, are instrumental to its prevention. Anaesthetists are well-placed to assist in preventing and decreasing the impact of psychological birth trauma. As Vogel and Homitsky suggest, "Our expertise in crisis management should also encompass acute emotional crisis management and the acceptance of our role as 'guardians of psychological safety'".[16]

STEP 1: AWARENESS OF FACTORS CONTRIBUTING TO PSYCHOLOGICAL BIRTH TRAUMA

Psychological birth trauma can be influenced by various risk factors, including unexpected events or complications during pregnancy, labour, and birth.[4,15,17,18] These may involve maternal, fetal or neonatal emergencies, as well as unplanned interventions that the patient does not fully understand. To mitigate such risks, early intervention and preventive measures should be integrated into pregnancy management, particularly for conditions like pre-eclampsia, haemorrhage, venous thromboembolism and sepsis.

A history of trauma, whether related to previous birth experiences or unrelated life events, can further increase vulnerability.[6] In such cases, a trauma-informed care approach is crucial, ensuring healthcare providers offer compassionate and patient-centred support that minimises re-traumatisation.[19] Additionally, pre-existing mental health conditions, including tokophobia — an intense fear of pregnancy and childbirth — can heighten psychological distress during the perinatal period. Socioeconomic disadvantage, social isolation, and limited health literacy further exacerbate the risk, making it essential for healthcare systems to provide targeted support to vulnerable populations.[1,11,20]

Physical pain and birth-related injuries are also key contributors to psychological trauma.[17,21] Ensuring effective pain management, along with strategies aimed at reducing physical trauma during birth, are both proactive and protective strategies. Furthermore, prolonged and precipitous labour have been associated with increased distress, as has the experience of being separated from one's baby immediately after birth.[17] Early recognition of these risk factors, combined with proactive education and support, can significantly improve outcomes.[11] Although some instances of birth trauma are inevitable, better recognition, preparation and support are paramount to help manage the impact.[7]

Importantly, psychological birth trauma is not solely the result of patient-related risk factors; external influences within the healthcare system also play a significant role. The structure of maternity models can either protect against or contribute to trauma, with patient survey data indicating a strong preference for continuity of care and trusted relationships with providers. Access to these models can be limited by socioeconomic factors, pregnancy-related factors and geographic location.[7] Regardless of the model, collaborative, compassionate and trauma-informed care is protective against birth trauma.[3]

Mistreatment and neglect within healthcare settings further compound the issue. Reports indicate that one in ten birthing individuals have experienced dismissal, neglect or inappropriate treatment. At the same time, recent Centers for Disease Control and Prevention (CDC) data in the United States of America suggest that 20% of obstetric patients encounter some sort of mistreatment.[3,7,22] Violations of physical privacy, ignored requests for help, and verbal abuse are among reported concerns, with rates being disproportionately higher among minority and disadvantaged populations.[22] In addition, a lack of informed consent and choice, as well as misdiagnosis and delayed diagnosis, have all been identified as contributing to the incidence of birth trauma. When these issues are accompanied by a failure to provide open disclosure, the psychological impact is often worsened.[7]

Another significant factor is the denial of pain relief or the perception that one's pain is being dismissed. Inadequate pain management can greatly intensify distress.[23] Similarly, medical interventions that occur in an urgent or chaotic environment can be particularly distressing. According to the Centre for Women's Health Research and Maternity Choices Australia, the interventions in Table 1 are particularly triggering:[4,7,24-26]

Table 1. Interventions and their risk of emotional distress during labour

Intervention	Increases risk of emotional distress during labour by
Induction of labour	1.5x
Episiotomy	1.3 to 1.6x
Instrumental delivery	1.6 to 2.4x
Emergency caesarean birth	2.5 to 3.1x

PTSD is defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM) as exposure to a traumatic event perceived as a threat of death or serious injury to oneself or others and subsequent symptoms of reexperiencing, avoidance and hyperarousal. According to a pan-European multidisciplinary group of birth trauma researchers known as COST Action DEVOTION Ca18211, PTSD is estimated to occur overall in one in 11 patients with caesarean deliveries at two months postpartum and is predicted to occur more often in low or middle-income countries. However, research is limited in these settings.[4] Caesarean sections after induction of labour (odds ratio (OR) 1.8), postpartum haemorrhage (PPH) (OR 1.6) and high-intensity pain during the postpartum stay (OR 1.90) are also associated with increased risk.[4]

The complex interplay of patient, system and social risk factors, such as stigma around the 'right' way to birth and mental health in general, all contribute to the potential for developing birth trauma.[27] Workforce shortages and pressures on our health systems only compound this. Addressing psychological birth trauma requires a multifaceted approach that not only acknowledges individual patient risk but also recognises the broader systemic influences at play.

STEP 2: ANTENATAL PREPAREDNESS

The Joint RANZCOG/ANZCA/RACGP Position Statement on the provision of Obstetric Anaesthesia and Analgesia Services states "women should be informed prospectively of the obstetric anaesthesia and analgesia offered by a facility/institution. Where specific services (e.g. epidural analgesia) are unavailable, women and their partners should be informed and offered to transfer antenatally to a centre with more comprehensive services".[28] Antenatal access to obstetric patients by anaesthetists is variable and, if it occurs at all, is usually late in the antenatal journey. The mismatch of pre-birth expectations and actuality can lead to birth dissonance and disappointment.[23] Birth trauma could be prevented if parents were better prepared and were provided with well-balanced, evidence-based resources and education prior to delivery, as well as information about the resources available in their birthing environment as recommended by RANZCOG, ANZCA and RACGP.[7,23,28] Many primiparous patients in Australia aim for a birth that avoids pharmacological pain relief due to a widespread but unfounded belief that it is better for them and their baby. However, 75% of pregnant people in Australia ultimately request pharmacological pain relief.[23] Statistically, one in five patients will have an unplanned caesarean section and one in four first-time patients will have an instrumental delivery.[7] Many pregnant people reach the birth suite not having a sound understanding of these procedures. As a result of the inquiry into birth trauma, the NSW government has supported the recommendation to develop minimum standards for access to comprehensive, evidence-based antenatal education for birthing and non-birthing parents covering all aspects of birth.[29] This would include available models of care, potential interventions and a discussion of rights during the birth process

Access to antenatal resources is highly variable and depends on the model of care, marketing of what is available, affordability and palatability of various modalities. In-person attendance to classes often requires a highly motivated, health-literate patient cohort who is time-rich and may incur a cost. Time limitations and a fear of overwhelming new parents can lead to omissions during available education sessions. Overuse of jargon can compromise understanding. Engagement with written or online information requires direction and encouragement to avoid dilution with non-evidence-based opinions freely and easily accessible to parents online or via hearsay. Access for linguistically and culturally diverse populations can also be particularly challenging.

Parents remark that they would have made more informed decisions or felt more comfortable if they had more awareness beforehand.[7,30] All care team members must acknowledge bias based on their own exposures and experiences around birth and be mindful not to project them onto patients. This includes anaesthetists. Ideally, all patients should receive evidence-based information on all options of analgesia and

anaesthesia for delivery. All members of the maternity health care team should be aware of the high-risk patients in which an early labour epidural would be additionally beneficial from a morbidity point of view, and this should be discussed, consented to and planned well before arriving at the birth suite.[31]

In the absence of standardised anaesthetic antenatal education throughout Australia and New Zealand, it is up to providers to know what is available at their centres and direct patients to these resources.[28] Anaesthetists must advocate for reliable anaesthesia-related patient education to be provided during antenatal care. This requires collaboration with other members of the maternity team who see the patient regularly in their antenatal journey and guidance on resources available in the absence of tailor-made programs for the health service (Table 2). Acknowledging that feasibility may be challenging, requests by patients of all risk profiles for anaesthesia review for specific questions about potential anaesthesia involvement in the birthing process should be welcomed, encouraged and funded appropriately.

Table 2. Freely available written antenatal anaesthesia resources

1. ANZCA Pain relief in labour fact sheets[32]
2. LabourPains: Information for expectant parents and healthcare professionals on pain relief choices during labour[33] – multilingual
3. ASA Epidural during childbirth, epidural & spinal anaesthesia and analgesia patient information pamphlets[34]

ANZCA: Australian and New Zealand College of Anaesthetists; ASA: Australian Society of Anaesthetists.

Armed with balanced, unbiased information about potential procedures involved in birth, patients can confidently share their well-thought-out birth preferences while remaining psychologically prepared for the unexpected.

STEP 3: LABOUR AND DELIVERY CONSIDERATIONS

Informed consent

Anaesthetists are legally obliged to obtain consent, including financial consent, where relevant. Consistent with all medical interventional care, it is vital that patients are aware of material risks prior to administering analgesia in labour or providing anaesthesia for deliveries in the operating room.[35] Consent should be individualised and not simply be a tick-box exercise or a standard script for all. Informed consent is an essential element of person-centred care and should be voluntary, free from coercion or pressure, with adequate discussions of alternatives, including the possibility of declining the intervention. Valid consent can be challenging and potentially compromised by a chaotic environment, a sense of urgency, the influence of pain, systemic analgesia and a lack of antenatal preparedness.[36] Although there are unique challenges in the maternity environment, the suggestion that labouring patients are not capable of giving informed consent, even when in pain or medicated, has been debunked in the literature and judiciary,[37,38] Despite this, a 2006 survey demonstrated that 70% of ANZCA anaesthetists believed active labour inhibits a patient's ability to give 'fully informed consent'.[35,39] Concerns included a pregnant person's capacity to consent while experiencing labour pain, the urgency with which some patients demand the procedure, as well as external pressures and stigma.[38,40] Failure to provide informed consent is associated with poorer birth outcomes and directly violates ethical and legal requirements.[41] According to the Birth Trauma Association (BTA) in the UK and ABTA, a lack of informed consent and a perception of coercion are reported by many patients who experience preventable psychological birth trauma.[17,29,42]

Key strategies to provide better-informed consent to labouring and pregnant patients include:

1. Empowering pregnant people with anaesthesia and birth-related information before labour and delivery via antenatal education and the use of written or visual aids.
2. Clear and tailored communication that is simple, jargon-free, calm, concise and structured to accommodate the patient's pain.
3. Use of teach-back methods or asking the patient to repeat key points to confirm understanding.

4. Demonstrate respect for individual preferences when discussing options and reaffirm consent as a continual process throughout the labour.
5. In emergency scenarios, when time is limited, the patient and support person should receive essential information in a structured manner.
6. Work collaboratively with the maternity care team to ensure a cohesive approach.

The ABTA provides helpful resources to patients to understand informed consent and frame it as an important empowering tool for advocacy and autonomy via the ThinkNatal Program.[42] The key areas of focus important to patients are:

1. Clear, evidence-based and comprehensive information before procedures (as much in advance as possible) that includes benefits, risks and alternatives.
2. Expectation setting and how the patient may participate to support self-advocacy.
3. Opportunity and encouragement to ask questions.
4. Voluntary decision-making without pressure or coercion, with respect for values and preferences, whenever possible. A mutual understanding that consent may change as the situation evolves and ensuring the patient knows they can refuse at any time is important to declare outright.
5. Clear and accurate documentation that can be accessed by the patient. Particularly in obstetrics, written information of the discussion provided to the patient and support person can be highly valuable reminders of the conversations had during stressful events.

Compassionate care and communication

Sussan Stanford provides an impactful recount of her psychosocially traumatic but technically "mundane" elective caesarean section, where a lack of warmth, an unequal patient-doctor relationship and failure of communication were key contributors to her poor experience.[27,43] In 2024, the ABTA surveyed 100 members and asked how their anaesthetic or the anaesthetist affected their birth experience, positively or negatively.[44] Patients commented that when an anaesthetist was protective against or decreased the impact of birth trauma, it was because they treated them with kindness, reassured them that they genuinely cared and would do everything possible to provide the patient with a safe delivery. They explained procedures simply and honestly and empathised with the feelings of fear and excitement in a way that felt genuine. The use of "teach-back", where the patient can relay their understanding of the information they are provided in their own words, was empowering.[22,45] Feeling unrushed was paramount to respectful maternity care.[22] Patients vividly remember their interactions with anaesthetists and are positively impacted by those who ask about patient preferences and make attempts to facilitate them. This includes ensuring skin-to-skin contact can be facilitated as soon as possible after birth and limiting parent-baby separation, which are known to be protective against birth trauma.[29] In addition, if appropriate, creating a less intimidating medical environment by slightly altering lighting or including music is a low-effort intervention with a significant impact for anxious parents entering often foreign and overwhelming operative environments. Finally, role modelling and advocating for the whole theatre team to maintain a shared focus on the patient, their support person and their baby and avoid irrelevant background discussions was reported on positively.[3] This data demonstrates that our demeanour and communication style are two of the most powerful influences we have.

The anaesthetist's interpersonal skills can greatly impact the patient experience. Mindful language, particularly avoidance of negative suggestions and nocebos that can enhance pain and anxiety, should be implemented by all anaesthetists with all patients.[46] Adequate introductions, a friendly demeanour, eye contact and avoiding looking panicked even in the most time-critical scenarios can improve connection and help build the necessary trust required for successful psychological safety.[22,43] When the patient understands the rationale for clinical decision-making, they can be powerful allies in their own positive care experience. Poor communication is often at the heart of patient complaints, litigation and adverse incidents.[4]

Preventing and managing pain

The perception of pain despite anaesthesia during labour or delivery is a high risk for psychological morbidity, especially if combined with delays to management or a perception of being dismissed or

ignored.[27,43,47,48] Up to 23% of patients experience pain during caesarean delivery.[48] In her own case, Stanford recounts feeling pressured to agree that the block was sufficient despite her better judgement due to a power imbalance between the anaesthetist and the performance pressure of the theatre environment.[27,43] A rigorous test of the quality of the block with a focus on maternal satisfaction, in addition to objective evidence of the adequacy of neuraxial anaesthesia, is crucial.[49] The literature suggests the utilisation of multimodal testing, including fine touch (gold standard), cold and motor response (bilateral motor block in legs) prior to initiation of surgery.[47,50] Strict criteria for good quality neuraxial block, including a clear block to sensation (ideally two modes, including light touch) to T5 or higher and inability to straight leg raise against gravity bilaterally, should be achieved or mitigated with troubleshooting measures such as repeat neuraxial or offering general anaesthetic prior to commencement of surgery.[47]

We must disconnect ourselves from the feeling that objective assessment indicating adequate neuraxial block may still not meet adequate standards for patient comfort. Practitioners should confidently educate patients during consent that blocks do not always work effectively despite technical signs to the contrary.[27] Expectation setting and discussions of common breakthrough pulling, stretching, pressure and proprioceptive sensations is also crucial during the consent process.[47] However, so is the caveat that if these sensations cause distress, this will not be tolerated. Patients should be encouraged to speak up.[47] Regardless of why or when the patient experiences pain, the patient must be immediately believed, with reassurance given that a new plan will be implemented to address the situation. This is also true of the labour epidural, which should be made available when the patient asks for it and adequately tested for maternal satisfaction.[23] Dismissive language such as "it's just pressure" and "the spinal/epidural is working", despite being an attempt usually to reassure, can leave parents highly distressed.

A positive childbirth experience is individually defined. Therefore, for optimum planning and shared decision-making, it is paramount to understand a patient's priorities, preferences and expectations. Knowing from the outset that a general anaesthetic is available at any time, although not preferred for a variety of valid safety reasons as the first-line option, can alleviate the perception of being trapped in a painful caesarean delivery and allow patients to be more open to the normal sensations of birth with neuraxial anaesthesia.[51]

There is evidence that patients who experience severe acute pain after childbirth, regardless of delivery mode, have a 2.5 times increased risk of persistent pain and a three times increased risk of postpartum depression.[52] Trauma-informed care and proactive consideration of post-delivery pain by all involved practitioners, along with the adoption of evidence-based guidelines such as the Procedure-Specific Postoperative Pain Management (PROSPECT) guidance for caesarean section, are highly recommended.[53] Patients should be given information prior to and at the time of delivery regarding expected discomfort after delivery and be encouraged to escalate their concerns early to their care teams to allow for proactive intervention. They should be reassured that their pain will be managed and that their management will be individualised.

STEP 4: POST-DELIVERY CONSIDERATIONS

Ideally, all patients cared for by an anaesthetist during their birthing experience should receive a post-delivery check-in by a member of the anaesthetic team. However, this can be practically challenging to achieve due to staffing, funding and workload pressures. In situations such as difficult epidural insertion, inadequate pain relief in labour, pain during operative delivery or major adverse events, it is highly recommended that the anaesthetist provides a dedicated post-delivery consult to address these events. We should also be highly responsive to postnatal referrals from concerned obstetric and midwifery staff. Whether the anaesthetist who performed the initial procedure is the most appropriate person to respond will depend on the relationship built with the patient and whether there were any interpersonal conflicts during the care. Unexpected emergencies should trigger a check-in to review the events and decision-making with the patient and ensure questions are answered. It is not the remit of the anaesthetist to provide formal psychological debriefing as additional training is required for this. We are also unable to provide the longevity of care that may be required. However, an early check-in with the patient to clarify questions, events, and decision-making during the anaesthesia episode can benefit patients and their partners, particularly when there is a lack of clarity. The early check-in also shows care and concern. As per the statutory duty of candour guidelines, patients should be offered a formal apology, and escalation through safety and quality channels should be followed whenever possible to promote process improvement.

Positive care immediately after birth trauma provides an opportunity for patients to process the experience and start to recover.[54] Drawing on trauma-informed care and psychological first aid principles, we propose

the PILAR Check-In to support initial care and provide a positive foundation for further psychological care in post-anaesthesia-related childbirth trauma.[55,56] The PILAR Check-In consists of five dynamic processes: Preparation (P), Introductions (I), Listening (L), Apology (A), and Reassurance (R). It aims to provide a safe space for patients to express their experience, provide reassurance, prevent re-traumatisation, and foster a positive foundation for further professional support. The PILAR Check-In should be employed at the first anaesthesia consultation that occurs after childbirth.

Preparation

The clinician should be prepared for possible behaviours associated with trauma responses.[57] Initial post-trauma responses include sadness, anxiety, agitation, confusion, detachment and withdrawal, distress, and dissociation.[58] Further preparation involves ensuring sufficient time is allocated for care. The PILAR Check-In should not be rushed and should not be interrupted unnecessarily. Allowing time for the patient to express the experience rebuilds respect and trust.[59,60] Consider an appropriate quiet location and ensure support people and staff are available to attend when possible.

Introductions and invitations

It is important to introduce yourself and any accompanying clinicians. Introductions also involve clearly stating the rationale for your visit to support transparency and trust in the relationship.[59,61] Having an awareness of demeanour is essential in these first few moments. Maintaining an open posture, making eye contact, and vocalising in a calm, clear, and thoughtful manner are vital to fostering a positive foundation for further communication.[60,62] Ideally, the clinician aims to establish a trusting, respectful, safe, and open dialogue for ongoing communication.[63]

A clinician inviting the patient to share the experience provides an opportunity to re-establish trust by re-empowering the patient to alter the power balance within the relationship.[62] If the patient declines the request to share their experience, reassure them that if/when they are ready to share, you will be open to listening. The clinician should be mindful that retelling events within the first 48-72 hours may cause further distress for some patients.[64] Thus, it is essential during recall that the clinician is supportive, not forceful, respectfully listens and provides reassurance where necessary.[60]

Listening

Listening is an art, and when performed well can support recovery after a distressing experience.[65,66] Often referred to as “attentive listening”, the aim is to demonstrate respect for the patient’s experience and build trust.[66] Listening should occur without interruption, and the clinician will need to use communication skills like eye contact, nodding and paraphrasing to acknowledge understanding.

Apology

An apology is an important step after healthcare-related adverse outcomes to rebuild trusting relationships.[67-69] The apology should be simple, in plain language, and authentic. It should emphasise that the experience was unplanned and not in keeping with the desired outcome. Dialogue box 1 provides some examples.

Dialog Box 1

I am sorry you had this experience; it was not our intention.
We appreciate that it was difficult to retell. Thank you.

I’m sorry. I can see how this experience would be upsetting. Thank you for sharing it with me.

I am sorry you had this experience. I believe we can do better. Thank you for sharing.

It is not always necessary to provide a rationale for the outcome, and it is challenging, especially if it is unknown at the time of the review. While the clinician might not have the answers, it is essential to emphasise that an explanation is important and will be fed back when available. In the aftermath of adverse outcomes, patients often wish to be provided with relevant information on how the issue will be addressed, and this has been shown to support recovery.[70,71]

Reassurance

Providing reassurance is centred on the patient’s needs. Ask the patient if they have any questions. Explore what can be done for them now. Encourage patient re-empowerment by offering formal feedback avenues. If acceptable within your departmental governance framework, ask the patient if they would like you to provide feedback on their behalf.

Another important aspect of reassurance is transparency about the investigative phases and offering the patient involvement in this process.[70,72] Outline the review process, which may include analysing the event history, interviewing participants, requesting and reviewing feedback from patients and families, root cause analysis, or alternative adverse event reporting.

After any traumatic events, it is essential to offer further support. Collaborative care with clinical psychology, midwife liaisons, psychiatry and social work has demonstrated positive outcomes for patients who have experienced psychological trauma and is essential to optimal recovery.[73-76] Promotion of freely available resources on discharge for both parents, such as their maternal child health nurse, the ABTA, Perinatal Anxiety & Depression Australia (PANDA), Mums Matter Psychology, the Gidget Foundation Australia, and other local online, phone or community services, can be highly beneficial to ensure the patient is as protected against severe psychological distress as possible. Before closing this episode of care, create a plan for re-connection if the patient desires to do so. This further supports trust and reassurance. Post-birth obstetric anaesthesia clinics can be highly valuable avenues for this.

Limitations

The PILAR Check-In has not been designed as a complete psychological care package. It considers that many healthcare professionals are not formally trained in trauma-informed care or psychological first aid and provides basic care guidance to promote a positive platform for future psychological care. It aims to prevent any negative consequence associated with care discussions. The PILAR Check-In is not designed to replace psychological or adverse incident medical debriefing. Often, such debriefing requires more extensive and collaborative care planning. While the PILAR Check-In process has foundations in trauma-informed care and psychological first aid, it has yet to undergo rigorous testing. Finally, the PILAR Check-In does not address issues of trauma in the partner or support person who may be suffering due to witnessing or learning of a traumatic birth event.

STEP 5: STAFF WELFARE AND TRAINING

According to Make Birth Better, vicarious birth trauma (also known as secondary traumatic stress) describes the indirect trauma that can occur when one is involved in a difficult birth, fatality in birth, mistreatment, inadequate care or a serious adverse event.[77] Signs include feeling detached from your patients, difficulty “shaking off” anger, sadness or mistrust after incidents, a sense of guilt and shame around the involvement in incidents, frequent thoughts of the incident which may be intrusive, pessimism, empathy fatigue, low mood, anxiety and burnout. Therefore, it is imperative to be aware that the emotionally charged maternity environment can have profound impacts on not only the patient and their support network but on the staff as well. Recognising the signs and proactive engagement with a trusted local doctor, psychologist, employee assistance program, mentor and mental health practitioner, as appropriate, is vital to maintaining good mental health and longevity in the industry.

Resources available to practitioners who want more training in birth trauma include:

- Make Birth Better course.
- ABTA professional resources, including the ThinkNatal Education and Training eLearning Hub.
- BTA professional resources.

CONCLUSION

Birth trauma is more common than most maternity providers realise. It is a significant and ongoing issue in Australia and New Zealand, and globally. It is often underdiagnosed and undertreated, which highlights the need for greater awareness and support in this area. Armed with an increased understanding of the issue, anaesthetists are well placed to decrease the impact of this potentially avoidable and detrimental complication, particularly through prevention and management of complications, early recognition and management of psychological triggers and utilisation of the PILAR Check-In.

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When the placenta won't let go – placenta accreta spectrum

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INTRODUCTION

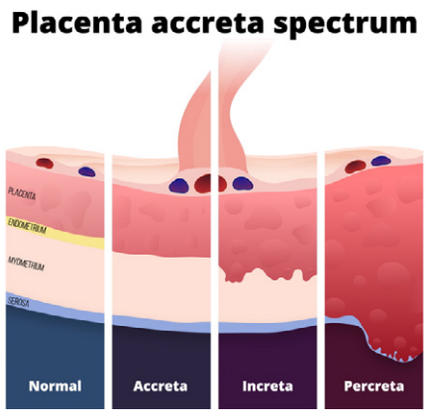
Placenta accreta spectrum (PAS) is a rare complication of pregnancy associated with significant morbidity and mortality; however, the incidence is increasing worldwide. Managing PAS represents one of the most complex challenges in modern obstetric and anaesthesia practice, demanding meticulous preparation and seamless collaboration across different specialties. As Benjamin Franklin aptly observed, "By failing to prepare, you are preparing to fail." This principle holds true in the management of PAS, where success is predicated on early recognition, comprehensive planning and a multidisciplinary approach.

TERMINOLOGY

The histopathologic term "placenta accreta" was first described by obstetrician Frederick Irving and pathologist Arthur Hertig in 1937 at the Boston Lying-In Hospital.[1] They described cases of "abnormal adherence of the afterbirth in whole or in parts to the underlying uterine wall." In many of their patients, attempts to remove the adherent placenta resulted in catastrophic haemorrhage, often requiring emergency hysterectomy. Luke et al then described the concept of PAS disorders in 1966 as including both abnormally adherent and invasive placentas.[2]

Three categories are now considered under the spectrum,[3] shown in Figure 1.[4]

Figure 1. Illustration of PAS categories



Placenta *accreta* (PA) – the most common, where the placental villi penetrate only to the surface of the myometrium. Placenta *increta* (PI) – where the placental villi invade the myometrium. Placenta *percreta* (PP) – where the villi invade beyond the myometrium to the uterine serosa and potentially involves adjacent organs, such as the bladder.

PATHOPHYSIOLOGY

PAS is associated with an increased risk of postpartum haemorrhage (PPH) caused by the abnormal separation of the placenta from the uterine wall. Several theories have been proposed for the mechanisms by which PAS occurs. The current most accepted hypothesis is that PAS occurs in the setting of abnormal decidualisation.[5] A healthy-formed decidua normally regulates trophoblast invasion. A defect of the endometrial-myometrial interface, which may occur in the setting of a uterine scar from a previous caesarean delivery, leads to failure of normal decidualisation. This allows abnormal deep placental anchoring villi and trophoblast infiltration into and through the myometrium.

The development of PAS has been linked to iatrogenic interference of the endometrial-myometrial interface from uterine entry procedures such as caesarean section or myomectomy. PAS can be associated with more superficial damage, as may be caused by curettage, manual removal of the placenta or postpartum endometritis.[6] It is thought that even microscopic defects, as may occur in conditions such as adenomyosis, fibroids, bicornuate uterus and myotonic dystrophy, can lead to abnormal villous tissue adhesion or invasion. These conditions may be the underlying cause of PAS in primiparous women.

RISK FACTORS

Four major independent risk factors have been identified for the development of PAS.[7]

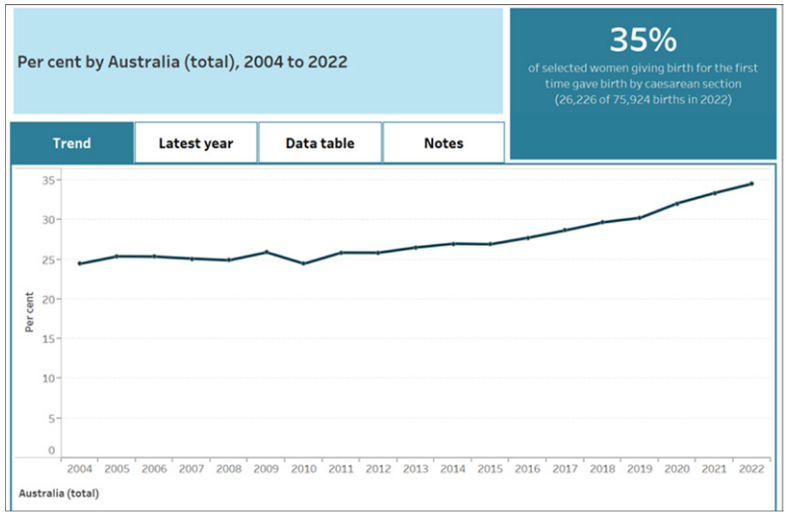
Table 1. Independent risk factors for placenta accreta spectrum (PAS)

Prior caesarean section
Advanced maternal age
Antenatal diagnosis of placenta praevia
Multiple birth

EPIDEMIOLOGY

The reported incidence of PAS in Australia and New Zealand is approximately 44.2 per 100,000 women,[7] or 1 in 2262 births. The incidence is increasing in Australia due to an increase in caesarean section rates and increasing maternal age. Caesarean section rates for primiparous women in Australia have increased from around 25% in 2004 to almost 35% in 2022 (see Figure 2).[8] This is consistent with trends from our institution, where there are increasing rates of both caesarean sections and PAS. The risk of PAS also increases after each subsequent caesarean delivery.[9] Mortality associated with PAS has been reported as high as 6-10% in older studies.[10] Modern management with early diagnosis and multidisciplinary care has reduced mortality rates to approximately 0.05%.[11]

Figure 2. National core maternity indicators – caesarean section rates



DIAGNOSIS AND IMAGING

The definitive diagnosis of PAS can only be made during surgery and subsequent histopathological confirmation. Antenatal diagnosis, however, is crucial to minimise associated maternal morbidity and mortality. Early recognition of PAS in the antenatal period allows appropriate planning for delivery in a tertiary centre, under the care of a specialised multidisciplinary team.[12]

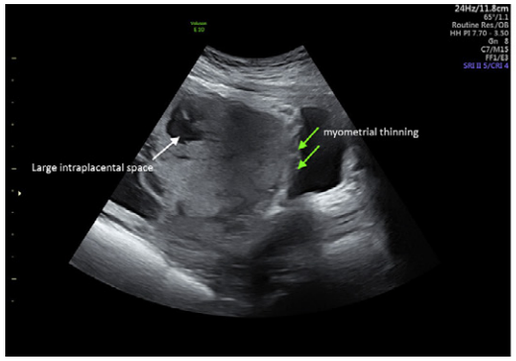
PAS is diagnosed in the antenatal period through a combination of risk factor assessments (see Table 1) and imaging studies. Previous caesarean section is the most important risk factor, and for these women, an ultrasound examination is recommended in the early first trimester to assess for features of caesarean scar pregnancy (CSP), which is a precursor to PAS.[13] Typical PAS features are present on ultrasound scanning in most women by 11-14 weeks' gestation.[14] Early detection facilitates appropriate counselling, referral and planning. Serial scans should be performed throughout the antenatal period to predict the extent of invasion and allow appropriate risk stratification and planning.

Antenatal ultrasound (USS) by transabdominal and transvaginal approaches using grayscale and colour doppler imaging has a high accuracy for diagnosing PAS, although some cases can remain undiagnosed until delivery.[15] It is recommended as the first-line diagnostic tool, given its accessibility and low cost. USS has a reported sensitivity of 90.72% (95% CI, 87.2-93.6%) and a specificity of 96.94% (95% CI, 96.3-97.5%).[16] The ultrasound signs of PAS are listed in Table 2 and demonstrated in Figure 3.[12]

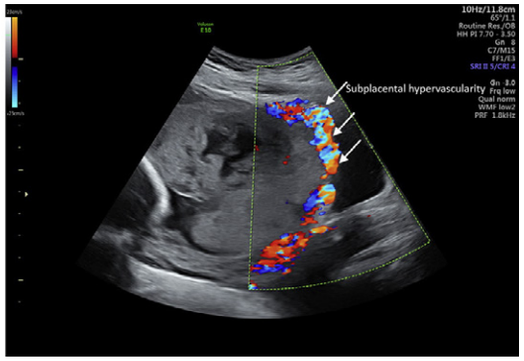
Table 2. Ultrasound signs in placenta accreta spectrum (PAS) disorders

Intra-placental lacunae with diffuse or focal vascular flow
Abnormally thick placenta (>50 mm at 32-34 weeks' gestation)
Loss of retroplacental clear zone with increased sub-placental vascularity
Reduced myometrial thickness (<1 mm) in the inferior uterine segment
Interruption of the bladder flap, placental bulge, exophytic masses

Figure 3. USS images with features of PAS at 21 weeks



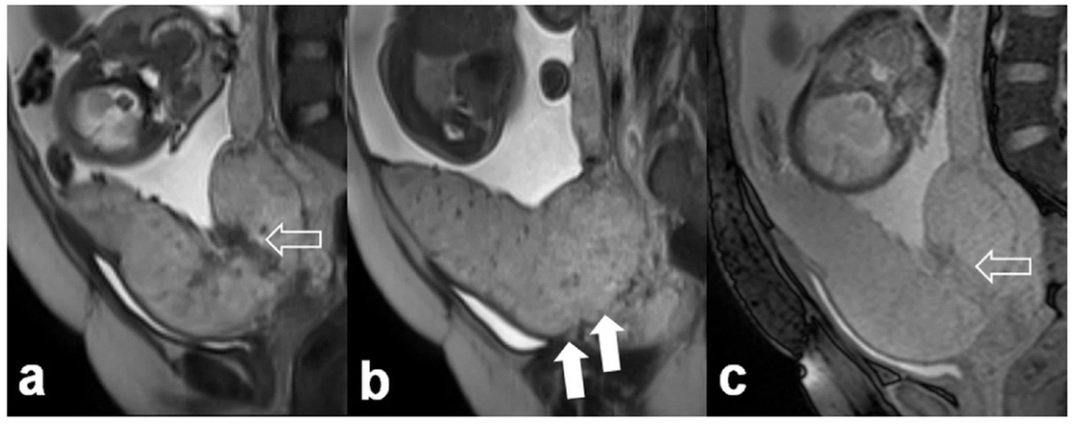
Large irregular sonolucent intra-placental space (white arrow) and myometrial thinning (green arrows).



Colour doppler ultrasound images showing increased vascularity at sub-placental region (white arrows).

Magnetic resonance imaging (MRI) is increasingly being used as a second-line diagnostic tool. Evidence suggests a high sensitivity and specificity of MRI for diagnosing PAS and determining depth of invasion.[17] Features such as uterine bulging, heterogeneous signal intensity within the placenta, dark intra-placental bands and focal myometrial interruptions are suggestive of PAS. In women with ultrasound images suggestive of PAS, MRI may be beneficial in further assessing topography of placental invasion and surgical planning.[15] MRI may also be a useful diagnostic tool where ultrasound is non-diagnostic, the placenta is posterior, or in morbidly obese parturients. The MRI signs of PAS are demonstrated in Figure 4.[18]

Figure 4. Placenta accreta with dark bands (open arrows) and loss of the uteroplacental interface (full arrows)



ANTENATAL MANAGEMENT

Preoperative management

Patients with suspected PAS should be referred to a tertiary centre with the expertise and resources for ongoing care. This includes transfusion services, surgical specialities proficient in advanced pelvic surgery, adult and neonatal intensive care, and obstetric anaesthetists.

Multidisciplinary team

Patients should be reviewed and managed by a multidisciplinary team (MDT) experienced in PAS shortly after diagnosis.[3,19] At our institution, all patients with suspected PAS have an MDT that includes experienced obstetricians, obstetric anaesthetists, gynaecological oncology surgeons, maternal-foetal medicine, interventional radiology, neonatology and midwifery. A comprehensive checklist is used to formulate a standard care plan that addresses both elective and emergency delivery options. This includes reviewing imaging to map placental location to discuss surgical and anaesthetic options, identifying key personnel required for delivery as well as determining the appropriate theatre location for surgery. Our MDT model of care is in keeping with guidelines from the International Federation of Gynaecology and Obstetrics (FIGO) and the Royal Australian and New Zealand College of Obstetrics and Gynaecology (RANZCOG). The FIGO consensus statement heavily emphasises the importance of the MDT in reducing morbidity and mortality in women with PAS, particularly those with more invasive forms.[19,21]

Gestation for delivery

There is no robust evidence to specify the optimal gestational age for delivery in women with PAS. The balance between the risk of prematurity and the increased risk of unplanned emergency surgery is required to minimise the risk to the mother while optimising foetal maturity. As the majority of PAS is associated with placenta previa, the likelihood of antepartum haemorrhage increases with gestational age.[19] Consensus guidelines recommend delivery between 34-37 weeks' gestation, unless there are specific risk factors for preterm delivery.[3,21]

Surgical management

No PAS patient is the same, and therefore, the management must be tailored to the individual. The optimal surgical management for PAS is widely debated, and published data is heterogeneous. There are broadly two approaches to the management of PAS - elective caesarean hysterectomy or conservative techniques, which aim to preserve fertility. The major concern during surgical management is the propensity for massive haemorrhage, disseminated intravascular coagulation (DIC) and end-organ dysfunction. The average reported blood loss is 3 to 5 litres, and around 90% will require a blood transfusion.[11,19,22] Other complications include damage to adjacent structures such as the ureters or bladder.

Caesarean hysterectomy is the most common definitive surgical management and the gold standard recommendation of care.[3,9-21] Generally, a vertical midline abdominal incision is undertaken, and the external surface of the uterus is carefully examined. At this stage, intraoperative ultrasound may be used to map the placenta further to avoid the upper margin. The infant is delivered via an upper trans-fundal uterine incision, away from the placenta, and the placenta is left in situ. The incision is then quickly sutured before proceeding with a hysterectomy (Figures 5-6). Manual removal of the placenta should be avoided in confirmed PAS patients undergoing hysterectomy, as this is associated with increased rates of blood loss, blood transfusion and maternal morbidity.[19,21,23] The mortality rate from elective caesarean hysterectomy is low, however, morbidity remains high.[24]

Figure 5. Exteriorised uterus prior to delivery

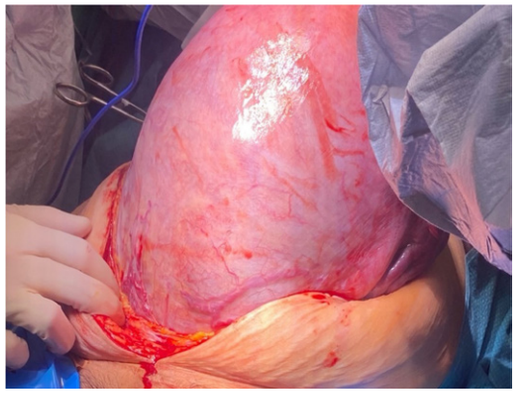


Figure 6. Surgically removed uterus showing placenta percreta

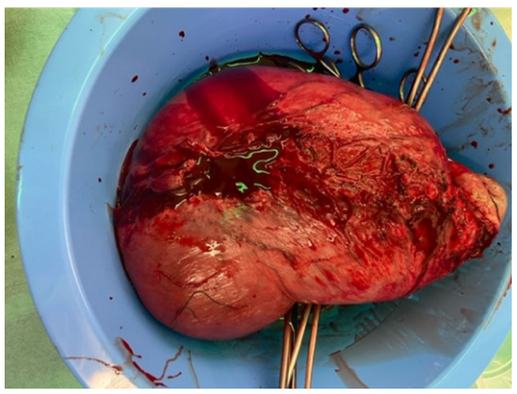
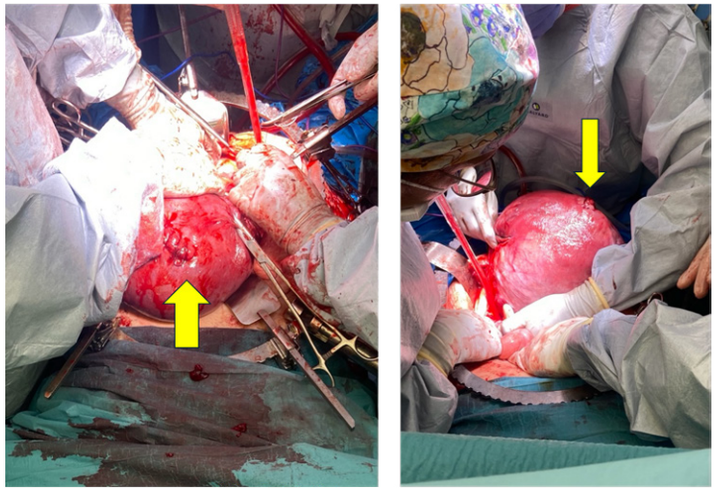


Figure 7. The neonate has been delivered, and the arrows indicate closure of the fundal incision prior to hysterectomy



In cases where there is a significant invasion of the placenta to adjacent structures, making surgical conditions challenging, a staged surgical approach called *delayed hysterectomy* may be undertaken. Following the delivery of the neonate, both the placenta and uterus are left in situ, and the patient undergoes a hysterectomy several weeks later. During this period, the vascularity of the placenta decreases, and there is partial resorption of the placenta, providing improved surgical conditions. Patients who undergo delayed hysterectomy must be highly compliant with close follow-up due to the increased risk of emergency hysterectomy, secondary haemorrhage, sepsis and coagulopathy.

Conservative techniques aim to avoid hysterectomy to preserve fertility, with some studies suggesting decreased blood loss and overall morbidity.[19,22,25] There are four methods of conservative surgical techniques described:[26]

1. The extirpative technique is where the placenta is manually removed.
2. Expectant management – "leaving the placenta in situ".
3. Surgical resection of the accreta area and myometrium.
4. The triple-P procedure, which involves **P**lacental localisation, **P**elvic devascularisation with interventional radiology and **P**lacental non-separation with myometrial excision.

The extirpative technique is not recommended once PAS is diagnosed intraoperatively, as it may lead to catastrophic haemorrhage. Where a diagnosis is uncertain, a "gentle tug test" of the placenta may be employed to observe for normal placental separation before proceeding to manual removal. However, experts agree that manual removal should be avoided if there are any suggestions of abnormality.[26]

Expectant management consists of leaving the entire placenta in situ following delivery of the neonate and waiting for complete resorption. A large retrospective study has found uterine preservation in 78% of women undergoing expectant management, with a maternal morbidity rate of 6%.[27,28] Expectant management has been found to be associated with decreased blood loss and blood transfusion requirement when compared to caesarean hysterectomy.[29] However, arterial embolisation and re-hospitalisation rates were higher in the conservative group.[25] Complete resorption of the placenta may take up to six months and again requires close follow-up. FIGO guidelines recommend weekly follow-up for the first two months and then monthly if no complications are present.[26]

A few centres describe local surgical resection of the myometrium with reconstruction of the uterus and have suggested a lower incidence of complications compared to caesarean hysterectomy.[27,29] The evidence is limited, though expert consensus suggests it may be an appropriate option in select cases for uterine preservation.

The triple-P procedure describes a combination of approaches. It requires interventional radiologists to

place prophylactic occlusive balloons in the common iliac arteries prior to surgery. Following the neonate's delivery, the occlusive balloons are inflated to allow pelvic devascularisation and limit blood flow to the uterus. The adherent placenta and underlying myometrium are then removed. This method has been described by a handful of institutions with promising outcomes, including lower blood loss and transfusion rates overall.[22,26]

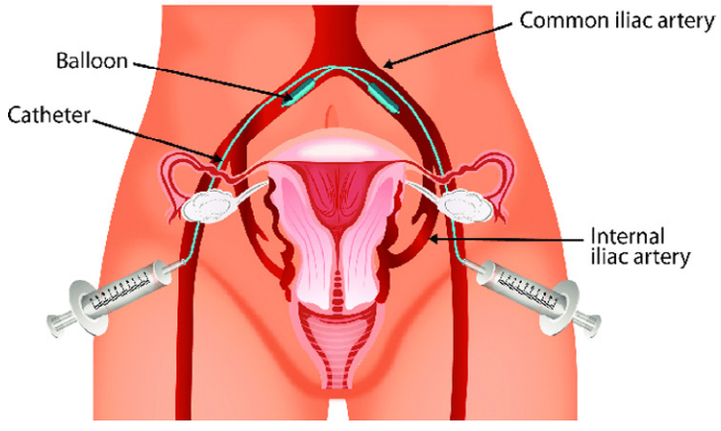
Interventional radiology (IR)

IR's evidenced-based role in PAS is unclear, and the evidence is conflicting. IR is not routinely recommended in the management of PAS,[3,21] but may be useful in complex cases when challenging surgical conditions are anticipated, along with high bleeding risk. The primary blood supply of the uterus is the uterine arteries, which originate from the anterior division of the internal iliac arteries. Secondary blood supply from the ovarian arteries originates below or from the renal arteries.[30] There is also collateral blood supply from the inferior epigastric and inferior mesenteric arteries. This dense vascular network enlarges significantly during pregnancy to increase uterine blood flow.

Pelvic arterial embolisation has mostly been used to prevent major haemorrhage in conservative management of PAS. The literature is mixed and of low quality. The International Society of Abnormally Invasive Placenta (IS-AIP) does not recommend routine prophylactic uterine artery embolisation in conservative management.[27] However, they do suggest therapeutic embolisation in the management of severe PPH during conservative surgery to prevent hysterectomy.

Prophylactic balloon occlusion catheters can be placed within the internal iliac arteries (PBOIIA), common iliac arteries (PBOCIA), uterine arteries (PBOUA) or abdominal aorta (PBOAA) (see Figure 8). To date, one meta-analysis has assessed the effectiveness and safety of these interventions in PAS.[31] The review found less blood loss in patients who underwent intervention compared to those who did not, as well as a lower hysterectomy rate. However, the data was highly heterogeneous and predominantly consisted of low-quality cohort studies or case series.[31] The review found one small, randomised control trial that compared PBOIIA to no intervention, which showed minimal differences in blood loss, blood transfusion or hysterectomy rates.[32]

Figure 8. Prophylactic balloon occlusion catheters can be placed within the internal iliac arteries, common iliac arteries, uterine arteries or abdominal aorta



The meta-analysis also found PBOAA was potentially superior to PBOIIA for blood loss, transfusion rates, drier surgical field and overall complication rates. This is in keeping with emerging literature favouring PBOAA (abdominal aorta) for haemorrhage control in PAS. Due to extensive neovascularisation and possible aberrant blood supply from the external iliac arteries in PAS, PBOIIA (internal iliacs) may be less effective and possibly even worsen bleeding.[33,34] PBOAA has the advantage of one insertion point in the femoral artery compared with bilateral placement in PBOIIA/PBOCIA, and lower radiation doses. The use of balloon catheters is not without risk, and complications are not infrequent.[35] These include vascular injury, thrombosis, lower leg ischaemia and infection. It is unclear from the literature which patients benefit from the radiological intervention for PAS, and larger-scale trials are required.

The use of IR can increase the total length of the surgical time and possibly require transfer between multiple locations. At our institution, women having balloon occlusion intervention are managed in the main hybrid operating room to avoid transfer between different clinical areas and potential displacement of catheters. The catheters are usually placed under neuraxial anaesthesia before proceeding to caesarean section (Figures 9 and 10).

Figure 9. Insertion of bilateral balloon occlusion catheters

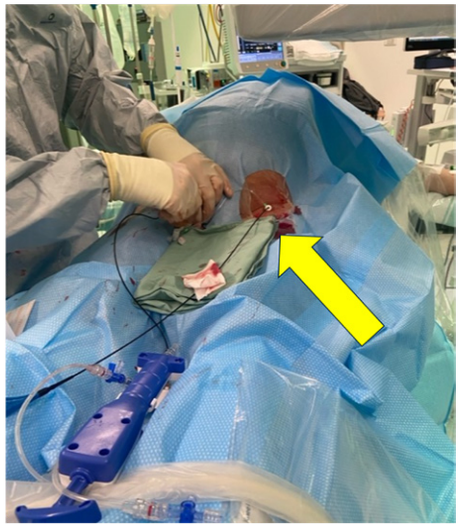


Figure 10. Balloon occlusion catheters secured to legs in lithotomy position

Pre-anaesthetic assessment

At our institution, patients are reviewed in the high-risk obstetric anaesthetic clinic pre-operatively. In addition to routine anaesthetic assessment, particular attention should be given to factors that will influence anaesthetic management, such as potential difficult airway, contraindications to neuraxial procedures, venous access and risk factors for haemorrhage.

Anaemia is common in pregnancy and should be optimised given the high risk of bleeding. A valid group and hold should be taken to identify antibodies to allow transfusion services time to prepare for delivery.

When discussing the anaesthetic approach with the patient, past birth experiences and wishes for delivery should be explored. Important points to highlight include theatre environment, procedures, likelihood of massive transfusion, need for intensive care postoperatively and pain management. A shared decision-making approach allows the anaesthetic plan to be tailored to the patient. The risks and benefits of the approach are discussed in detail and formalised as part of the PAS MDT plan.

INTRAOPERATIVE MANAGEMENT

Preparation is key and can be categorised into personnel, environment, and patient issues. Anaesthetic-specific checklists can decrease cognitive load and be tailored to institutional preferences (Figure 11). Surgical safety checklists and team timeouts have been shown to improve patient safety and are a standard recommendation of care in PAS.[27]

Figure 11. Anaesthetic checklist for PAS

Placenta Accreta anaesthetic checklist

Westmead Anaesthesia

Day prior to surgery

- ❑ Valid G+H, notify transfusion Haematologist. Place eOrder for blood products to be placed in theatre blood fridge.
- ❑ Confirm MDT plan, location (K3 Hybrid or F4), start time, personnel.
- ❑ Notify ICU
- ❑ Checklist provided to anaesthetic nursing teams

Monitoring and equipment

- ❑ Large bore peripheral access - minimum 2 (consider RICC)
- ❑ Arterial line
- ❑ +/- CVC
- ❑ BIS
- ❑ Urinary catheter temp probe, under body and upper body Bair Hugger
- ❑ NMT monitor
- ❑ Ultrasound in bay
- ❑ 2 TIVA pumps + 2 standard pumps available
- ❑ 2 IV pump sets with fluid warmers (resus lines) or Rapid infuser device
- ❑ Consider separate IV line for infusions (e.g. TIVA, vasopressors)
- ❑ Cell salvage
- ❑ Pre-labelled TEG (blue) coagulation blood tubes, FBC (purple) blood tubes
- ❑ Video laryngoscope
- ❑ 7.0 ETT
- ❑ Supraglottic airway device
- ❑ Positioning low lithotomy
- ❑ If balloon catheters placed – urinary catheter inserted prior
- ❑ Correct operating table for lithotomy if in hybrid operating room
- ❑ Correct arm boards for hybrid bed

Regional

- ❑ Neuraxial kits (spinal needles/CSE)
- ❑ Abdominal block needles/catheters and local anaesthetic of choice

Drugs

- ❑ +/- IT morphine, fentanyl, heavy marcain
- ❑ Induction and maintenance drugs of choice
- ❑ Routine antibiotics prophylaxis
- ❑ Tranexamic acid 1g
- ❑ Uterotonics **NOT** to be administered unless already discussed
- ❑ +/- PCA

Prior to starting

- ❑ Team huddle
- ❑ Surgical safety check list
- ❑ Time out

Massive haemorrhage considerations

- ❑ X-match 4-6 units RBCs in blood fridge ready
- ❑ Minimise large crystalloid administration (>2L)
- ❑ Quantify blood loss volume every 30 mins
- ❑ TEG and arterial blood gas every 15-30mins
- ❑ Activate massive transfusion protocol early for unstable bleeding
- ❑ Consider early cryoprecipitate administration
- ❑ Aim normothermia
- ❑ Re-dose antibiotics if blood loss > 1.5L
- ❑ Calcium administration
- ❑ Close communication with surgical team +/- interventional radiologist regarding ongoing management of uncontrolled bleeding
- ❑ Consider aortic compression/damage control surgery
- ❑ Cell salvage return

Personnel preparation

PAS management involves collaboration between several teams. Before commencing anaesthesia, a "team huddle" allows all team members to introduce themselves and their specific roles. Beyond the routine elements of the WHO surgical checklist and time out, specific issues to discuss for PAS are:

- Mode of anaesthesia.
- Specifics of IR, if used, e.g. placement of balloons and who will operate them.
- Major haemorrhage management.
- Plan for uterotonics.
- Post-op disposition confirmed.

The anaesthetist plays a central leadership role intraoperatively. The goals are to provide optimal surgical conditions for a complex and challenging procedure while maintaining vigilance in a rapidly dynamic situation. This requires excellent communication and preparation for massive haemorrhage. The presence of two senior anaesthetists allows cognitive offloading and prevention of task fixation. Roles can be divided into someone leading resuscitation and the other to leading anaesthesia. Anaesthetic nurses provide an essential role, and at least two should be allocated in these high-risk cases. Prior role allocation to tasks, such as blood checking, administration, cell salvage and having a "blood runner" streamlines resuscitation management.

Environment preparation

It is important to ensure the layout and ergonomics of the operating room enable a cohesive work environment for all team members and to prevent overcrowding. Our institution's hybrid and main operating rooms allocated to PAS surgery provide sufficient space for these complex cases. Specific areas should be allocated for the neonatal and midwifery team, as well as cell salvage and rapid infusion devices. If a hybrid setting is used, this may be an unfamiliar setting for the obstetric and gynaecological surgical teams. The anaesthetist should maintain adequate space and access to the patient to enable a coordinated approach to resuscitation and anaesthesia.

Patient preparation

In addition to routine monitoring, bilateral, large-bore intravenous cannula access should be established and dedicated to resuscitation. These should have in-line fluid warmers with pump sets or rapid infusion devices. A third separate intravenous cannula can be used for drug administration and peripheral vasopressors. Intra-arterial cannulation is established before anaesthesia, allowing close blood pressure monitoring, regular blood gas analysis, and viscoelastic testing. Central venous access is not necessarily indicated unless there are significant comorbidities, such as cardiac disease or pre-eclampsia. The patient is positioned in a low-lithotomy position with arms abducted, allowing access to intravenous lines. The anaesthetist should be aware of balloon occlusion catheter placement and access points.

Choice of anaesthesia

There is no strong evidence regarding the optimal form of anaesthesia in PAS, and the choice is widely debated. Both neuraxial and general anaesthetic (GA) techniques have been described successfully, with some literature suggesting lower morbidity related to haemorrhage with regional compared to GA.[19] Conversion from regional to GA is reported between 8-45% but appears predominantly to be in lower-income countries and undiagnosed PAS cases.[19] Elective general anaesthesia has the advantage of avoiding the sympatholytic effect of neuraxial anaesthesia. GA is preferable in a patient with a potentially difficult airway to ensure intubation is controlled at the beginning of the case. In high-risk patients where there is anticipated bleeding and the likelihood of blood transfusion with significant volume shifts, controlled ventilation is desirable. For a regional approach, a combined spinal-epidural (CSE) technique allows titration of anaesthesia and the ability to extend the duration of anaesthesia in longer cases. The surgical incision may be extensive, and therefore, the regional technique of choice must provide adequate coverage. Given the high risk of intraoperative conversion to GA, airway equipment and drugs should be prepared beforehand.

At our institution, the predominant surgical approach is caesarean hysterectomy under GA. However, depending on the location of PAS, risk of bleeding, airway assessment and patient wishes, neuraxial anaesthesia has been undertaken for delivery of the baby, with subsequent GA for hysterectomy. This allows the mother and partner to partake in the birth experience, minimise GA exposure to the neonate and provide superior pain relief postoperatively. The risks of immediate bleeding, instability and rapid conversion to GA must be explicitly informed to the patient.

Uterotonics

The role of uterotonics in preventing and treating PPH is well established. However, there are no studies evaluating uterotonics in PAS, and as such, their use is contentious. With normal placentation, uterotonics promote placental separation and uterine contraction, thereby decreasing PPH secondary to atonic uterus. In PAS, however, there is abnormal neovascularisation and invasion of the placenta to adjacent structures, where separation can lead to catastrophic bleeding. Consensus expert guidelines suggest omitting uterotonics in confirmed PAS patients undergoing caesarean hysterectomy.[19,21] If the diagnosis of PAS is uncertain or not confirmed, then uterotonics may be administered in fertility conserving techniques in conjunction with preparation for massive haemorrhage. The plan for uterotonics must be discussed and clearly documented during the MDT, then re-confirmed during the team huddle prior to surgery.

HAEMORRHAGE MANAGEMENT

Measurement of blood loss

Accurately quantifying blood loss is essential to guide appropriate resuscitation and should be conducted at regular intervals. A multimodal approach is recommended to estimate intraoperative blood loss.[36] This includes blood collection drapes, weighing surgical sponges, and assessing surgical suction canisters.

Control of bleeding

Where attempts are being made to preserve fertility, surgical haemostatic measures include balloon tamponade of the uterus, brace suturing and ligation of uterine or internal iliac arteries.[37] The use of manual aortic compression may provide temporary haemostasis and allow surgical field visualisation to aid definitive haemorrhage control by hysterectomy.

Pharmacological interventions

Tranexamic acid has been well-established in the trauma setting and is also recommended for PPH following the WOMAN trial.[38] The recommended dose is 1 gram intravenously, with the consideration of re-dosing for ongoing haemorrhage.

Ionised calcium levels fall in massive blood transfusions due to the presence of citrate in packed cells. Therefore, calcium levels should be monitored and replaced to maintain ionised calcium levels greater than 1.1 mmol/L to aid coagulation.

Volume resuscitation

Large volumes of crystalloid solution (>2 litres) are not recommended for infusion, as they exacerbate coagulopathy through dilution of coagulation factors.[39] The judicious use of crystalloids with permissive hypotension has been associated with improved survival and lower blood product requirement.[40] A systolic blood pressure target of 80 to 90 mmHg or mean arterial pressure of 50 to 60 mmHg is recommended until bleeding has been controlled.[41]

Blood products (packed red cells, fresh frozen plasma and platelets) should be administered in a 1:1:1 ratio during haemostatic resuscitation.[40] Several large studies in trauma patients have shown survival benefits from this balanced approach in severe bleeding,[42,43] and the same ratios are applicable in the management of obstetric bleeding.[44] In addition, early fibrinogen replacement (cryoprecipitate or fibrinogen concentrates) is recommended in managing severe PPH, as these factors are rapidly consumed in obstetric haemorrhage.[36] Autologous blood recovered by cell salvage can be safely re-infused via a leukocyte depletion filter, reducing the requirement for allogeneic blood products.[45]

Standardised massive transfusion protocols (MTPs) assist in the efficient delivery and use of blood products in major haemorrhage scenarios in PAS patients.[40] The expedited preparation and delivery of balanced blood product packs to the operating theatre, along with early communication with a haematologist, allows rapid and effective haemostatic resuscitation. In our institution, blood fridges are kept in close proximity to the operating theatres to allow storage and accessibility to urgent blood products.

Point-of-care testing and targets

Serial assessment of arterial blood gases, blood counts and coagulation are recommended to guide treatment during haemorrhage related to PAS.[36] Targeted clinical and laboratory goals will guide appropriate therapy and cessation of massive transfusion protocols, minimising unnecessary blood product transfusion.[46]

Table 3. Clinical and laboratory targets in massive haemorrhage

MAP > 65 mmHg	Ca^{2}+ >1.1 mmol/L
Temperature >35°C	Platelets >50 x10^{9}/L
pH >7.2	PT <22 sec
Base excess <-5	APTT <50 sec
Lactate <4 mmol/L	Fibrinogen >2.0 g/L in obstetrics

Viscoelastic testing such as Thromboelastography (TEG) and Rotational Thromboelastometry (ROTEM) provides rapid results, and their use is associated with reduced blood product usage and related morbidities such as transfusion-associated circulatory overload (TACO), and transfusion-related acute lung injury (TRALI).[47,48] Several algorithms have been published describing the use of these viscoelastic tests in guiding targeted coagulopathy treatment in PPH.[49,50] The use of a hybrid strategy, where an MTP with fixed blood product ratios is used initially for severe PAS haemorrhage, followed by targeted therapy guided by viscoelastic point-of-care testing, has been suggested as an optimal approach to resuscitation.[51]

Other considerations

Hypothermia must be avoided, as it worsens coagulopathy. Temperature monitoring, active warming devices, fluid warming, and increased ambient theatre temperature should be used in PAS patients. If blood loss exceeds 1.5 litres, prophylactic antibiotics should be re-administered.[52]

POSTOPERATIVE MANAGEMENT

Women with PAS require careful attention in the postoperative period, particularly focusing on disposition and monitoring, pain management and psychological support.

Disposition

Regardless of which surgical and anaesthetic technique is used, a high proportion of patients with PAS require post operative admission to a high-dependency (HDU) or intensive care unit (ICU). Ongoing high-level care for these patients may be required due to continued fluid or blood product resuscitation, correction of coagulopathy, and the need for vasoactive medications or mechanical ventilation.[35,53] Serial measurements of haemoglobin, acid-base status, coagulation and core temperature are required, with specific monitoring focusing on ongoing bleeding or transfusion-associated pathologies like TRALI or TACO.[51] Mechanical and chemical thromboprophylaxis should be implemented as early as possible in the postoperative period, once bleeding and coagulation are controlled, as patients with PAS are at increased risk of venous thromboembolism.[51] Early mother-child bonding should be prioritised if the mother's condition allows.

Pain management

Post operative pain management in PAS patients may be challenging due to more complex surgical techniques, with larger incisions and longer operating times.[53] Optimal postoperative analgesia is important for maternal mobility, interaction with the newborn and psychological wellbeing. A multimodal analgesia regimen is the gold standard for pain management after caesarean section.[35] If a neuraxial technique is used intraoperatively, long-acting neuraxial opioids like morphine can provide high-quality analgesia for up to 24 hours, with a reduction in systemic opioid requirements. If general anaesthesia alone is used, regional techniques such as transversus abdominal plane block, quadratus lumborum block or erector spinae block can be useful for post-op analgesia.[54] Regular paracetamol and non-steroidal anti-inflammatories should be used unless there are contraindications to their use. Dexamethasone, in addition, may provide analgesic benefits.[55] Rescue opioids should be available for breakthrough analgesia. The oral route is as effective as the intravenous route and should be preferred if available, with patient-controlled intravenous opioid analgesia reserved for severe cases.[56]

Psychological support

Patients with PAS have a significantly higher risk of post-traumatic stress disorder compared with routine caesarean sections.[57] The psychological impact of PAS diagnosis and subsequent interventions during pregnancy, delivery and the postpartum period need to be acknowledged, allowing early intervention to prevent the development of severe and potentially chronic symptoms. Women with PAS should routinely be offered postnatal debriefing sessions, with all members of the multidisciplinary team being available as required.[58] Long-term follow-up options for psychological care should be provided upon hospital discharge.

Future fertility

Although data is limited, subsequent fertility does not appear to be compromised after successful conservative treatment of PAS.[26] Adverse maternal outcomes such as recurrent PAS, uterine rupture and PPH, however, are more likely in future pregnancies. The risk of PAS in subsequent pregnancies is close to 30%.[59] Women who plan for further pregnancies should be warned of the high risk of PAS recurrence.[26]

Team debriefing

All multidisciplinary team members should meet for a debriefing session to discuss management details of the case, what was performed well, and what could be improved.[60] During this session, any communication or safety concerns can be effectively discussed, and system improvements can be planned for future cases.

CONCLUSION

PAS is a growing problem and one that obstetric anaesthetists will increasingly encounter. Women with PAS should be delivered at institutions with the expertise to manage these high-risk women. The optimal surgical and anaesthetic management is not known; however, meticulous assessment, early USS diagnosis, MDT planning and preparation will give the best chance of a healthy outcome for mother and baby.

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Anaesthesia for the pregnant patient undergoing non-obstetric surgery: Contemporary evidence and practical guidance

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Edited by Associate Professor Matt Doane

INTRODUCTION

The intersection of obstetric physiology with non-obstetric surgery presents a high-stakes challenge for anaesthetists. While elective surgery is best delayed until after delivery, urgent and emergent surgical procedures in pregnancy are not uncommon and often proceed in the context of limited institutional guidance. This article provides a comprehensive review and practical framework for anaesthetising pregnant patients undergoing non-obstetric surgery, with trimester-specific considerations and up-to-date evidence on anaesthetic techniques, drug safety, monitoring strategies, and multidisciplinary planning.

Internationally, there is an increasing focus on the rising or, at the very least, stagnant rates of maternal morbidity and mortality. In the United States, maternal mortality has more than doubled in the past two decades.[1] While maternal mortality rates in Australia and New Zealand remain comparatively low, they have plateaued rather than declined, with increased risk observed in persons aged 35 and older.[1] Furthermore, the lifetime societal cost of a disabled child is estimated to be $USD2.4 million each year.[2] Improving anaesthetic care for pregnant patients, especially in non-obstetric contexts, is a significant opportunity to optimise outcomes and support this vulnerable group.

SUMMARY OF MANAGEMENT PRINCIPLES AND GOALS

Surgical factors

Urgent or emergency surgery should be performed, regardless of trimester.[3]

Elective surgery that cannot wait until after delivery is best performed in the second trimester, but if feasible, it should be delayed until after delivery.[3]

Surgical techniques should aim to minimise intra-abdominal pressures, and care should be taken with the insertion of laparoscopic ports and trocars to avoid the gravid uterus.

Modifications may be needed to facilitate left lateral tilt and intraoperative fetal monitoring.

Patient factors

Fetal heart rate should be documented pre- and postoperatively.[3] Individualised decision-making is required regarding the decision to monitor fetal heart rate intraoperatively, in conjunction with the obstetric team.

Counselling of pregnant patients on the accurate rate of preterm delivery associated with non-obstetric surgery varies depending on their medical comorbidities. Reported values are based on observational studies and expert opinion.

Anaesthetic factors

The safest technique is a regional anaesthetic with no sedation.

Endotracheal intubation should be considered from the first trimester and is usually required from the second trimester onwards due to hormonal and mechanical factors**.** Uterine displacement should be initiated in the second trimester to prevent aortocaval compression. Consider from the time the patient is visibly pregnant, certainly from 20 weeks onwards and earlier in cases of multiple gestation (such as twins).

Formulate a plan and ensure that multidisciplinary communication is in place. This is essential for both preparing for and responding to the variety of situations that may arise during the perioperative journey.

TRIMESTER-SPECIFIC CONSIDERATIONS

First trimester

Timing of surgery

Risk of teratogenicity is highest <10 weeks' gestation, and baseline miscarriage rates can be up to 10%.[3] Non-elective surgeries that cannot wait until after delivery are best deferred until the second trimester, as rates of pregnancy loss are lower and organogenesis is largely complete.[3]

Fetal monitoring

The appropriateness of fetal monitoring should be decided in consultation with the on-call obstetric team. Handheld Doppler assessment of the fetal heart rate (FHR) at early gestation may not be technically possible. Inability to assess the FHR with a handheld Doppler may cause anxiety for the patient and the medical team. Before 10 weeks, a simple bedside ultrasound scan is recommended to confirm the presence of a fetal heartbeat. A handheld Doppler may be attempted as early as 10 weeks of gestation. However, a bedside ultrasound should be immediately available if this is not successful. This process should be repeated postoperatively at the bedside to confirm fetal wellbeing. Continuous fetal heart monitoring has not been shown to improve outcomes in this trimester.[3]

Non-viable pregnancies

Disseminated intravascular coagulation (DIC) is very uncommon following a first-trimester pregnancy loss unless there is massive haemorrhage. Cases of incomplete miscarriage or retained products of conception are at greater risk of infection than patients with a non-viable pregnancy with no bleeding. Current guidance is to check the patient's coagulation profile before neuraxial procedures if a non-viable pregnancy is confirmed, especially if the time of fetal demise may not be known, or >48 hours.[4]

Anaesthetic drug safety

Avoid medications like benzodiazepines, nitrous oxide, and ondansetron due to potential teratogenicity (refer to Table 4).

Other considerations

Maintain normothermia, low-normal $PaCO_2$, PaO_2 and mean arterial pressure (MAP). Evidence suggests first-trimester losses are more associated with these factors than with sedatives.[3]

Second trimester

Timing

The second trimester is an optimal time for surgery due to a lower risk of miscarriage (<1%) or preterm labour,[3] as well as technical aspects (uterus is smaller, easier to position pregnant persons and easier to monitor fetus). Consider antenatal steroids for fetal lung maturation at 24 and 48 hours preoperatively if the fetus is considered viable, usually after 24 weeks. This requires discussion with obstetrics and neonatology and will depend on the assessment of fetal weight before proceeding with surgery. Surgery may be delayed to facilitate fetal optimisation, and this decision must be balanced against any potential increased risks to the patient (e.g. deep vein thrombosis, infection).

Fetal monitoring

At a minimum, fetal heart rate should be documented both pre- and post-surgery. Consider intraoperative cardiotocography (CTG) if the fetus is at a viable gestation. This decision will ultimately be based on the obstetric team's recommendations for the patient in the context of the proposed surgery and pathology. This will require the availability of a midwife to remain with the patient to monitor the CTG throughout and communicate the fetal condition to the anaesthetic and surgical teams.

There should be clear documentation and communication of the multidisciplinary team's (MDT) plan if abnormalities in the CTG are detected intraoperatively.

Be aware that if a CTG has an abnormal trace, an obstetrician and neonatologist must be available in the event of an emergency caesarean section (C/S) being required. Ensure this is appropriate in the clinical setting for this patient and has been well-discussed with the midwifery, obstetric, surgical, and NICU teams at a pre-procedural huddle or time-out.

Continuous CTG may be challenging in obese patients or those having abdominal surgery, which is frequently the nature of the required emergent surgical procedure.

Interpretation of CTG may also be difficult given the expected decrease in fetal heart rate under anaesthesia. Increasing intravenous fluids and FiO_2, maintaining adequate maternal MAP, and facilitating left tilt may be incorporated to improve utero-placental perfusion.

Non-viable pregnancy

The risk of DIC and sepsis may be higher in the second and third trimesters due to greater placental and fetal tissue. Blood tests should be taken within 48 hours if intrauterine fetal demise (IUFD) occurs at <4 weeks. In cases of IUFD >4 weeks (or earlier if sepsis is present), the risk of DIC increases; therefore more recent complete blood count and coagulation studies should be performed. If it is diagnosed on hospital admission, the duration of demise may be unclear, as the last normal scan may have been an anatomy scan at 18–22-week gestation.

Anaesthetic drug safety

Some antiemetics previously not used in the first trimester may be used, such as ondansetron and dexamethasone (refer to Table 4).

Positioning

Uterine displacement should be initiated after 18–20 weeks of gestation to help address aortocaval compression. This should be considered earlier in cases of multiple gestations.

Other

Aspiration prophylaxis with a combination of sodium citrate and omeprazole is strongly recommended.

Third trimester

Timing

Procedures in the third trimester carry an increased risk of preterm labour and premature rupture of membranes. Surgical positioning can be more challenging in the setting of a large gravid uterus, and there is a subsequent higher risk of aortocaval compression.

Fetal monitoring

Fetal monitoring should be continuous, which can be challenging to integrate with surgery. It will ultimately be based on discussions with the obstetrics and gynaecology team and their recommendations for this patient and surgery. The requirements for thorough documentation and MDT discussion on the plan of action if a CTG trace becomes abnormal are the same as those for second trimester considerations. Overall, fetal monitoring is technically easier to carry out and interpret in the third trimester compared with other trimesters.

Non-viable pregnancy

See sections on first trimester and second trimester.

Anaesthetic drug safety

See sections on first trimester and second trimester.

Other

Peripartum risks to the pregnant patient return to baseline six weeks postpartum.[3] The gastrointestinal effects of progesterone (lower oesophageal tone, increased gastric residual volume and lower pH) can return to normal as early as 72 hours after caesarean section or 48 hours post vaginal delivery.[5] Evidence is conflicting in this area, with some studies indicating a delay if opioids are used.[6]

PREOPERATIVE CONSIDERATIONS

Timing

Non-emergency, non-obstetric surgery should be delayed until post-delivery, where possible.[7] If this is not possible, surgery should be completed in the second trimester, as this is associated with the lowest risk to the fetus and pregnant patient.[3]

Fetal monitoring

Fetal monitoring should be considered, especially after 24 weeks of gestation, depending on the procedure and gestational age. Some centres will discuss viability from 22 weeks' gestation.

Non-viable pregnancy

If there has been a fetal demise >48 hours prior, DIC and/or sepsis should be considered, and platelets and a coagulation profile should be ordered.[4] Fibrinogen should be > 2 g/L, and all other tests within a normal range.[4]

Anaesthetic drug safety

Avoid known teratogenic drugs and consider pharmacokinetics altered by pregnancy.

Safest technique

A regional technique with no sedation and avoiding airway manipulation is the safest technique when appropriate.

Multidisciplinary planning

Collaboration with surgeons, obstetricians, midwives and neonatologists is vital.

Counselling patients

When counselling patients about the risks of anaesthesia to the fetus, it should be conveyed that the risk of anaesthesia-related teratogenicity is an area of ongoing research; however, there is no strong evidence of increased risk from single exposure to anaesthetic agents, even when used during early pregnancy.[7] The risk of miscarriage and preterm labour is mitigated with appropriate planning, timing, anaesthetic/surgical technique and MDT involvement. Commonly encountered questions are presented in Table 1.

Table 1. Patient counselling and guidance: Common questions asked by obstetric patients having non-obstetric surgery

Question	Answer
Does general anaesthesia (GA) increase the risk of miscarriage or preterm labour?	Studies show there is a small increase in risk of miscarriage if you have had surgery. It is unclear if this is due to the health problem or illness that has caused the need for surgery, the surgery itself, the anaesthesia, or the stress on the body around the time of surgery.[3,8] The risk of a miscarriage after surgery in the first trimester is estimated to be about 10%, less than 1% in the second trimester and between 5-8% in the third trimester. This is in addition to the baseline miscarriage risk of 10-20% in the first trimester and 2-3% in the second and third trimester. These numbers are based on observational studies and should be individualised to the patient by considering medical, obstetric and surgical risk factors.[3,8]
Does GA increase the risk of future behaviour or learning issues for children?	A single anaesthetic is unlikely to cause future behaviour or learning challenges. Research shows these types of outcomes are more likely due to a combination of factors such as prolonged medication use, multiple surgeries, and broader social or economic influences.[3,7]

INTRAOPERATIVE CONSIDERATIONS

Surgical

Ensure the surgical team is aware of the need to do the operation with left lateral tilt, pneumoperitoneum with limited insufflation pressures <15 mmHg, and guided insertion of trocars to avoid uterine trauma. A NICU bed should be available (depending on stage of gestation) and a clear plan should be in place if concerning features develop on intraoperative CTG and emergency C/S is required.[3]

Positioning

In the second trimester, left lateral tilt is required to avoid aortocaval compression. Guidelines recommend 15 degrees; however, studies show 30 degrees may be more effective.[9] The degree of tilting may need to be increased depending on the uterine size/gestation/multiple pregnancy. Notably, many newer models of operating tables have limits on their side-to-side tilt, with many restricted to a maximum of 20 degrees. Ensure the patient is securely strapped and a side rail is in place. If prone positioning is required, the Jackson table may be preferred due to its open frame design, which reduces abdominal pressure.

Monitoring of blood pressure

If the supine position is required for surgery, expect blood pressure to fall due to aortocaval compression syndrome, which may not be easily corrected despite intravenous fluid and vasopressors. Invasive and non-invasive blood pressure at the arm may not reflect perfusing pressure at the placenta, regardless of position, and leg non-invasive blood pressure monitoring (focusing on MAP) or Doppler may be considered as an adjunct in high-risk patients. There are no current guidelines to support this emerging trend.[10,11]

Monitoring of anaesthetic depth

Depth of anaesthesia monitoring is encouraged if a GA is considered. There are no guidelines to suggest that the readings being displayed are significantly altered for pregnant patients. Obstetric patients may have a lower anaesthetic requirement, but this must be balanced with higher rates of awareness.[12] There is no evidence to support the superiority of a proprietary processed EEG system (SEDline vs BIS, etc.) in this patient cohort.

Anaesthetic technique

General anaesthesia (GA)

If a GA is required, sevoflurane may be preferred in some instances as it may reduce uterine contractions

and preterm delivery.[3] Ketamine can increase uterine tone.[3] Propofol total intravenous anaesthesia (TIVA) has the benefit of a reduction in postoperative nausea and vomiting, which is advantageous in this at-risk group, especially in the context of morning sickness/hyperemesis gravidarum.

The occurrence of propofol infusion syndrome (PRIS) in neonates born preterm following maternal GA with TIVA is not well-documented.[13] However, it may be a concern when doses exceeding 4 mg/kg/hr are administered for more than 48 hours, such as during prolonged operations and/or sedation in the ICU. If the mother is carnitine-deficient, the neonate is likely to be deficient at birth, given that it passes through the placenta, which can impair fatty acid metabolism in the newborn and theoretically increase risk.

Regional anaesthesia

A regional technique (neuraxial or peripheral nerve block) is the preferred modality for avoiding systemic drug administration and airway risks. Lower doses of spinal/epidural may be required in the third trimester due to mechanical and hormonal factors.[14] There may be a faster onset and shorter duration of block in this cohort, too. Prior to the third trimester, similar or slightly higher doses compared to those in non-pregnant patients may be required.[14] A combined spinal and epidural (CSE) may be a good option to allow titratability and rescue a failed block, if time allows.

Airway

Pregnant patients have increased oxygen consumption and a lower functional residual capacity, making them prone to desaturation.

Positioning

Ramp the patient well (flextension and torso elevation) to improve airway and respiratory mechanics. Note, flextension is a relatively new term to describe optimal head and neck positioning for airway management.[15]

Aspiration risk

Due to changes in the lower oesophageal sphincter and a gravid uterus displacing abdominal contents, rapid sequence induction with endotracheal intubation is strongly recommended. There is currently a lack of high-quality evidence to support the use of cricoid pressure in obstetric patients; hence, its use should be individualised. There is no consensus for a gestational age where endotracheal intubation is required; however, it should be considered in all trimesters, especially as pregnancy progresses and if the patient has nausea/vomiting/reflux or a full stomach. Patients can have gastrointestinal symptoms from as early as four weeks.[16]

Difficult airway

Historically, it was reported that one in 250 pregnant patients had a failed intubation. In the NAP4 national UK audit, only four cases of failed intubation (incidence of one in 1700–16,000) were reported.[17] For these reasons, it is difficult to draw robust conclusions that demonstrate a confirmation of this previous concern. A "difficult" airway may be expected due to anatomic and physiological changes in pregnancy; however, failed intubation may be less common due to increased awareness and advances in technology and training.

The Difficult Airway Society (DAS) and the Obstetric Anaesthetists' Association (OAA) recommend that video laryngoscopy should be used as a first-line approach in this population.[17] If using direct laryngoscopy, a short handle should be used. Videoscopes with a screen attached to the handle (e.g. Glidescope Go) can create a longer handle, which can pose ergonomic challenges. Consider using a separate screen or an alternative video laryngoscope with a more favourable ergonomic profile.

Note in DAS's *Management of difficult and failed intubation in obstetrics guidelines,* two attempts at laryngoscopy are recommended as opposed to three to reflect increased airway oedema/friability.[17]

Figure 1. Management of difficult and failed intubation in obstetric patients

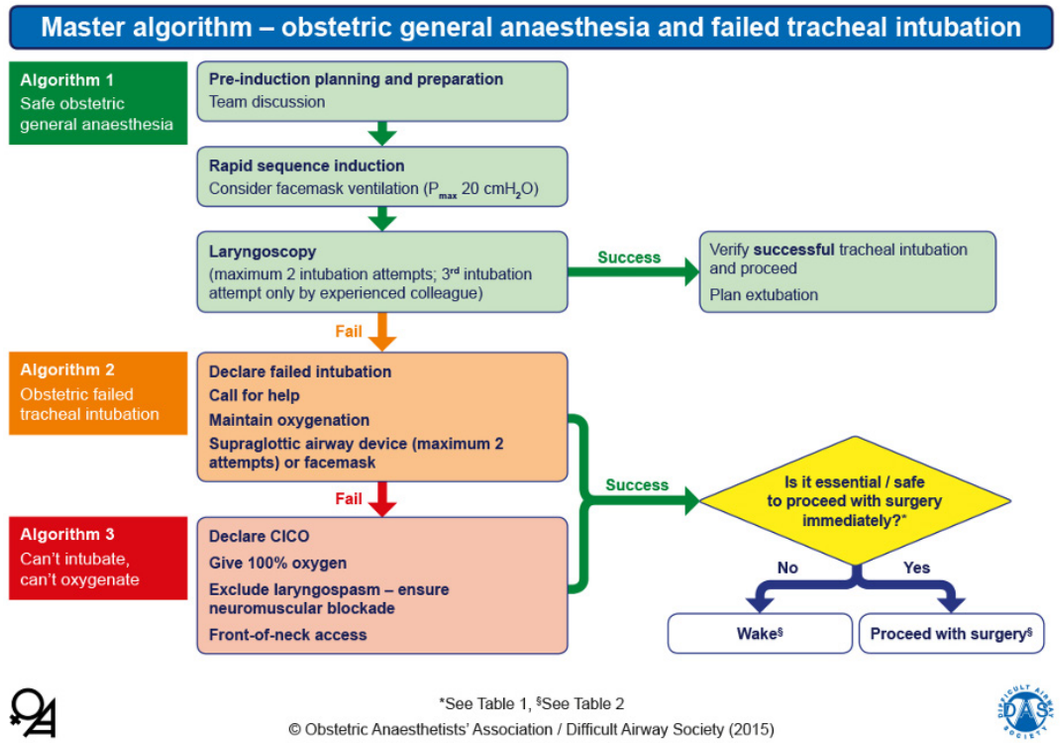

Image reproduced from Obstetric Anaesthetists' Association and Difficult Airway Society (2015)[18]

High-flow nasal prongs (HFNP) aiming for an ETO_2 > 90% can provide a longer apnoeic time until desaturation compared with standard face mask preoxygenation. The benefits of HFNP may be limited when BMI exceeds 50 in pregnancy.[19]

Breathing

Ventilation

Set ventilator to high-normal tidal volume (VT) (5-7 mL/kg) and target low-normal $ETCO_2$ (30-32 mmHg or 4-4.3 kPa), to reflect compensated metabolic alkalosis. This may theoretically facilitate fetal oxygenation at the placenta (a right shift in the oxygen-dissociation curve on the maternal side, allowing oxygen to be offloaded). Excess CO_2 crosses the placenta and can cause fetal myocardial depression and acidosis.

Oxygenation

A universally prescribed FiO_2 threshold is not well-established in the literature. Current guidelines emphasise the importance of preserving normal maternal oxygenation, acid–base balance, and uteroplacental perfusion to optimise fetal outcomes. FiO_2 may be set at a higher value during preoxygenation and vulnerable periods to provide an adequate buffer, acknowledging that fetal oxygenation is dependent on maternal oxygen tension. However, routine prolonged use of higher FiO_2 has not been shown to provide benefit and may be associated with fetal retinopathy.

Circulation

Ensure stable blood pressure and uteroplacental perfusion. Hypotension should be promptly treated with fluids and vasopressors, such as phenylephrine, metaraminol, noradrenaline or ephedrine.

Choice of vasopressors

There are no international guidelines on blood pressure targets; however, a systolic >100 mmHg and

MAP>65 (or within 20% of baseline) is reasonable. While there are no specific guidelines solely focused on the choice of vasopressors for obstetric patients undergoing non-obstetric surgery, evidence from caesarean section anaesthesia suggests early peripheral noradrenaline (7 mcg/mL concentration) may offer advantages as it is not associated with the reflex bradycardia that is sometimes seen with phenylephrine/metaraminol, nor reduced fetal pH/increased fetal heart rate, as seen with ephedrine.[20] This is likely due to its mixed alpha and beta action, which increases both cardiac output (CO) and systemic vascular resistance (SVR), thereby enhancing placental perfusion. The risk of extravasation injury is low with concentrations <8 mcg/mL and short-duration infusions.[21] If unfamiliar with peripheral noradrenaline, metaraminol is a good alternative. If bradycardia occurs with its use, consider atropine or glycopyrrolate rather than ephedrine.

Deep vein thrombosis (DVT) prophylaxis

The risk of DVT is 5x greater in pregnancy.[22] The hypercoagulable state is highest in the first six weeks postpartum, peaks in the first three weeks (20x higher than non-pregnant) and returns to normal at 12 weeks postpartum. Sequential compression devices (SCDs) and limb mobilisation are required every 2-3 hours during lengthy procedures. A decision can be made together with the surgical team at surgical sign-out regarding whether low-molecular-weight heparin (LMWH) or thromboembolic stockings (TEDs)/SCDs are preferred, along with avoidance of dehydration and encouragement of early mobilisation.

Obstetric haemorrhage

Pregnant patients have high CO and may be at higher risk of cardiac arrest if hypovolemia is not recognised early and corrected.

In the third trimester, a blood loss of more than 1.5 L is required in a 70 kg patient before signs of decompensation develop. Individualised calculation of blood volume by weight is necessary to ensure that a significant haemorrhage is not missed in smaller patients, as well as vigilance and strong communication among surgeons, nurses, and anaesthetists. An overreliance on blood pressure and heart rate is not recommended, especially since pregnant patients typically have a higher resting heart rate and lower blood pressure. Common estimates for different patient weights are presented in Table 2.

Table 2. Calculated blood volumes in the third trimester

Body mass index (BMI)	Blood volume in third trimester (100 mL/kg)	20% blood loss
18.5-24.9 – healthy Example: 50 kg	5 L	1 L
18.5-24.9 – healthy Example: 70 kg	7 L	1.4 L
> 30 – obesity Example: 100 kg	7 L*	1.4 L

*In obesity, lean body weight should be used to calculate blood volume or 70 mL/kg if total body weight is used.[23]

When managing major bleeding in obstetric patients undergoing non-obstetric surgery, the principles of permissive hypotension, balanced blood products, and damage control surgery are generally applied as for non-obstetric patients, with additional considerations outlined in Table 3.

Table 3. Considerations for pregnant patients with major bleeding

Principle	Additional considerations	Practice point
Permissive hypotension	MAP of 50-60 will significantly reduce fetal perfusion pressure given the placenta is pressure passive.	This is a high-stakes intervention. It is considered when maternal life is at imminent risk and resuscitative hysterotomy may also be under consideration. Maternal survival is the priority and a period of reduced uteroplacental perfusion may be required. If fetal demise is already confirmed or very likely this decision is clear. The extent of permissive hypotension should be guided by: 1. Severity of maternal injury. 2. Fetal viability. 3. Likelihood of ability to gain surgical control of bleeding.
Balanced blood products	Pregnancy is a hypercoagulable state with higher fibrinogen (4-6 g/L) and clotting factors. Studies in postpartum haemorrhage reveal fibrinogen is consumed faster than clotting factors despite volume of blood loss.[24] Excessive fresh frozen plasma (FFP) can lead to dilutional coagulopathy, volume overload, acute/delayed immune reactions and, specific to pregnancy, reduced oxygenation of the fetus. Recent MBRRACE reports reveal inadequate or delayed correction of coagulation, especially fibrinogen, leading to maternal deaths.[24] Tranexamic acid (TXA) is safe in pregnancy.[25] Cell salvage may increase the risk of maternal alloimmunisation if Rh D incompatibility and fetal red cells are present in salvaged blood.[24] There is little evidence it may increase the risk of amniotic fluid embolism.[24] Evidence from postpartum haemorrhage cannot be directly extrapolated to non-obstetric causes of bleeding or early pregnancy but can be used as a guide.	Obstetric massive haemorrhage pathway (MHP) should be activated for advanced pregnancy or uterine-related bleeding with early Cryoprecipitate or fibrinogen concentrate and TEG or ROTEM guided provision of blood products. Standard non-obstetric MHP can be activated for early pregnancy with non-obstetric bleeding. Fibrinogen should be maintained >2 g/L in the later stages of pregnancy. If it falls to a normal range for non-obstetric patients, this may be early DIC, which requires aggressive correction. Prothrombin time and activated partial thromboplastin time should be maintained at less than 1.5x normal.[24]
Damage control surgery	This may be more challenging in advanced pregnancy given the ergonomics of a gravid uterus.	Fetal delivery may be required to optimise maternal morbidity and mortality.[25] In cases of uterine abruption, trauma or rupture, uterine emptying will be required.[25]

Drugs

If a general anaesthesia (GA) is required, propofol induction followed by sevoflurane maintenance, paralysis, fentanyl, morphine, noradrenaline, metaraminol, atropine, and reversal with neostigmine and glycopyrrolate is safe in all trimesters.

Other common drugs used during general anaesthesia and the recovery period can be found in Table 4. In the US, the Food and Drug Administration removed the A, B, C, D and X risk categories in 2015 and replaced them with the new classification system, the Pregnancy and Lactation Labelling Final Rule (PLLR).[26] The authors have utilised information from the New Zealand Drug Formulary in the creation of this guideline and recommend its use when caring for pregnant patients in the perioperative period.

Evidence for teratogenicity secondary to perioperative interventions is an area of ongoing research, with no strong evidence of increased risk from anaesthetic agents.[3]

Maintenance of normal physiology – blood pressure, O_2, temperature and compensated metabolic alkalosis with CO_2 (30-35 mmHg) and pH (7.4-7.45) provides the best conditions to reduce fetal distress intraoperatively.[3]

Table 4. Drugs used in pregnancy: Safety profile of commonly used anaesthetic drugs

Drug	Safety in pregnancy
Dexamethasone	Utilise if the potential maternal benefit far outweighs the potential fetal risk.[27] **Caution:** Use in the **first trimester** has a small absolute risk of oral clefts.
Midazolam	No association with congenital deformities in the first or second trimesters. **Caution:** Use in **third trimester** may be associated with adverse neonatal neurobehaviours. This is based on animal data after repeated or lengthy use.[27]
NSAIDs	Can be considered in the second trimester, if benefits to parturient outweighs risk to fetus, and at the lowest dose, shortest duration. **Caution:** Contraindicated in the **third trimester** as can cause closure of patent ductus arteriosus, renal or platelet impairment. Potential association with teratogenicity in **first trimester**. Risk of neonatal renal impairment present in **second and third trimester.**[27,28]
N_2O	Weak teratogen in animals. Theoretical risk given mechanism (inhibiting methionine synthetase and impairing DNA production). No evidence in humans that it increases rates of congenital malformations. **Caution:** Despite this reassuring evidence, it is generally avoided in the **first trimester**.[27]
Ondansetron	Two large national studies, one from Denmark and the other from Sweden, have found significant increases of cardiac anomalies when ondansetron was used in the first trimester. Association with oral clefts may be present. **Caution:** Generally avoided in **first trimester**.[27]
Opioids	The National Birth Defects Prevention Study found evidence that opioid use during organogenesis is associated with a low absolute risk of congenital birth defects. A second study also found a similar association.[27] **Caution:** Avoided in **first trimester** unless benefits to mother outweigh risks to fetus and used at the lowest dose, shortest duration.
Sugammadex	The Society for Obstetric Anaesthesia and Perinatology (SOAP) issued a consensus statement that sugammadex should be avoided in early pregnancy and used with caution or avoided at near term or term.[29] **Caution:** Avoided in **first trimester** and used with caution in **second and early third trimesters.**

Sugammadex

Neostigmine should be used where possible; however, if clinically indicated, sugammadex is reasonable given growing evidence and case reports of its safety in pregnancy. Earlier concerns are related to the potential for the drug to encapsulate progesterone and potentially disrupt the integrity of the pregnancy.[29] Theoretically, sugammadex could pose a greater concern in the first trimester, as early pregnancy is highly dependent on progesterone. Although no human studies have demonstrated teratogenicity, it is reasonable to exercise caution due to the limited human data available.

Antibiotics

Aminoglycosides, penicillin, cephalosporins and clindamycin have good safety profiles.

Magnesium

This may be started preoperatively by the obstetric team in cases of severe preeclampsia/toxemia (PET) to minimise maternal seizure risk, or for fetal neuroprotection or expected premature labour (for tocolysis).

Local anaesthetics

LAST (local anaesthetic systemic toxicity) risk is increased due to a relative reduction in the concentration of protein, pH changes, and increased sensitivity of nerve and cardiac tissue to local anaesthetics.

Tocolysis

It may be requested by the obstetric team to mitigate the risk of preterm delivery. Some tocolytic drugs (magnesium, beta agonists, GTN) can cause haemodynamic instability. Prostaglandin inhibitors (indomethacin) and slow-release calcium channel blockers may cause less haemodynamic instability. These medications should only be administered under the guidance of an obstetrician.

Other considerations

Fetal considerations

Avoid significant maternal hypoxia, hypotension, hypercarbia, hypothermia or hyperthermia and acidosis to prevent fetal distress.

Radiology

Radiology should be completed if needed. Discuss with the radiologist to pick the best modality and minimise fetal exposure. Non-abdominal/pelvic imaging exposes the fetus to <1 mGy and can proceed normally. Abdominal/pelvic imaging (single abdominal X-ray or limited computed tomography (CT) scan) may expose the fetus to >1 mGy (mean: 1 mGy, max: 4 mGy).[30]

Doses >10 mGy may be associated with a small increased risk of childhood cancer.[30] Doses >100 mGy may be associated with first-trimester loss and neurological effects.[30] Some CT abdominal/pelvis protocols used in trauma, obesity, and with older machines may expose the fetus to 10-35 mGy.[30]

Some guidelines recommend shielding the breasts during radiological procedures due to the theoretical risk of breast cancer and increased breast tissue in pregnancy.[31]

Other considerations include incorporating the risk of radiology scans into consent paperwork and discussions, considering whether ultrasonography can be used as an alternative, optimising radiation dose, calculating fetal dose exposure, and positioning boards pre-emptively before patient positioning.

POSTOPERATIVE CONSIDERATIONS

Position

Continue left lateral tilt until the patient can mobilise or easily adjust their position.

Pain management

Use of multimodal analgesia is encouraged to minimise opioid use.

Fetal monitoring

The obstetric team may recommend ongoing fetal monitoring for viability and recovery.

Preterm labour risk

The obstetric team may recommend commencing or continuing tocolysis if necessary to prevent preterm labour.

DVT risk

Patients should be commenced on weight-based dosing of LMWH as soon as it is safe. Early mobilisation and TEDS or SCDs are encouraged.

SPECIAL POPULATIONS

Preeclampsia

These patients require adequate sympathetic blockade for laryngoscopy and surgical stimulus to avoid catastrophic hypertension and associated subarachnoid haemorrhage.

Tramadol and pethidine are not strictly contraindicated but are generally avoided in preeclampsia due to their potential risks of lowering seizure threshold. Alternatives with better safety profiles are commonly available now and should be considered.

Careful maintenance of fluid balance is required. Consider an arterial line and early involvement of obstetricians if blood pressure is difficult to manage.

Recent consensus guidelines state that if pre-eclamptic toxaemia (PET) alone is suspected, it is unlikely to cause a precipitous fall in platelets within 72 hours.[32]

A subsection of patients will develop HELLP syndrome and will require an up-to-date coagulation screen and platelets. SOAP states that platelet counts may fall rapidly in these patients, and the optimal frequency of platelet testing prior to neuraxial procedures remains uncertain.[32]

Between 15-20% of patients may develop atypical HELLP without hypertension or proteinuria. Consider screening for HELLP if PET symptoms are present.[32]

There is limited evidence on the safety of neuraxial procedures with PET, particularly in patients with low platelet counts and those using aspirin.[32]

Gestational diabetes

Usual considerations for non-pregnant diabetic patients apply. These patients should have their procedures scheduled as early in the morning as possible and their blood sugar level should be checked on arrival and intraoperatively. Consider glucose/insulin/potassium (GIK) infusion and resume insulin postoperatively. These patients are at higher risk of PET and preterm birth.

Intrahepatic cholestasis of pregnancy (ICP)

Consider a recent (<6 hours prior) coagulation panel to assess for Vitamin K deficiency and early replacement of deficient factors if significant bleeding is present. This may also contraindicate the use of a neuraxial technique if these levels are deranged.

Obstetric trauma

Trauma surgery in the obstetric patient necessitates a combination of obstetric and trauma management principles.

Airway

1. Secure the endotracheal tube early, given the risk of regurgitation. Expect difficulty and manage appropriately, as discussed prior.

Breathing

2. Thoracostomy should be inserted two spaces higher when needed.[33]
3. Thoracic trauma may cause abdominal organ involvement.[25]
4. Ventilator settings and targets are as discussed prior to optimise fetal perfusion.

Circulation

Manual left uterine displacement is advised, as opposed to tilting the patient. This is to improve CPR success, if needed.[33]

CT has improved sensitivity and specificity compared with trauma eFAST scans.[25] It should be considered and prioritised for maternal wellbeing despite the radiation risk to the fetus.[33]

Resuscitative hysterotomy is required in cardiac arrest, with delivery <5 mins of arrest.

Provision of blood products may be required, with early administration of cryo, O-blood, TXA, warming devices and viscoelastic haemostatic assays (VHAs) guiding further transfusion, as briefly presented in Table 3.

Vasopressors are suggested after fluid resuscitation if time allows.[33]

Pelvic trauma requires rapid escalation, given the risk of rapid cardiac arrest from dilated and exposed blood vessels. The ergonomics of placing a pelvic binder may require adjustments and compromise. In trauma, pelvic binders usually sit over the greater trochanters; however, this may be challenging in advanced pregnancy if purpose-made binders are unavailable.[25]

Damage control surgery may not be possible without emptying the uterus.

Placental abruption can occur in 50% of major traumas.[25] This can be concealed and challenging to diagnose on ultrasound alone.[33] A vaginal exam may be performed as part of the A-E assessment once placenta praevia is ruled out by the obstetric team. The timing and necessity of this exam should be coordinated with the obstetric team.

Disability

ATLS guidelines recommend hard C-spine collar and manual in-line stabilisation.

Treatment for raised ICP (osmotic therapy, hyperventilation, hypothermia, barbiturates and sodium nitroprusside) can impair fetal oxygenation.[25] Head elevation should be performed with ongoing L uterine displacement.

Extra

- Fetal assessment and monitoring are indicated after primary surgery of the patient, following ATLS guidelines. Fetal distress may be the first sign of placental abruption, uterine rupture and/or impending maternal hypovolemic shock.[33]
- Anti-D, tetanus and antibiotics are safe for the fetus and the pregnant patient.
- Kleihauer testing should be performed to calculate the Anti-D dose.
- Screening for interpersonal violence should be considered.
- Tocolytics are generally not recommended if evidence of preterm labour as the underlying cause is pathological rather than uterine irritability.
- Steroids may be indicated, as discussed previously.

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Anaesthesia for open fetal surgery: Myelomeningocele repair

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INTRODUCTION

Fetal surgery is a rapidly evolving field that offers life-saving interventions and improved quality of life for unborn babies with congenital abnormalities.[1] Myelomeningocele, the most severe form of spina bifida, is a common neurologic condition with proven benefit from prenatal repair. Intrauterine interventions require a collaborative effort from a diverse multidisciplinary team to ensure the health and safety of both the expectant mother and the developing fetus.

The Mater Mothers' Hospital began fetal surgery in 2001, performing more than 400 cases to date. This includes 25 open myelomeningocele repairs, the most common open fetal surgery. As of 2018, the Mater was one of 34 hospitals globally performing this procedure[2] and remains the sole Australasian referral centre for open fetal surgery. As additional centres around the world prepare to offer fetal surgery, it is important to understand the perioperative considerations of these complex interventions.

OBJECTIVES

This article will provide a brief overview of fetal surgery, followed by a discussion on myelomeningocele, highlighting the key maternal, fetal and anaesthetic considerations specific to open fetal surgery for its repair.

MATERNAL-FETAL SURGERY OVERVIEW

In 1982, the International Fetal Medicine and Surgery Society published criteria for fetal disorders amenable to in-utero intervention.[3] These included the availability of accurate fetal diagnosis and staging, an individualised prognosis, lack of effective postnatal treatment, proven feasibility of in-utero surgery and involvement of a specialised multidisciplinary team.[4] Over the past two decades, there has been significant growth in the number of fetal surgical indications and procedures. Broadly, fetal surgery can be categorised into minimally invasive, open, and ex-utero intrapartum treatment (EXIT) procedures.[5] Table 1 provides an overview of common fetal surgical procedures.

Minimally invasive procedures

Minimally invasive maternal-fetal interventions include both ultrasound-guided procedures and fetoscopic surgery; the latter involves percutaneous placement of trocars through the uterus. The most common fetoscopic procedure performed at Mater is laser photocoagulation for twin-twin transfusion syndrome and is typically conducted under local anaesthesia with sedation.

Open procedures

Open maternal-fetal surgery involves the induction of general anaesthesia and the performance of a maternal laparotomy for uterine exposure. Hysterotomy or fetoscopy is then performed to allow surgical correction of the fetal defect. Upon completion, the uterus and abdomen are closed, and the pregnancy continues. Fetal myelomeningocele repair is the most common indication for open maternal-fetal surgery.

EXIT procedures

The EXIT procedure is a surgical procedure used to deliver babies with significant airway or lung compression. It involves operating on the fetus while the uteroplacental circulation remains intact to provide oxygenation, followed by delivery at the completion of the procedure.[6,7]

Table 1. Indications for common fetal surgical procedures
Adapted from Weber and Kranke, 2019 and Chatterjee et al, 2021

Type of fetal surgery	Indication	Procedure	Type of anaesthesia
Minimally invasive – USS guided	Fetal genetic testing	Percutaneous umbilical blood sampling	LA
	Fetal anaemia	Intrauterine transfusion	LA
	Aortic stenosis with evolving hypoplastic left heart syndrome	Balloon valvuloplasty	Neuraxial or general anaesthesia
Minimally invasive – fetoscopic	Twin-twin transfusion syndrome	Laser photocoagulation	LAWS or neuraxial
	Amniotic band	Surgical release	LAWS or neuraxial
	Congenital pulmonary airway malformation (CPAM)	Thoracoamniotic shunt	LAWS or neuraxial
	Bladder outlet obstruction	Vesicoamniotic shunt	LAWS or neuraxial
	Congenital diaphragmatic hernia	Fetal endoluminal tracheal occlusion	LAWS or neuraxial
	Spina bifida	Myelomeningocele repair (total percutaneous approach)	General anaesthesia
Open - laparotomy with hysterotomy or uterine fetoscopy	Spina bifida	Myelomeningocele repair	General anaesthesia +/- neuraxial
EXIT procedure	Oropharyngeal mass/neck mass/severe micrognathia	Securing airway	General anaesthesia
	CPAM/bronchogenic cyst/ sacrococcygeal teratoma	Resection of malformation/ cyst	General anaesthesia

*LA = Local Anaesthesia; LAWS = Local Anaesthesia With Sedation; USS = Ultrasound Scan

MYELOMENINGOCELE CORRECTION

Spina bifida is the most common congenital malformation of the neural tube, affecting approximately 1 in 1000 births worldwide.[8] It is characterised by failure of the neural tube to close during the fourth week of gestation.[9] Myelomeningocele is the most common and severe form of spina bifida, and is defined by the extrusion of the spinal cord and meninges through a bony defect without overlying skin.[9,10] It is associated with Chiari Type 2 malformation and subsequent hydrocephalus, commonly requiring management with a ventriculoperitoneal shunt. The level of the lesion determines the extent of neurologic impairment, which may result in lower limb weakness, altered sensation or paralysis, as well as bladder, bowel and sexual dysfunction.[10]

Neurologic deficits associated with myelomeningocele may arise from two pathways – the primary developmental abnormality of the spinal cord and secondary damage to neural tissue from exposure to amniotic fluid and trauma in utero.[10]

Historically, there were two options for managing a pregnancy complicated by spina bifida: termination or delivery followed by postnatal repair.[10] Advances in fetal surgical techniques now enable in-utero repair of myelomeningocele, potentially reducing secondary neurologic damage and improving long-term comorbidities.[11]

In 2011, the landmark Management of Myelomeningocele Study (MOMS)[12] compared open prenatal surgical repair between 19- and 26-weeks' gestation with standard postnatal repair. It found prenatal repair decreased the rate of death or need for ventriculoperitoneal shunt placement at 12 months. Prenatal surgery also improved mental function, motor scores and ambulation at 30 months and decreased the incidence of hindbrain herniation.[12] However, prenatal surgery was associated with earlier delivery (34.1 weeks versus 37.3 weeks) and increased incidences of preterm delivery, uterine dehiscence at delivery, placental abruption (6.6% versus nil) and maternal pulmonary oedema (5.5% versus nil).[13]

Longer-term follow-up of the MOMS participants at school age showed persisting sensorimotor benefits, decreased incidence of Chiari malformations and hydrocephalus, fewer shunt placements and shunt revisions compared to postnatal repair. Quality of life and family impact metrics were significantly improved.[14]

Following the MOMS, in 2014, the Maternal-Fetal Management Taskforce published guidelines for fetal myelomeningocele repair centres.[15] These include a multidisciplinary approach to care with around-the-clock access to a specialised spina bifida team, neonatal intensive care, experienced maternal-fetal medicine specialists, an ethics review board, and patient advocates. Patients should receive thorough counselling on options (including pregnancy termination and pre or postnatal myelomeningocele repair) covering risks for both the baby and the mother. Long-term standardised paediatric treatment and evaluation services should also be available.

PREOPERATIVE CONSIDERATIONS

The multidisciplinary team

Optimising maternal and fetal outcomes requires a coordinated group of specialised healthcare workers. This routinely comprises maternal-fetal medicine, neonatology, paediatrics (including clinical genetics), anaesthesia, neurosurgery, plastic and reconstructive surgery, radiology, perioperative nursing, midwifery, and social work.[5] An ethics committee typically oversees the creation of a fetal surgical service. Collaboration of the entire team is required to fulfil the preoperative considerations outlined in Table 2.

Table 2. Preoperative considerations for open myelomeningocele repair

Preoperative considerations
Maternal and fetal evaluation
Multidisciplinary counselling of maternal and fetal risks
Surgical and facility preparation – environment and equipment
Plan for potential fetal resuscitation or emergent delivery
Crossmatched blood available for fetal or maternal transfusion

Patient selection

Maternal-fetal medicine specialists conduct a detailed review of the maternal and fetal state to determine eligibility. This includes fetal MRI to assess the severity of spinal and intracranial pathology, fetal ultrasound to investigate co-existing malformations, and fetal echocardiography.[16] Fetal genetic studies, including karyotyping and microarray, may be performed to rule out chromosomal abnormalities, microdeletions or microduplications which contraindicate surgery.[17,18]

Maternal considerations

The anaesthetist's initial role involves assessing maternal suitability for surgery and providing counselling. Preoperative anaesthetic review allows adequate provision of information, helps facilitate rapport and allay maternal anxieties. Evaluation should focus on both physiologic and pathologic conditions associated with pregnancy. A thorough history and examination should be conducted, including an assessment of the mother's spine. Given the potential for catastrophic blood loss, a blood group with antibody screening should be arranged, with further investigations dependent on specific clinical concerns.[16] It is routine to discuss standard fasting procedures, general anaesthesia, arterial cannulation, spinal and epidural procedures, analgesia and the expected postoperative course.[11]

Although women may be physically well, the psychological impact of fetal surgery can be profound. Anxiety regarding an uncertain fetal outcome, the lack of direct maternal benefit, and the need to travel long distances to specialist centres often contribute to feelings of isolation. Balancing geographical access with the maintenance of case volume for resource-intensive procedures remains a challenge.[19]

Fetal considerations

Considerations for fetal surgery must account for a range of clinical, socio-cultural, legal and ethical concerns.[20] With a decision to proceed, an assessment should be made regarding the eligibility of the fetus for resuscitation in the event of fetal distress or need for emergent delivery.[21] Comprehensive counselling with parents is essential and should include informed consent for fetal resuscitation based on individual risks and values.

Fetal heart rate, position, and placental location should be evaluated before commencing anaesthesia.[5] A preoperative estimate of fetal weight is useful for calculating intraoperative fetal drug doses.

INTRAOPERATIVE CONSIDERATIONS

There are three main surgical approaches to myelomeningocele repair. Open repair involves maternal laparotomy, exteriorisation of the uterus and hysterotomy aided by resorbable staples. Fetoscopic repair via maternal laparotomy involves exteriorisation of the uterus followed by placement of uterine trocars to facilitate fetoscopy. Total percutaneous fetoscopic repair avoids the need for maternal laparotomy. A systematic review in 2018 showed no significant differences in fetal mortality or rates of shunt placement for hydrocephalus between surgical approaches.[22] Percutaneous fetoscopy was associated with higher rates of dehiscence and CSF leak at the fetal myelomeningocele repair site that required subsequent postnatal intervention (30 vs 7 per cent). There was also a greater incidence of premature rupture of membranes (79 vs 6 per cent) and preterm birth. Open repairs were associated with higher rates of uterine dehiscence (11 vs 0 per cent).[22,23] Given the risk of uterine dehiscence and rupture, performing a hysterotomy for open myelomeningocele repair mandates that all future pregnancies be delivered via caesarean section.[11]

Depending on the surgical approach, various anaesthetic techniques may be used for myelomeningocele repair. While there is limited evidence for the superiority of a specific technique,[5,24] understanding the impact of interventions on maternal and fetal outcomes is crucial. Intraoperative goals for open fetal surgery include managing uterine tone, maintaining uteroplacental circulation, optimising surgical conditions, monitoring fetal haemodynamics, and minimising risks to both mother and fetus.[25] At our institution, two senior anaesthetists work together to care for the mother and fetus. Table 3 outlines the salient intraoperative considerations for anaesthesia for open myelomeningocele repair.

Table 3. Intraoperative considerations for open myelomeningocele repair

Intraoperative considerations	
Access	Two large-bore peripheral IV cannulae Arterial line
Antibiotics	Broad spectrum coverage with cefazolin and azithromycin
Maternal monitoring	Standard ANZCA monitoring Cardiac output monitoring via arterial pulse contour analysis to optimise uterine blood flow BIS Temperature Neuromuscular monitoring to ensure adequate reversal prior to extubation Urine output
Fetal monitoring	Ultrasound • Umbilical artery doppler • Intermittent fetal echocardiography
Environment	Latex-free to prevent fetal exposure
Analgesia	Thoracic epidural placed pre-induction, loaded with ropivacaine prior to emergence Spinal anaesthesia pre-induction (0.5% heavy bupivacaine, fentanyl, clonidine)
Maternal anaesthesia	Modified RSI with left-lateral tilt Maintenance with sevoflurane
Uterine tone	Magnesium 10 mmol bolus (prior to exteriorisation of uterus and again prior to uterine closure) Volatile (up to 2 MAC at time of hysterotomy) GTN (third-line if required)
Maternal haemodynamics	Peripheral adrenaline and phenylephrine to maintain MAP
Amniotic fluid replacement	Infusion of warmed crystalloid solution (volume guided by USS)
Fetal anaesthesia	Intramuscular fentanyl and vecuronium

Maternal considerations

As for all obstetric patients, physiologic changes of pregnancy necessitate specific anaesthetic considerations. This includes securing a definitive airway given the increased risk of aspiration, and consideration of left uterine displacement to facilitate adequate venous return.[11,26] Ventilation should account for the physiologic increase in tidal volume and minute ventilation during the second trimester, noting that hypocarbia may cause uterine vasoconstriction and should be avoided.

Uterine tone

Profound uterine relaxation is required for hysterotomy. In open fetal surgery, high-concentration volatile anaesthetics (1.5-2.5 MAC) have historically been used for the maintenance of anaesthesia. Volatiles reduce uterine tone in a dose-dependent manner,[27] with concentrations greater than 2 MAC effectively minimising myometrial contraction to stimuli. However, such concentrations cause significant reductions in maternal cardiac output and uterine blood flow by up to 30 per cent.[28] Additionally, high-concentration volatile anaesthesia has been associated with fetal cardiac depression as well as maternal seizure activity.[29,30]

Multimodal uterine relaxation aims to avoid the risks of high doses of single agents. Varying combinations of volatile anaesthesia, glyceryl trinitrate (GTN), propofol, magnesium and remifentanil have been described to achieve adequate anaesthesia and tocolysis.[31-33] Surgical palpation provides useful feedback on the degree of uterine relaxation. GTN may be administered in boluses of 50-100 mcg or by a continuous infusion of 0.5-1 mcg/kg/min in cases of insufficient tocolysis.[34] Magnesium administration reduces volatile anaesthetic requirements, facilitates tocolysis, and provides fetal neuroprotection in the event of preterm labour.[35,36]

When administered at maternal skin incision as opposed to at uterine closure, magnesium was associated with a significant reduction in MAC and fetal volatile anaesthetic exposure, with no difference in vasopressor requirements or blood loss.[35] A retrospective analysis of 22 open myelomeningocele repairs found that intraoperative remifentanil infusions were associated with lower volatile anaesthetic requirements and reduced vasopressor use while maintaining adequate uterine relaxation, with no adverse effects on fetal outcomes.[37] By reducing volatile anaesthetic exposure, remifentanil may help to minimise fetal cardiac dysfunction.[24]

Haemodynamics

Maternal cardiac output can increase by up to 50 per cent during pregnancy.[38] Mean arterial pressure (MAP) may fall due to a reduction in systemic vascular resistance. As uteroplacental blood flow is not autoregulated, it primarily depends on maternal cardiac output.[38] Since many drugs used for uterine relaxation also cause hypotension, vasopressors and inotropes are used to keep MAP within 10 per cent of maternal baseline to maintain fetal perfusion.[11] Phenylephrine may have favourable effects on fetal acid-base status,[39] while ephedrine and glycopyrrolate are helpful in maintaining maternal heart rate and cardiac output. Adrenaline similarly helps maintain maternal cardiac output, with the added benefit of tocolysis due to beta-2 adrenoreceptor agonist effects.

In addition to an arterial line, advanced cardiac monitoring such as the FloTrac system™ (FloTrac; Edwards Lifesciences, Ivine, CA, USA) allows for estimates of parameters such as cardiac output index and stroke volume variation. Although it is yet to be validated in this group, advanced cardiac monitoring may be useful in guiding fluid replacement therapy in the context of hypotension. This is particularly important given the risk of postoperative pulmonary oedema following open myelomeningocele repair.[40] For this reason, many centres advocate restricting intravenous fluid volume to less than two litres.[11] The use of colloids, while not routine, may have fluid-sparing effects.

Other maternal considerations

Other routine anaesthetic considerations for the obstetric patient should be followed, including appropriate antibiotics and venous thromboembolism prophylaxis. Azithromycin provides broad-spectrum antibiotic coverage and readily crosses the placenta. Maintenance of normothermia is paramount, as the fetus is unable to autoregulate temperature, and hypothermia may trigger fetal bradycardia.[11] The use of magnesium for uterine relaxation can potentiate neuromuscular block. Hence, neuromuscular monitoring should be used to ensure adequate reversal of muscle relaxation prior to extubation. As the relaxed uterus is prone to haemorrhage (especially during hysterotomy and uterine stapling), large-bore IV access is prudent. Fortunately, the need for blood transfusion is rare.[34] Uterotonics should be emergently available in the event of conversion to caesarean delivery.[5] The risk of imminent delivery poses an enhanced risk of postpartum haemorrhage in the presence of uterine relaxation.[41]

Fetal considerations

Fetal anaesthesia and analgesia

Whether a fetus experiences pain during surgery, and at what gestation, remains a complex debate. Fetal stress responses are elicited as early as 18 weeks in the pituitary-adrenal, sympatho-adrenal and circulatory systems, independent of maternal responses.[42-44] By 19 weeks, reflex withdrawal to a painful stimulus occurs.[45] Although these responses are attenuated by opioid administration,[42] this is not synonymous with adequate analgesia. The complex development of the higher cortical structures required for pain perception suggests that pain perception is unlikely before 24 weeks.[45] Electroencephalogram studies at 24 weeks demonstrate cortical activity only 2 per cent of the time, as opposed to 80 per cent at 34 weeks.[46] Therefore, although the pathways may exist at 24 weeks, nociceptive signals may not equate to pain perception. While volatile anaesthetics and opioids readily cross the placenta,[5,25] long-term effects of fetal stress and pain remain unknown. From mid-gestation onward, there is a general tendency to err on the side

of caution and provide direct fetal analgesia.[5,47] Fetal analgesia can improve surgical conditions by reducing fetal movement,[48] and can be delivered by maternal transfer or directly to the fetus. Fentanyl is commonly given via intramuscular injection at a dose of 15-20 mcg/kg.[26,34,41,49] Direct fetal analgesia may also help to prevent bradycardia resulting from pain.[50]

Fetal monitoring

Fetal wellbeing is primarily evaluated by sonographic monitoring of fetal heart rate and umbilical artery blood flow.[11] In the fetus, heart rate is crucial to cardiac output, given relatively poor myocardial compliance and minimal response to changes in preload.[51] Absent or reversed umbilical artery diastolic blood flow is associated with increased perinatal morbidity and mortality.[52] Intraoperative fetal echocardiography can also be used to monitor ventricular function, valve competence, ductal patency and amniotic fluid index.[18,25] At our institution, this role is performed by a neonatologist.

Common causes of fetal bradycardia include mechanical compression or kinking of the umbilical cord, uterine contractions, placental separation, maternal hypotension, umbilical artery vasospasm or hypoxaemia.[5] Less common causes include fetal hypovolaemia, hypothermia and anaemia.[5] Fetal cardiac events may be reduced when volatiles are supplemented with IV anaesthesia.[29]

To manage fetal bradycardia, it is essential to ensure adequate uterine blood flow, assess the uteroplacental interface, and relieve umbilical or placental compression. Fetal intramuscular atropine (20 mcg/kg) may be administered, with some fetal therapy centers using it prophylactically.[11,34] The anaesthetist should increase maternal inspired oxygen, stabilise maternal haemodynamics, address aortocaval compression, and administer additional tocolytics or increase volatile agents if contractions occur. The surgeon should address mechanical cord compression through fetal repositioning and increasing amniotic fluid volume.[5]

Other considerations for fetal monitoring include blood loss and temperature. Maternal and fetal bleeding can be challenging to quantify but may be aided by laboratory testing. Fetal transfusion is possible via the umbilical vein. With an inability to thermoregulate, vasoconstrict, or shiver, general anaesthesia with an open hysterotomy places the fetus at significant risk of hypothermia and subsequent bradycardia.[11] Monitoring of both maternal and amniotic fluid temperatures is recommended. Aside from standard measures to maintain maternal normothermia, warm fluids should be used for intrauterine irrigation.[11] A warm intrauterine crystalloid infusion helps prevent fetal hypothermia, provides tamponading pressure to the placental bed, prevents cord compression, and aids surgical access by elevating the fetus.[11,18] Minimising fetal exposure helps preserve both temperature and uterine volume.[25]

Table 4. Common causes of fetal bradycardia and their management

Cause	Management
Mechanical compression or kinking of umbilical cord	• Relieve mechanical compression • Fetal repositioning (surgical) • Increase amniotic fluid volume
Uterine contraction	Tocolysis • Volatiles, magnesium sulfate, GTN, remifentanil, atosiban
Maternal hypotension	• Consider vasopressors, inotropes or fluid (guided by cardiac output monitoring) • Review depth of anaesthesia • Relieve aortocaval compression
Maternal hypoxaemia	• Increase maternal FiO2 • Optimise ventilation
Umbilical artery vasospasm	Warm intrauterine irrigation
If initial management fails, consider fetal resuscitation with intramuscular atropine or adrenaline, intravenous fluid or blood products, or chest compressions *If bradycardia persists, consider delivery and neonatal resuscitation if indicated*	

Optimising surgical conditions

Fetal immobility is desirable for optimal surgical conditions. Volatile administration, placental transfer of maternal analgesia, and direct fetal analgesia all promote fetal immobility. It is common to administer fetal muscle relaxant (rocuronium, vecuronium or pancuronium) along with fentanyl and atropine in a single IM injection.[5,11,16,25,26,41]

Fetal resuscitation

Cardiovascular compromise during open fetal surgery is common. Rychik et al report a 7 per cent incidence of serious cardiovascular events and a need for fetal resuscitation with external cardiac compressions in 4 per cent of cases.[53] In-utero resuscitation or emergency delivery may be required to improve fetal, neonatal and maternal outcomes,[25] and neonatal specialists should be immediately available. Atropine (20 mcg/kg), adrenaline (10 mcg/kg), and crystalloids (10 ml/kg) in a sterile preparation should be available for surgical administration to the fetus.[11] Blood should be immediately available for fetal transfusion in the event of significant bleeding (type O-negative, irradiated, leucocyte-depleted, cytomegalovirus-negative and cross-matched against the mother).[11] In a global survey study of twenty-eight fetal surgical centres, there was no standard protocol for fetal resuscitation or subsequent neonatal resuscitation when confronted with an imminent delivery.[21]

POSTOPERATIVE CONSIDERATIONS

Key postoperative considerations are outlined in Table 5.

Table 5. Postoperative considerations after open myelomeningocele repair

Postoperative considerations	
Tocolysis	Magnesium infusion PR indomethacin
Maternal analgesia	Thoracic epidural (continuous infusion for 2 days postoperatively) Regular and PRN oral analgesia
Maternal monitoring	Premature labour Pulmonary oedema – minimal IV fluids Infection
Fetal monitoring	One-to-one midwifery care in birth suite for 24-48 hours Fetal heart rate monitoring as directed by MFM Obstetric ultrasound within 48 hours

Tocolysis

Since uterine instrumentation can precipitate contractions and preterm labour, it is imperative to monitor uterine activity and provide tocolysis postoperatively. In more than a third of cases, open fetal surgery resulted in uterine thinning at the surgical site.[12] Due to risks of placental abruption, uterine dehiscence and uterine rupture, active labour should be avoided, and all pregnancies should be delivered via caesarean section.[12] Magnesium remains a mainstay of tocolysis, beginning in the intraoperative period and typically continued as an infusion for 24-48 hours.[5, 25] Other agents utilised include nifedipine and indomethacin, the latter requiring fetal monitoring for premature closure of the ductus arteriosus.[25] Despite such efforts, there is a significant risk of premature labour, with MOMS reporting an average gestational age of 34 weeks and a 13 per cent incidence of births occurring before 30 weeks following open fetal surgery.[12]

Analgesia

Postoperative analgesia is principally managed with epidural and oral analgesia. Although epidurals are not universally used,[24] their use is well supported for open procedures.[5,25] Patient-controlled analgesia (PCA) with IV opioids may be used as an adjunct. Opioids improve patient analgesia and can decrease the risk of preterm labour,[54] but may reduce fetal heart rate variability,[55] raising concerns for fetal wellbeing.

Pulmonary oedema

The MOMS reported a 6 per cent rate of maternal pulmonary oedema following open myelomeningocele repair.[12] Pulmonary oedema is postulated to result from increased vascular permeability in the setting of gestational physiologic changes, tocolytic medications and liberal fluid therapy.[56] The use of GTN for tocolysis has been associated with more severe cases, possibly due to an immune complex-mediated reaction.[40] However, a more recent retrospective study[34] did not identify any significant association with fluid administration, crystalloid volume, colloid volume, sevoflurane dose, GTN dose or number of postoperative tocolytic drugs, and evidence does not support restrictive fluid regimes.[11] Most cases are not severe and can be treated with simple measures such as oxygen, positioning and diuresis. Patients remain closely monitored in our birth suite for 48 hours postoperatively.

Fetal monitoring

Fetal wellbeing is routinely monitored for 48-72 hours postoperatively. Aside from preterm labour, fetal risks include heart failure, intracranial haemorrhage and fetal demise.[5] A predetermined plan for delivery, resuscitation and/or palliation should be established in the event of fetal distress, carefully considering the medical circumstances, gestational age and the wishes of the parents.[21] There is a lack of consensus among fetal therapy centres regarding the gestational age at which neonatal resuscitation may be considered in the event of emergent delivery.[21] Due to the need for regular postoperative fetal monitoring, patients must remain within close proximity of their fetal therapy centre until delivery.

FUTURE DIRECTIONS

As surgical techniques evolve, so too must the complementary anaesthetic approach. In recent years, there has been an increased uptake of fetoscopic approaches to myelomeningocele repair.[34] Although technically challenging, the use of fetoscopy rather than hysterotomy in open fetal surgery reduces uterine stimulation and, therefore, requires less tocolysis. Such an approach allows for reduced volatile requirements, with less haemodynamic instability and subsequent need for vasoactive support.[34] Total percutaneous fetoscopic repairs have obvious maternal advantages in minimising pain and improving postoperative recovery. The approach may also allow for subsequent vaginal delivery, given open repairs carry similar risks of uterine rupture to classical caesareans. However, future fertility and abnormal placentation rates remain unclear.[57]

Anaesthetic techniques may also change as new drugs become available. Atosiban, an oxytocin receptor antagonist, has been demonstrated to be safer than magnesium sulfate for tocolysis during open fetal surgery.[58] It provides comparable uterine relaxation with fewer maternal complications, although it is yet to be made available for routine clinical use in Australia.

The effects of anaesthesia on fetal neurodevelopment remain of interest. Reassuringly, follow-up of the initial MOMS patients did not show impaired cognitive outcomes compared to postnatal repair. Furthermore, the subset of patients who did not require shunts or developed hydrocephalus may have improved cognitive outcomes.[14] However, ongoing research is needed to tailor anaesthesia to reduce long-term risks.

CONCLUSION

Anaesthesia is integral to the highly specialised multidisciplinary care required for fetal myelomeningocele repair. Knowledge of fetal and maternal physiology allows anaesthetists to play a pivotal role throughout the perioperative period. Given low case volumes and the complexity of research in the area, care must be based on established practices and continually refined with emerging data. While confined to specialised centres, global collaboration will help to inform evidence-based protocols and improve the delivery of care for patients undergoing fetal surgery.

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Accreditation of anaesthesia departments: Current practice, best practices and future directions

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Edited by Associate Professor Matt Doane

INTRODUCTION

Five-yearly accreditation of your department can feel like an imposition. The process requires enormous amounts of time and effort from everyone involved. However, training site accreditation is not only required under law in Australia and Aotearoa New Zealand, it also plays a crucial role for the college to support training, maintain professional standards, and advocate for our specialty with governments and health services in both countries.

For the college, the accreditation of a department evaluates whether the anaesthesia curriculum is being implemented as intended in every training location. For departments, it highlights areas where anaesthesia training is going well and areas that need improvement. For trainees, it ensures they are training as intended, in environments that support their learning and professional development. Accreditation supports ANZCA supervisors, giving them time and other resources for their roles. College accreditation supports departments and health services to train specialists who can provide optimal clinical care for the patients they serve. This is a collaborative model, where the college develops the curriculum, assessments and required standards, and training sites subsequently employ trainees and their supervisors while providing the necessary clinical and clinical support experiences.

Currently, accreditation is a “hot topic” for governments, health services and colleges. Governments are driven by various concerns, including workforce shortages in the wake of the COVID-19 pandemic, especially in rural and regional areas.[1] This article provides a brief overview of anaesthesia accreditation for fellows, trainees, and departmental heads, including what it is, how it currently works, ongoing drivers for change,

what the future may hold, and what this means for departments. We outline international best practices and principles in accreditation and the importance of the Clinical Learning Environment (CLE) for anaesthesia training. While the Faculty of Pain Medicine (FPM) accredits pain units for training under the auspices of the college, this article focuses only on anaesthesia accreditation.

WHAT IS ACCREDITATION, AND WHAT DOES IT ACHIEVE?

An internationally accepted definition of accreditation (Table 1) highlights that it is a process of external (usually peer) review, focused on ensuring minimum training standards. In our region, postgraduate (specialist) accreditation works at several levels. Each specialist medical college accredits training sites or posts to ensure they meet discipline-specific training requirements. Additionally, all the medical colleges are accredited by the Australian Medical Council (AMC) and/or the Medical Council of New Zealand (MCNZ), with the two bodies collaborating on the accreditation of binational colleges like ANZCA.

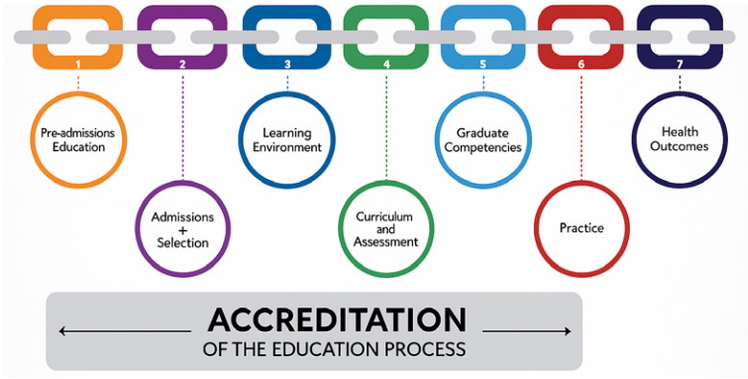
The AMC and MCNZ accredit all aspects of the medical education continuum from medical school through to specialists' continuing professional development. Aspects of college training that the AMC and MZNC accredit include college governance, graduate outcomes (defined in Table 1), the curriculum, teaching and learning methods, the program of assessments (exams, workplace-based assessments and the ANZCA scholar role assessments), monitoring and evaluation processes and outcomes, trainee-related issues (selection, involvement in college governance, college communications, wellbeing and resolution of training problems), and supervision/supervisors.[2,3] The AMC and MCNZ also accredit college accreditation standards and procedures for training sites.

Table 1. Accreditation glossary

Specialist accreditation	The process by which a credible, independent body assesses the quality of an education program to provide assurance that it produces graduates that are competent to practise safely and effectively as specialist practitioners.[4]
Clinical learning environment (CLE)	How trainees experience the curriculum in their workplaces. It includes interpersonal interactions, culture and resources.[5]
Curriculum	A statement of the intended aims and objectives, content, assessment, experiences, outcomes and processes of a [training] program, including a description of the structure and expected methods of learning, teaching, feedback and supervision. The curriculum should set out the knowledge, skills and professional qualities [each] trainee is to achieve.[2]
Competency-based medical education (CMBE)	Outcomes-based approach to the design, implementation, assessment, and evaluation of a medical education program using an organising framework of competencies.[6]
Cultural safety	The need for doctors to examine themselves and the potential impact of their own culture on clinical interactions and healthcare service delivery; and The commitment by individual doctors to acknowledge and address any of their own biases, attitudes, assumptions, stereotypes, prejudices, structures and characteristics that may affect the quality of care provided; and The awareness that cultural safety encompasses a critical consciousness when healthcare professionals and healthcare organisations engage in ongoing self-reflection and self-awareness and hold themselves accountable for providing culturally safe care, as defined by the patient and their communities.[7]
Graduate outcomes	The minimum learning outcomes in terms of discipline-specific knowledge, discipline-specific skills including generic skills as applied in the specialty discipline, and discipline-specific capabilities that [each] graduate or any given specialist medical program must achieve.[2]
Training rotation	A regionally-based group of ANZCA-accredited departments that together are able to provide trainees with a comprehensive and integrated training experience covering all essential requirements of the training program.[8]

Analogous to "closing the loop" in clinical quality improvement processes, accreditation is part of medical education's "quality chain" (Figure 1), ultimately leading to well-trained specialists and better health outcomes. Most elements of this quality chain are developed by ANZCA and accredited by the AMC and MCNZ.

Figure 1. The quality chain in medical education[9]



HOW DOES ANZCA ACCREDIT ANAESTHESIA TRAINING SITES?

ANZCA accredits anaesthesia training sites throughout Australia and New Zealand using the standards and procedures outlined in the ANZCA Handbook for Accreditation.[8] The aim of ANZCA accreditation is to ensure that anaesthesia departments meet training and clinical care standards to ensure high-quality training. Accreditation is overseen by the Training Accreditation Committee (TAC), which implements ANZCA policy on accreditation and reports directly to the ANZCA Council.

ANZCA accreditation standards

The seven ANZCA accreditation standards are:

1. Quality patient care
2. Clinical experience
3. Supervision
4. Supervisory roles and assessment
5. Education and teaching
6. Facilities
7. Clinical governance

These standards align with ANZCA professional documents and the anaesthesia training program curriculum.[10] The *ANZCA Handbook for Accreditation* lists the criteria that underpin each standard, including minimum requirements and how each criterion is assessed. When evaluating a department against the standards, some requirements are quantitative (e.g. the number of specialist-led acute pain rounds), while many are qualitative (e.g. how labour epidurals are assessed for beyond Level 1 Supervision).

ANZCA accreditation procedures

An accreditation team of two to four ANZCA accreditors selected from a pool of volunteer fellows and trainees inspects each training site at least once every five years. There are over 180 ANZCA-accredited training sites across Australia and New Zealand, representing about 50 visits per year, a considerable workload, and one that represents a key "frontline" contact between the college, its fellows and trainees, and health services. Table 2 summarises how accreditors are appointed and trained.

Table 2. ANZCA anaesthesia accreditor management

Selection	Self-nomination. Two referees, both FANZCAs, at least one a current or past ANZCA accreditor. Selection criteria include demonstrated clinical leadership and teaching experience, recent knowledge of the ANZCA training program and associated governance and professional documents.
Orientation and training	Compulsory for all new accreditors. Provided with role description (terms of reference). Videos and guides on Learn@ANZCA. Initial accreditation visit with a more senior visitor (team lead is an experienced accreditor).
Performance appraisal and feedback	Feedback from training site after visit. No individual performance assessment.
Appointment terms and reappointment	Three-year terms to maximum 12 years. Automatic reappointment.
Accreditation team	Led by a senior inspector (a current or former ANZCA councillor or TAC member). Comprises members outside the department and region, and ideally one inspector from the same region (but not the same rotation). Balance of gender and accreditation experience. Trainee included (from 2022). All team members must declare potential conflicts of interest, and these are managed in accordance with ANZCA policy to minimise bias.

Inspection of a training site typically lasts a whole working day. It involves a series of interviews with the head of the anaesthesia department, hospital executives, trainees, supervisors of training and other ANZCA fellows, as well as a physical inspection of all anaesthetising locations to evaluate compliance with ANZCA standards. When a rotation is inspected, a full team of four accreditors visit the larger hospital(s) in that rotation and then splits into pairs to inspect the smaller hospitals. At the end of each hospital visit, the inspection team gives an initial summary of recommendations, which form the basis of their report to TAC. TAC considers the report, determines the accreditation outcome and duration, and any recommendations that must be addressed to achieve unqualified accreditation. A decision to withdraw accreditation can only be made by ANZCA Council. Should TAC consider withdrawal of accreditation, then the hospital, department, and health service will be notified of this outcome and will be allowed to respond before a decision by ANZCA Council. Accreditation decisions can be challenged via the ANZCA reconsideration, review and appeals processes.[11] Table 3 summarises ANZCA accreditation procedures.

Table 3. Overview of ANZCA accreditation procedures

Procedure	How ANZCA does this
New accreditation application	Initiated by the anaesthesia department which must join a training rotation for accreditation to be considered.
Self-assessment	A department member populates the accreditation datasheet in the ANZCA TSA portal, self-assessing site compliance with criteria under each standard.

Evidence	TPS data: Case numbers per SSU, WBA completion rates, supervision levels, elective versus emergency workload. ANZCA trainee survey results for current and prior HEY. Site rosters (staffing), formal teaching programs, hospital and department metrics (e.g. case load, theatre numbers, trainee numbers, SOT, SSU and other supervisory roles, case details).
Accreditation report	Narrative overview of context and major findings (1-2 pages). Mandatory recommendations (linked to professional documents, training regulations and handbook) and suggestions for improvement (for department consideration). Draft to HOD to correct factual inaccuracies. Final report uploaded to the TSA portal. Letter with recommendations and timeline for compliance sent to hospital administration with copy to head of anaesthesia department.
Potential accreditation outcome	**Unqualified:** all standards and criteria met five years from inspection date. Certificate issued. **Conditional:** subject to corrective actions within a specified timeframe (usually up to one HEY only). Sometimes reinspection. Progress updates to each TAC meeting. Attaining unqualified accreditation depends on achieving full compliance. If struggling to meet standards, TAC may reduce accreditation duration or withdraw accreditation. **Withdrawal:** hospital unable to comply with standards, significant impact on training and professional standards. Requires ANZCA Council decision.
Accreditation duration	26, 52, 104 or 156 weeks of IT, BT and/or AT. Based on clinical and non-clinical educational opportunities, particularly the number of SSUs that can be completed at the site. PFT approval is a separate process.
Other types of ANZCA accreditation	Additional campuses: anaesthesia services provided by the department under the same governance structure (e.g. private hospital theatre with public work), part of same approval. Satellites: partnership arrangement between larger accredited hospital (partner hospital which may provide some accreditation requirements e.g. SOT) and a site with valuable training opportunities (satellite). Trainees allocated to the satellite by blocks of time or on a list-by-list basis. Time spent at the satellite is part of the maximum allowable time at the partner hospital.
Monitoring outside visits	Via the New Zealand national/Australian regional and trainee committees and accreditation officers (one in New Zealand and each Australian region). May result in out-of-cycle review and a visit.
Accreditation system administration	Funded by the college through training fees. Dedicated ANZCA staff members. Annual review of Handbook for Accreditation, including updating criteria underpinning each accreditation standard.

Abbreviations: AT Advanced Training, BT Basic Training, HEY Hospital Employment Year, HOD Head of Department, IT Introductory Training, PFT Provisional Fellowship Training, SOT Supervisor of Training, SSU Specialised Study Unit, TSA Training Site Accreditation, WBA Workplace Based Assessments.

WHAT IS AN INTERNATIONAL LEADING PRACTICE IN ACCREDITATION?

Accreditation decisions are high-stakes for all those involved – for trainees, their supervisors and the patients they will serve; for hospitals, health services and governments; and for accrediting bodies (like ANZCA, the AMC and MCNZ). While accreditation is a powerful mechanism and motivator for change,[12,13] it is also resource-intensive.[14,15] As part of its continuous improvement approach and to ensure an efficient and effective process, from 2019 to 2021, the college convened a project group to define key principles and leading practices in accreditation internationally, identify gaps in existing ANZCA and FPM practices, and make recommendations for future change.[5] The following section summarises the project's main findings.

The ANZCA and FPM Accreditation and Learning Environment Project (ALEP) used mixed methodology, including literature review, environmental scan, and consultation with colleges and regulatory bodies in Australia, Aotearoa New Zealand, the United States, Canada, the United Kingdom, and Ireland. Table 4 shows key aspects of accreditation in these countries.

Table 4. Specialist accreditation practices in Australia, New Zealand, Canada, the United Kingdom and the United States[5]

	Australia	New Zealand	Canada	United Kingdom	United States
Accreditation of colleges/ universities for specialist training	Australian Medical Council (AMC)	Medical Council of New Zealand (MCNZ)	Royal College of Physicians and Surgeons of Canada (RCPSC)*	General Medical Council (GMC) approves curricula developed by colleges	Accreditation Council for Graduate Medical Education (ACGME)#
Cycle length	10 years	10 years	8 years	Colleges apply for curriculum change approval	10 years
Accreditation of anaesthesia training sites or posts	ANZCA	ANZCA	RCPSC using both cross-specialty generic and specialty-specific standards	Postgraduate deaneries (England, Northern Ireland), Local Education and Training Boards (Scotland, Wales)**	ACGME using common program requirements and specific anesthesiology requirements
Cycle length	5 years	5 years	8 years	Variable	10 years
Anaesthesia examinations	ANZCA	ANZCA	RCPSC	The Royal College of Anaesthetists	The American Board of Anesthesiology

* The Collège des Médecins du Québec (CMQ) and College of Family Physicians of Canada (CFPC) accredit PGME in Quebec and for family medicine, respectively.
# Although this is a voluntary process, ACGME accreditation is required for federal funding and medical licensure in some US states.
** The Royal College of Anaesthetists has a separate accreditation process for anaesthesia clinical services – Anaesthesia clinical services accreditation.[16]

Principles of high-quality accreditation

The project identified five principles of high-quality accreditation: it provides public assurance and accountability, is outcomes-focused, combines quality assurance (QA) and continuous quality improvement (CQI), focuses on the clinical learning environment (CLE), and aligns health service and training priorities.[5]

The ultimate goal of medical accreditation is competent specialists who deliver high-quality and safe care for the patients and communities they serve, resulting in the best possible health outcomes (Figure 1); thus, public assurance and social accountability (to patients and the broader community) underpins specialist accreditation.[17]

Over recent decades, medical education has increasingly focused on outcomes, so-called competency-based medical education (CBME).[18] This is reflected in the ANZCA Training Curriculum through descriptions of outcomes at each stage of training and on graduation, teaching for those outcomes, and assessment of required outcomes to allow progression to the next training stage. Since accreditation is about evaluating how the curriculum is implemented at each training site, accreditation standards should align with the curriculum and focus on educational outcomes.[19,20]

Compliance with minimum standards has long been the main focus of specialist accreditation, including for ANZCA. However, the literature and international authorities increasingly recommend that accreditation evolve beyond this quality assurance (QA) focus to incorporate an ethos of continuous quality improvement (CQI).[21] This involves more regular local self-assessment, measurement, and improvement planning.

Finally, many medical accreditation bodies seek to align the priorities of health services and training organisations (like ANZCA) to achieve a win-win situation where thinking and resourcing achieve desired outcomes for both. This requires greater collaboration and mutual accountability, recognition of common priorities and breaking down of siloed thinking and activity. An example is the meaningful involvement of trainees in systems processes that improve healthcare delivery and in healthcare leadership. While these are priorities for future specialist practice (for both health services and for colleges), current siloed approaches do not necessarily prepare trainees for the responsibilities they will have on graduation.

Leading Australasian and international accreditation practices

While there is no consensus internationally about how accreditation systems should be designed, there is agreement that design must consider local needs and context. Several published frameworks guide accreditation system design decisions.[12,22] Table 5 summarises the findings of the ANZCA and FPM ALE project on leading Australasian and international practices in accreditation.

Table 5. Leading accreditation practices found in the ANZCA and FPM Accreditation and Learning Environment Project[5] *

Accreditation practice	Notes and examples
Explicit philosophy and purpose	Some organisations focus primarily on education and training with clinical care standards only considered where they affect training (e.g. RCPSC).
Aligns with community needs and educational developments	Accreditation standards aligned to curriculum which addresses community care needs (e.g. for culturally safe care). Strategic approaches to accreditation of rural and remote training sites to facilitate access to specialist care.
Proactive monitoring and benchmarking	Annual reporting by accredited sites (e.g. ACEM annual site census, trainee survey, examination report and WBA report). Mid-cycle paper-based monitoring (e.g. RANZCP). Defined quality indicators (e.g. ACGME).
Standards mapped to curriculum and expressed in a standards organisation framework	RCPSC framework includes domains, standards, elements and requirements (all measurable and mapped to the curriculum). CAI produces maps of accredited training sites and the training experiences they provide.
Balances standardisation and flexibility in how standards can be met (to encourage innovation)	RCPSC standards organisation framework includes mandatory indicators (required for compliance) and exemplary indicators (aspirational markers of excellence).

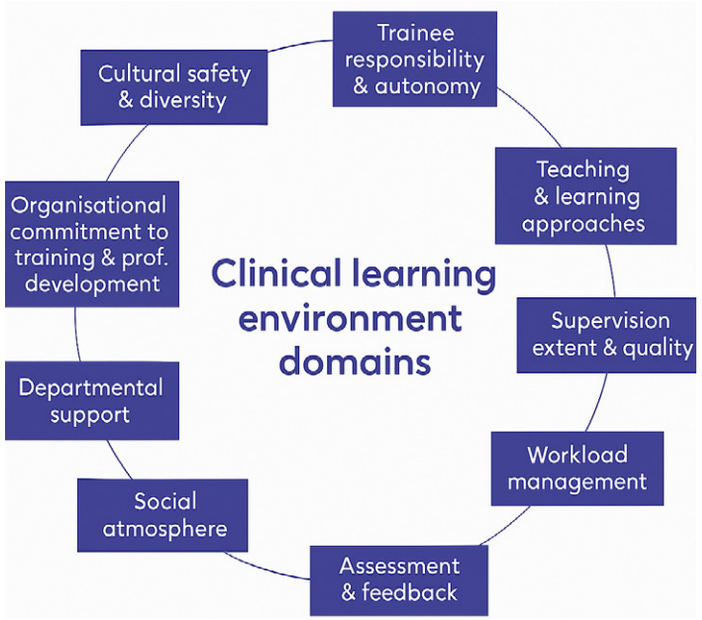
Includes self-assessment and planning for continuous improvement	ACGME Next Accreditation System (NAS) self-study includes local data collection, action plans and remeasurement.
Data driven with outcomes focus	Most accrediting organisations aspire to increase their outcomes focus, although to date this has mostly involved intermediate measures like exam pass rates, graduate satisfaction with training and sense of preparedness for practice, or employer surveys of graduate capabilities.
Promotes trainee voice and safety	Many organisations include trainee representatives on accreditation teams (e.g. AMC, ACEM, CICM, RANZCOG). Many colleges are investigating how to best use existing trainee surveys for site accreditation (while maintaining trainee safety). Some use annual or biennial supervisor surveys (e.g. ACEM, ACGME).
Optimises technological and staff support	Some organisations and colleges include staff members at site visits (e.g. ACEM, RANZCOG). ICT platform should allow easy access for sites and accreditors, allowing updating (rather than re-entry) of data over time, have dashboards displaying trends and a traffic light system for self-assessment and monitoring (e.g. RCPSC). Since the pandemic, the role of videoconferencing has increased, with some organisations using it to sample larger groups of trainees and supervisors (e.g. AMC, RANZCP).
Supports equity, healthcare access and cultural safety	Most Australasian colleges have cultural safety in their curricula and training accreditation standards and require relevant training for both trainees and their supervisors. MCNZ has specific accreditation standards on cultural safety for Māori. Many colleges also have or are working on accreditation standards that support training in rural and remote areas. RACS has a specific accreditation standard on culture of respect, addressing BDSH.
Optimises accreditor training and performance feedback	RCPSC has online training modules for sites, surveyors, and decision-making committees, with short online self-assessment tests.
Standards and procedures are subject to CQI	Regular review of standards (e.g. ACEM every 2 years, ACGME every 10 years).

*All examples from the ALEP Report have been checked for currency using organisational websites. Abbreviations: ACGME Accreditation Council for Graduate Medical Education (US), AMC Australian Medical Council, ACEM Australasian College for Emergency Medicine, BDSH Bullying Discrimination and Sexual Harassment, CAI The College of Anaesthesiologists of Ireland, MCNZ Medical Council of New Zealand, RACP Royal Australasian College of Physicians, RACS Royal Australasian College of Surgeons, RANZCOG The Royal Australian and New Zealand College of Obstetricians and Gynaecologists, RANZCP The Royal Australian and New Zealand College of Obstetricians and Gynaecologists, RCoA Royal College of Anaesthetists (UK), RCPSC Royal College of Physicians and Surgeons of Canada.

WHAT IS THE CLINICAL LEARNING ENVIRONMENT, AND WHY IS IT IMPORTANT FOR TRAINING AND ACCREDITATION?

The Clinical Learning Environment (CLE) is the sociocultural environment in which training occurs (see Table 1 for definition). For anaesthesia and other hospital-based specialties this is, primarily, the complex milieu of teaching hospitals. The CLE has multiple dimensions, including organisational and departmental commitment to trainees and their supervisors, quality of supervision, support and social atmosphere, cultural safety, workload management (e.g. rosters, access to required cases) and how teaching and assessment is conducted (Figure 2).

Figure 2. ANZCA and FPM clinical learning environment domains (developed as part of the ALEP)[5]



The CLE in anaesthesia departments can be measured using validated and reliable measures – the Anaesthetic Theatre Educational Environment Measure (ATEEM),[23] the Measure for the Anaesthesia Theatre Educational Environment (MATE) [24] and the Anaesthesia Clinical Learning Environment Instrument (ACLEI).[25,26] The MATE and ACLEI were developed by FANZCAs in New Zealand and Australia, respectively.

Not surprisingly, high-quality CLE motivates trainees and leads to improved learning, greater satisfaction and better examination performance,[27,28] while poor CLE adversely affects trainee wellbeing.[29] While there is limited evidence that directly links accreditation of training sites to patient outcomes, a few studies demonstrate that training location affects specific health outcomes, healthcare spending decisions or intermediary measures like new specialists' views on their "preparedness for specialist practice".[30,31]

There is widespread agreement that accrediting organisations should increase their focus on the CLE, through measurement and monitoring over time. For example, in the United States, the ACGME runs the Clinical Learning Environment Review (CLER) program that focuses on six dimensions of the CLE – including duty hours and fatigue management, supervision, and resident involvement in patient safety and quality systems.[32] CLER is currently optional and not directly linked to accreditation decisions, although findings are used to inform accreditation standards development.

WHAT ARE THE EXTERNAL DRIVERS FOR CHANGES TO COLLEGE ACCREDITATION PROCESSES?

Colleges are under pressure from governments on several fronts regarding accreditation. This has included the implication that training site accreditation may be removed from colleges in Australia. Concerns include that colleges withdraw accreditation with limited notice, impacting service delivery, and that training site accreditation is not sufficiently responsive to community workforce needs, both immediate requirements and longer-term planning.

In late 2023, the Australian National Health Practitioner Ombudsman (NHPO) reported on a major review of specialist training site accreditation.[33] Recommendations were made in five key areas: accountability and transparency of standards, fairness and transparency of procedures, strengthening monitoring of sites, consistency in managing site issues, and management of concerns about accreditation decisions and outcomes. Australian health ministers have directed that the Australian Medical Council work with all medical colleges on 15 NHPO recommendations.[34] The MCNZ is also involved in this work, continuing the close, ongoing collaborative partnership between the MCNZ and the AMC.

In Aotearoa New Zealand, the MCNZ bases its accreditation standards largely on those of the AMC, with country-specific standards, especially around cultural safety for Māori.[3] Standards alignment reflects similarities in healthcare systems and governance structures and streamlines processes for binational colleges. A longstanding and important difference is the requirement for specialist medical colleges to inform the MCNZ with reasonable notice of any intention to limit or withdraw accreditation from any training site. In 2023, ANZCA revised its accreditation processes to include notification to all jurisdictions in Australia and Aotearoa New Zealand of any intention to limit or withdraw the accreditation at a training site.

WHAT ACCREDITATION WORK IS CURRENTLY UNDER WAY?

The college is currently working on its responses to the findings of its internal accreditation project and the recommendations in the NHPO report. Fortunately, these two major work streams are considerably aligned.

The ANZCA and FPM Accreditation and Learning Environment Project

The ALEP final report made 15 recommendations for improvements in ANZCA accreditation standards and procedures.[5] These include:

- Initiating an accreditation renewal project across all college training programs (anaesthesia, pain medicine, diving and hyperbaric medicine, rural generalist anaesthesia).
- Redesigning accreditation standards by mapping them to each training curriculum, ensuring cultural safety at training sites, and supporting community needs, for example, by exploring options to facilitate accreditation of sites in rural and regional areas.
- Strengthening accreditation evidence by developing outcome measures to complement current process measures.
- Formally measuring the clinical learning environment at training sites, with results to be shared with sites for their review and planning for any necessary improvements.
- Introducing proactive monitoring of training sites between five-yearly visits, rather than the current reactive situation, which relies on concerns about sites being raised with the college.
- Strengthening trainee and fellow input to accreditation monitoring while ensuring trainee safety (especially at sites with small numbers of trainees).
- Enhancing support for volunteer accreditors, including through performance feedback for professional development.
- Strengthening accreditation of anaesthesia rotations and evaluating provisional fellowship training at site visits.
- Developing mechanisms to acknowledge and share examples of good practices and solutions to common or challenging problems.

In 2023, the college formed the Accreditation Renewal Steering Group, tasked with working through the ALEP recommendations. Recommendations such as aligning accreditation terminology and definitions across all ANZCA programs and revising the responsibilities, selection and appointment criteria for accreditation inspectors and leads have been finalised. Improving support for ANZCA's volunteer accreditation inspectors is progressing.

The group also works towards annual, bi-directional reporting between the college and anaesthesia departments. Ideally, these data would allow departments to be tracked and provide benchmarking of their own performance, enabling response, improvement, and creating space for training innovation. TAC could evaluate departmental progression in the preceding five years, rather than relying primarily on the current high-stress, resource-intensive, single-point-in-time assessment. The Training Portfolio System (TPS) dataset currently used by TAC, while valuable, has significant limitations, not least of which is that trainees stop entering cases once volumes of practice are achieved. ANZCA is currently developing the next version of the TPS, which has improved reporting capability and is a highly desirable specification.

However, in the past 12 months, the work of the ANZCA Steering Group has slowed, allowing ANZCA to focus on collaborative work with the AMC and the MZNC.

The NHPO Report recommendations

Individual colleges are working on some of the Australian NHPO recommendations,[33] while the AMC and MCNZ are working with all Australian and binational medical colleges on those recommendations that require harmonisation and streamlining for common approaches. Planned outcomes include:

- model accreditation standards
- best practice policies and procedures
- a common approach to managing complaints and concerns
- a data collection model and reporting process.[35]

Several work streams are now underway to advance progress in these outcomes.

An early result is *The Communication Protocol,* which aims to improve collaboration between colleges, training sites and health departments.[36] The protocol sets out roles, responsibilities and expectations about communication regarding the accreditation of Australian training sites, including the requirement to provide health departments in advance with a timetable of accreditation visits planned for each year. Importantly, if the withdrawal of accreditation is being considered, then colleges must notify both training sites and health departments, giving them reasonable time for a response and resolution of outstanding issues before any action is taken to withdraw accreditation.

In mid-2024, a forum involving more than 150 stakeholders considered recommendation 13 of the NHPO report on managing concerns and complaints about sites, especially regarding bullying, harassment, racism, and discrimination.[33] A significant focus of the forum was who holds what responsibilities when managing these concerns, and the need for all parties to consult, cooperate, and coordinate. This work is ongoing.

Table 6 shows the model accreditation standards to be used by each college, developed by the AMC, released for public consultation, and recently endorsed by the Australian Health Workforce Taskforce (made up of each jurisdictional health department) and the Health Chief Executives Forum. These are expressed in a standards organisation framework, in accordance with best practice. The model standards consultation document also included principles on identifying and using evidence to support accreditation decisions, along with examples of the types of evidence that might be used. Despite their different arrangement, many current ANZCA accreditation standards are reflected in these model standards.

Table 6. Model standards for college accreditation of training sites/posts[37]

Domain	Standard	Criteria
Trainee health and welfare	Training takes place in a learning environment that supports trainee health and welfare	Safe pathways to raise concerns Bullying, harassment, discrimination and racism identified, investigated, managed and recorded Flexible work arrangements Positive learning environment that fosters respect, diversity, inclusion and cultural safety for trainees of diverse backgrounds Risks to cultural safety of Aboriginal and/or Torres Strait Islander and Māori trainees identified, managed and recorded Fatigue risks identified, managed and recorded Access to leave Support for trainees returning to work after a break in training Adjustments for trainees with disabilities Resources to support health and welfare

Supervision, management and support structures	Clear governance structures support the delivery of effective education and training	Trainees can provide feedback on local training delivery Rostering, recruitment and other human resources function effectively to support training Effective orientation College engages with training networks (ANZCA rotations) to ensure training outcomes can be achieved
	Trainees receive appropriate and effective supervision	Effective clinical supervision Supervisors provide regular and timely feedback to trainees Support for trainees in difficulty Director of Training given time and resources Supervisors receive support, including for providing culturally safe supervision
	Trainees are supported in delivering quality patient care, including culturally safe care	Trainees supported in developing specific knowledge and skills including for culturally safe care for First Nations Peoples Opportunities to reflect on critical incidents and engage with local clinical governance/QA processes
Educational and clinical training opportunities	Trainees are provided with appropriate depth, volume and variety of clinical and other learning experiences	Clinical caseload and case mix to achieve training program outcomes Opportunities for structured and unstructured learning Clinical handovers Work in multidisciplinary teams
	Learning experiences are transparent, equitable and appropriate for the level of training	Increasing responsibility appropriate to skills and experience Opportunities transparent and equitable for all trainees Support to complete assessments in a timely way
Educational resources, facilities and equipment	Trainees have access to appropriate educational resources and facilities	Appropriate quiet space and internet access Educational resources
	Trainees have access to appropriate clinical equipment	Clinical equipment available, accessible and fit for purpose

The idea of common accreditation standards across colleges is not new. In 2016, Australian-based specialist medical colleges worked with the Federal Department of Health on agreed-upon accreditation standards for college training sites[38]. However, these were only adopted by a few colleges. The 2016 standards had considerable similarity to the 2024 ones (Table 6). However, the latter are expanded to include contemporary expectations, like cultural safety for First Nations trainees and patients, robust approaches to bullying, harassment, discrimination and racism; adjustment for trainees with disabilities; and equitable access to training experiences for all trainees.

WHAT DOES THIS MEAN FOR ANAESTHESIA DEPARTMENTS?

The college must redesign accreditation standards for all its training programs to align with the new harmonised standards (Table 6). After revising accreditation standards, subsequent steps will be to update accreditation processes and systems and explore potential changes to the ANZCA curriculum. Improved reporting from a revised ANZCA TPS will support these changes. Hospital departments will see changes to standards and procedures over the next two years, with full implementation required by 2027.

A known limitation of current ANZCA accreditation standards and procedures is that they only focus on individual training sites rather than on rotations as a whole. The training sites directly influence the quality of the clinical learning environment and ultimately employ a trainee. Yet, the rotations these trainees work through across multiple sites are what provide them with their comprehensive and integrated training experiences, covering all essential requirements of the training program. Current oversight of rotations is the responsibility of the ANZCA national and regional committees, without any central accreditation or formal reporting. Rotational supervisors liaise with the supervisors of training and heads of department within each rotation, as well as the education officer for the region. These interactions allow the rotational supervisors to better monitor the training delivered, the progress of all trainees within the training program, and their access to necessary training requirements. Some training outcome metrics, such as time to complete training and examination success rates, are better matched to rotations than individual sites and may be included in future ANZCA accreditation.

TAC members hold the basic assumption that all staff working in anaesthesia departments want to provide a high-quality clinical learning environment that supports patient care. Despite understandable apprehension about accreditation visits, accreditation inspectors are always warmly welcomed by departments who are keen to demonstrate their commitment to ANZCA training. From time to time, health systems struggle to support the demands of high-quality learning and patient care, and by highlighting the areas that require addressing and advocating on behalf of departments, TAC can work with health services to achieve sustained improvements. In recent years, ANZCA training sites in every region have come under TAC and ANZCA Council watch, which have subsequently achieved accreditation through proactive collaboration and advocacy.

CONCLUSIONS

Accreditation is an important evaluative mechanism for ensuring training quality. It plays a crucial role for the college in maintaining professional standards and advocating for our specialties with governments and health services. Even prior to current governmental demands for college training accreditation reform, the College recognised the need to benchmark ANZCA accreditation against contemporary best practices by initiating the Accreditation and Learning Environment Project. The findings of that project roughly align with the cross-college collaborative work with the AMC and MCNZ. Inevitably, significant change is coming. College fellows, trainees and departments may wish to keep ahead of likely developments by considering how their environments will perform against the model standards developed by the AMC, MCNZ and Australian and binational medical colleges. Critically, representatives of the college are involved closely in this work to advocate for the needs of our specialty. Much of what is proposed already exists within ANZCA standards and procedures, and alignment across specialties increases the likelihood that necessary systematic change will occur to further support high-quality training in the future.

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Humanising digital change

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Edited by Professor Alicia Dennis

INTRODUCTION

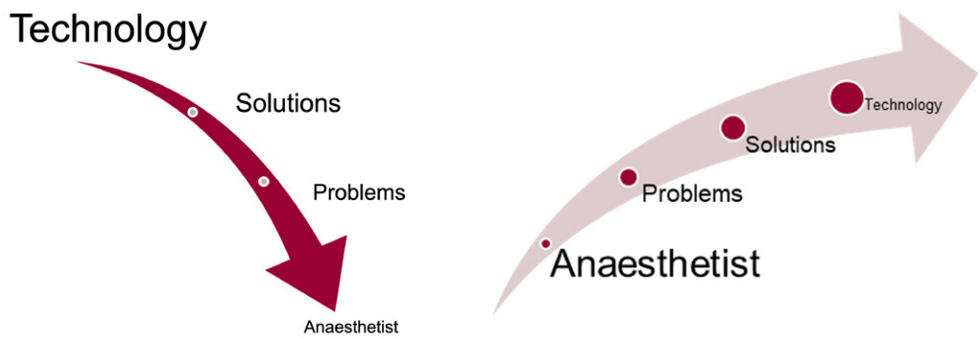
"Technology is nothing. What's important is that you have a faith in people, that they're basically good and smart, and if you give them tools, they'll do wonderful things with them."

– Steve Jobs

This article aims to introduce well-known concepts and principles of innovation theory from social science and business and adapt them to the implementation of an Anaesthesia Information Systems (AIMS). This chapter hopes to complement the traditional approach to digital change, which primarily focuses on specific technological solutions, with a focus on the humans who are impacted by the change – anaesthetists. The emphasis here is on connecting with and supporting the anaesthetists impacted by the transition, rather than optimising the technology.

From the moment we wake with phone alarms to the final email before bed, digital threads are woven into the fabric of our everyday lives. For a long time, the sheer scale and cost have been the biggest barriers to embracing the new technology paradigm. However, as we emerge from the disruptions caused by the peak of the COVID-19 pandemic, changes in health policy have created sufficient impetus for organisations to finally undertake digital transition.

Figure 1. Two complementary approaches to technological adoption in anaesthesia



The traditional approach, starting with the available technology, is contrasted against an approach that starts with the anaesthetist at the forefront.

This article is not about the merits of AIMS technology, the ideal system features, or the strategic planning that leads to procurement. Instead, it is a guide to navigating the *process of change execution* from the perspective of the anaesthetist and the anaesthesia department. It focuses on the human experience of digital transformation in the operating theatre and how to effectively deploy AIMS by prioritising the needs and perspectives of the clinical staff. It starts with the end-user and moves to a final goal of a physical solution (Figure 1).

Consider the varied responses to change among anaesthetists. Some, often termed "innovators" or "early adopters", may readily embrace new digital tools. Others, perhaps more experienced practitioners, may be more cautious. Let us illustrate the extremes with some fictional examples:
Sam grew up in the digital age. They are used to seeing patients after gleaning relevant information from digital sources first, and seamlessly switch between recording data and clinical interactions. In general, they are frustrated with the lack of technological progress in healthcare compared with their consumer tools such as smartphones and wearable devices. They are excited about the prospect of local, data-driven decisions in AIMS. Sam is an "innovator".

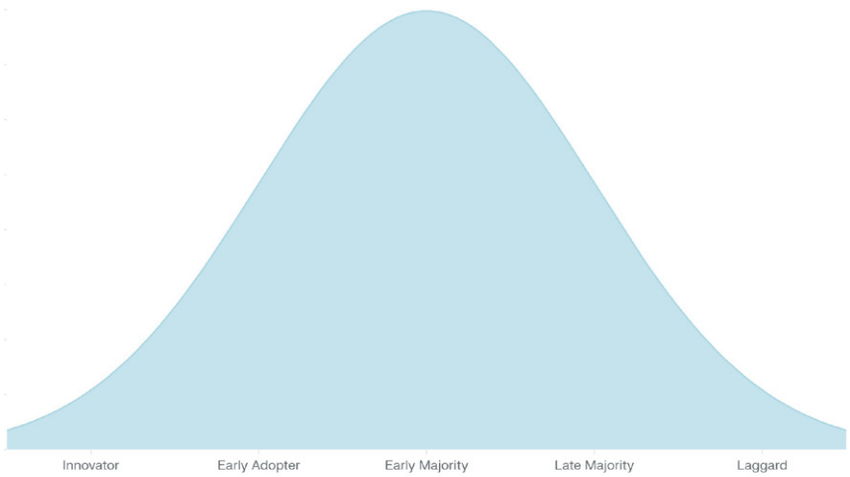
Alex has practiced anaesthesia for twenty years. They take great pride in being attuned to subtle in-person cues from their patients and thrive in detecting subtle clinical signs. Their notes form an abridged narrative or gestalt. During rounds, they find screens intrusive, impeding their ability to engage fully. They are most concerned about the distractions of digital processes during critical periods and are sceptical of the overall benefit of transitioning from their tried-and-true method of record-keeping. Alex is a "laggard".

It is crucial to dispel negative connotations associated with terms like "laggard". These terms simply describe positions on a continuum of responses to change. While innovators may initiate the push for digital systems, those who are more hesitant play a vital role in grounding the process, highlighting potential issues, and ensuring that the implemented solution is robust and clinically relevant. Effective deployment requires engaging with and valuing the perspectives of *all* users (in this case, anaesthetists), regardless of their initial stance on the technology.

Drawing on Everett Rogers' work on the diffusion of innovation, we recognise that successful change adoption depends on the interplay between the technology, the users, and the cultural context. When deploying an AIMS, the challenge lies in bridging the gap between the early enthusiasts and the majority, including those who are initially resistant. This transition, often referred to as "crossing the chasm", requires addressing the differing needs and concerns of these groups. Our focus here is on how to practically navigate this chasm during the *deployment phase*, ensuring that the human experience remains central.

In his seminal text on innovation, Rogers characterised a range of responses from American farmers to new seed crops. He used these responses to generate the now-familiar adoption curve (Figure 2). Using these findings, he introduced a model of change where the successful adoption of innovation depends on the confluence of technology, the users and the cultural context.[1] In our case, the 20:60:20 rule (20% early adopters, 60% majority, 20% laggards) is a reasonable approximation for the population.[2] When approximately 80% of users are invested in the new technology, the change is effectively normalised as a new paradigm.

Figure 2. Adoption curve



Users are categorised by their propensity to adopt a technological innovation. The area under the curve represents total number of adoptees.

During the height of the 1990s' dot-com boom, Rogers' concepts of innovation were adapted to digital technologies by Geoffrey Moore. Moore recognised that successful technology startups were those who managed to "cross" their products and operations between the innovators and niches into sustained mainstream adoption by the consumer market.[3] He described this transition in terms of the "chasm" (Figure 3) because he recognised that the biggest transition for technology was satisfying the differing needs of the early group (pre-chasm) and the majority (post-chasm). By crossing the gulf of requirements between the early adopter and the majority, an innovation will have crossed the major barrier to being the new norm. One of the reasons Apple™ has been so successful in consumer electronics is its ability to bridge this chasm for multiple devices.[4]

Figure 3. The chasm of adoption

Before we go on, we must dispel the unfortunate connotations of the common lexicon and recognise value in both innovators and laggards. Rogers used these terms arbitrarily to define a continuum of experiences. While change may begin with innovators and early adopters, it is the laggards who stop frothy speculation. They temper the momentum to chase after shiny new projects before operationalising existing ones. A challenge for leaders of departments is balancing the opinions of all people on the adoption curve in setting the choice and pace of change.

Our scenario with an AIMS is not different to any other technological paradigm. Most clinicians are aware of the benefits of digital health. Measurable improvements in patient safety, remuneration and operational efficiency, as well as data for research,[5] make compelling reasons for organisational change. Beyond the early adopters, however, most clinicians grapple with the conflict of collecting objective data against our expertly honed, holistic clinical opinion. Relentless screens of checkboxes and text walls can give rise to fears that the importance of clinical expertise will be diminished.[6] Schwartz reports that anaesthesia records are not simply a collection of objective data points but are our subjective narrative view of a unique physiologic experiment in real-time.[7] Because of this, many see our paper anaesthesia record as a symbolic reflection of us as clinicians and practitioners of a craft. Even with the ability to digitally record narrative notes, there is a fear that data can be reviewed without adequate recognition of our interpretations of rich, ambiguous and unrecordable clinical signs. Opposing AIMS implementation may seem the only way to resist an invasion of faceless, digital bureaucracy forming a Kafkaesque nightmare of inhuman healthcare. Further sowing seeds of distrust and disengagement are the multinational technology vendors for AIMS, as well as the cynicism that accompanies the medical-industrial complex. For the clinicians who are most affected by technological shifts, there is growing scepticism about whether the innovations of AIMS can fundamentally transform healthcare outcomes for the better.

APPROACH

With these factors in mind, an approach can be taken to address the human concerns of the anaesthesia cohort, as the primary tool for instigating and sustainably creating change. Engagement and trust from anaesthetists in developing and adopting the new paradigm is needed. From the ideas presented above, the following framework could be used when implementing AIMS in new organisations:

1. Communicate for alignment.
2. Find champions *and* connectors.
3. Start simple.
4. Collect data.
5. Keep learning.

Communicate for alignment

The phenomenon of messaging only the positive impact of change is self-evident in many examples in our own lives – we have all heard the trumpeting cries of why change is better from real estate agents, salespeople, and political campaigns. While it is important to communicate the advantages, it is tempting to focus solely on the positives. Upsides mainly seek to draw the interest of early adopters, while everyone else is more inclined to focus on the downsides. There is a commonly held view that the more information that is given about benefits, the more positive the engagement will be from the end-users. It is, however, quite the contrary. With AIMS implementation, the positives are often the subject of an organisational-wide campaign for awareness. Yet there is often plenty of scepticism about this unambiguously rosy outlook. We hear feedback such as:

We don't even have working computers in theatre.

They don't care that we have to spend thirty minutes writing notes before induction.

What will happen when there is a power outage?

Knowing this, reframing messaging away from "pros and cons" towards *alignment* can be very useful. Instead of re-stating *what* is going to change, it can be helpful to create questions about *how* the technology could be fit for purpose in the specific workplace. This aims to bring critical voices into the solution about how best to implement the change in each specific organisation. For example, the perceived inefficiency of digital records in an endoscopy suite, or other surgical lists where fast patient turnover is essential for efficient patient care, needs to be specifically addressed. It is necessary to first acknowledge that there could be settings where digital records slow the turnover of patients *before* working on a solution. From there, the team can find solutions – such as having the patient records started before patient arrival, which may allow for a more efficient flow of patients undergoing relatively simple and short-duration procedures. This can then be tested and refined in teaching materials at the time of implementation. Early direct involvement of the team undertaking the lists means that complaints regarding slower patient turnover due to AIMS can be minimised.

Find champions *and* connectors

One of the key psychological features of change is fear or anxiety about the uncertainty in the new paradigm. When faced with this uncertainty, our general instinct is to reach for simple black-and-white (yes/no) solutions. As well as reframing discussions away from binary outcomes toward collective alignment, we can also create champions and connectors. In order to engage those who are threatened, we need agents with whom high levels of trust exist. For us, these take the form of champions and connectors.

"Champions" are those who are seen to be experts; they often hold symbols of authority such as titles or degrees and are acknowledged as being "competent" in at least one relevant domain (technology or anaesthesia). They can be trusted to solve problems and explore areas of technical complication. Champions are essential for initial engagement and to confer some external validity to what is being done. Champions often come from the innovators or early majority group and may be the initiators of implementing an AIMS. However, they can also be intimidating if their passion is expressed without acknowledging or respecting broader hesitation from the rest of the potential adopters, which can create distance or mistrust if they are

perceived to be misaligned in other ways to the majority. It is therefore essential to avoid creating further distance from champions by being judicious in the use of jargon, titles, and decrees.

"Connectors" on the other hand, are those who conform to many of the behaviours and attitudes of the majority but are still aligned with the change. They are crucial in helping to bridge the gap across the chasm between innovators and the majority because their trust is created by other similarities and inclusion with the majority. They interact with a broad cross-section of the change cohort. Early in the implementation of an AIMS project, it is important that a balance of champions and connectors be intimately involved. Because connectors give input early, their voices can reflect the wider group's more conservative and reserved members at the outset. At this time, by representing the concerns and apprehensions of the group, their trust and inclusion can be further enhanced, especially if it differs from the organisational edict. Towards the end of the project, as the connectors become more confident of the changes and eventual outcomes, their endorsement can be seen as a considered choice representing the more cautious majority, rather than a dictum of authority.

Start simple

Technology products often begin with a minimum viable product – the most basic version that does the minimum required for the purpose it was designed for. For AIMS implementation, we may instead design a system that deviates the least from existing workflows. While early adopters appreciate flexibility and features in AIMS, the majority is far more comfortable with fewer features and options, as an increase in choice can be bewildering. This can be particularly relevant if there are other, less desirable changes occurring at the same time. If there is too much net change, the new system's benefits may be ignored while users spend time dealing with the less familiar and desirable aspects of the change. Over time, as familiarity increases, it may be possible to add features in a slow and considered way to improve functionality.

In many cases of AIMS implementation, vendors present the organisation with an overwhelming array of customisations. In many AIMS, commonly used anaesthesia tools such as drugs (propofol), procedures (airway management) and monitoring (blood pressure) can be packaged and customised. While it is possible to implement user-level customisations from the outset, it may instead be better to create global packages that cover the majority of surgical cases so that most users (the anaesthesia providers) have a more streamlined approach to using AIMS. Knowing the needs of the cohort for "essential" compared to "elective" options will help discern the level of initial customisation. Over time, requests for further customisation may occur, but these are usually non-urgent and can be prioritised after other support and essential fixes.

Collect meta-data

To complement "starting simple" is the idea of iteration. In order to create a sustained virtuous cycle of improvement, we must collect data on users' attitudes and the usage of parts of systems – meta-data. Before, during and after the project, this can take the form of a "temperature check" survey. In these, staff can qualify and quantify their engagement, involvement and inclination toward the change. With this information, it is possible to adjust the strategies used during the deployment of AIMS. When pre-implementation meta-data reveals a lack of engagement with online learning, changes can be made, such as appeals to management for extra staffing support during the week of implementation (Go-Live). A post-Go-Live survey can then be used to document the impact of these extra support hours, hopefully showing that this staffing increase made the most qualitative difference in the attitude of staff to the project.

Conversely, one of the biggest impediments to further improvements after AIMS implementation can be the lack of access to usage meta-data. Knowing how much time users spend engaging with each part of the AIMS may lead to insights about pain points in the user experience. These insights can lead to changes that make common tasks more efficient and effective. However, data extraction for this usage can be challenging and may require collaboration with institutional digital teams and technology vendors. Without these data there can be reduced ability to pre-emptively make changes to the AIMS system before they become clinically problematic. As it stands, many organisations still rely on less accurate and inefficient, informal channels for feedback.

Keep learning

The sustained acceptance of AIMS is also facilitated by an ability to adapt and keep learning. As leaders, we must recognise that our knowledge at the outset of a change project such as AIMS is going to be different in the target state. As we progress, new problems and solutions may become evident, and therefore there must be a mechanism to review and modify previous decisions. In the corporate world, a leader in this field is Amazon™. They have relentlessly pursued a strategy based on the idea of a "Day 1 company". Amazon™ culture is one centred on the experiences of their customers.[8] In AIMS, our "customers" are our users (anaesthesia providers). To create enduring value from AIMS, staff need to give feedback to organisational leadership, and then the leaders must translate these learnings to changes in AIMS. This means that a key attribute of change leadership is to live in the discomfort of uncertainty and to support the rest of the cohort through the same.

The most significant barrier can sometimes be that anaesthesia departments are nestled within the culture and operations of larger healthcare organisations. For AIMS leaders, the ability to manage up and down the organisational ladder is crucial. They need to remain open to the possibilities presented by users and work to constantly understand their feedback. Leaders should always look for alternative solutions rather than dismiss how suggestions can't or won't work in the organisation. When there are larger forces dictating changes, it is important to hear why concerns exist and look for workarounds where possible. Where there is a mismatch between what the organisational process requires and what the users want, leaders must work hard to bridge the gap. This doesn't mean taking sides in the debate but facilitating communication between the teams that generate policy and those that deliver and exist within them.

CONCLUSION

It is important to recognise that digital change is just one aspect of greater societal change. We may be on the cusp of a major paradigm shift in the Anthropocene. Climate, geopolitics, artificial intelligence and autonomy, as well as policy and demographics,[9] are all likely to have significant ramifications for the next generation of anaesthetists. Knowing how change occurs in the AIMS setting can be the template for other changes in the future. We must be courageous enough to acknowledge our own limitations, weaknesses and errors, and constantly seek out ways to learn from colleagues, trainees and patients, as well as from sources outside our industry. We should consider our decisions with the benefit of a broad spectrum of lessons. We can better create solutions by listening and understanding who is being asked to change. Change is not what happens to people, it is what is brought about by people.

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Anaesthesia medication shortages in Australia and New Zealand

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INTRODUCTION

Worldwide, there are drug and equipment shortages across high-, middle-, and low-income countries, affecting many areas of medicine. As noted by Zivot, safe and reliable medical practice depends on reliable medical technology and unfettered access to needed supplies, equipment, and pharmaceuticals.[1] Most recently, the shortage of intravenous fluids, and in the recent past, shortages of personal protective equipment (PPE), propofol (in 2014, 2020, 2021 and 2025) and remifentanil (ongoing since 2022), have impacted anaesthesia practice in Australia and New Zealand. Both Australia (through the Therapeutic Goods Administration (TGA)) and New Zealand (through the Medicines and Medical Devices Safety Authority (Medsafe)) have strict regulatory processes for assessing, monitoring and licensing of medications, which ensure the highest safety standards for medication usage. However, these appropriately stringent standards may cause issues when medication shortages occur and there is a need to access other medications or formulations. In this chapter, we will look at how medication shortages may more significantly impact the provision of anaesthesia than other medical disciplines, the causes of medication shortages, the potential clinical and ethical problems of medication shortages, and mitigation strategies when shortages occur.

THE VULNERABILITY OF ANAESTHESIA TO MEDICATION SHORTAGES

Several core classes of medications are essential to anaesthesia practice: induction and maintenance agents, analgesics, local anaesthetics, muscle relaxants and reversal agents. Over the past decade, the use of propofol as an induction agent has become almost universal in adult anaesthesia, and is used increasingly for anaesthesia maintenance. Although the use of volatile anaesthetic agents has decreased, in part due to environmental concerns, there remains a place for these agents in the induction and maintenance of anaesthesia. These environmental concerns have led to a dual impact regarding the utilisation of volatile anaesthetic gases. The first is a reduction in the use of these agents overall. The second is a reduction (or in some cases, an elimination) of desflurane, secondary to concerns about its greater impact as a greenhouse gas. This change in practice has subsequently seen sevoflurane increasingly become the sole volatile agent in common usage and availability. Similarly, fentanyl, hydromorphone and remifentanil are increasingly becoming the most frequently prescribed opioids of modern anaesthesia practice in Australia and New Zealand. With the reduction in the use of bupivacaine, local anaesthetic usage has essentially been restricted to lidocaine and ropivacaine.

Within a variety of anaesthetic-relevant medication classes, a range of different pressures has led to an ever-diminishing choice, or in some classes, no choice, of alternative medications. Compared to other medical specialities, alternative medication choices in anaesthesia are very limited. For example, within the

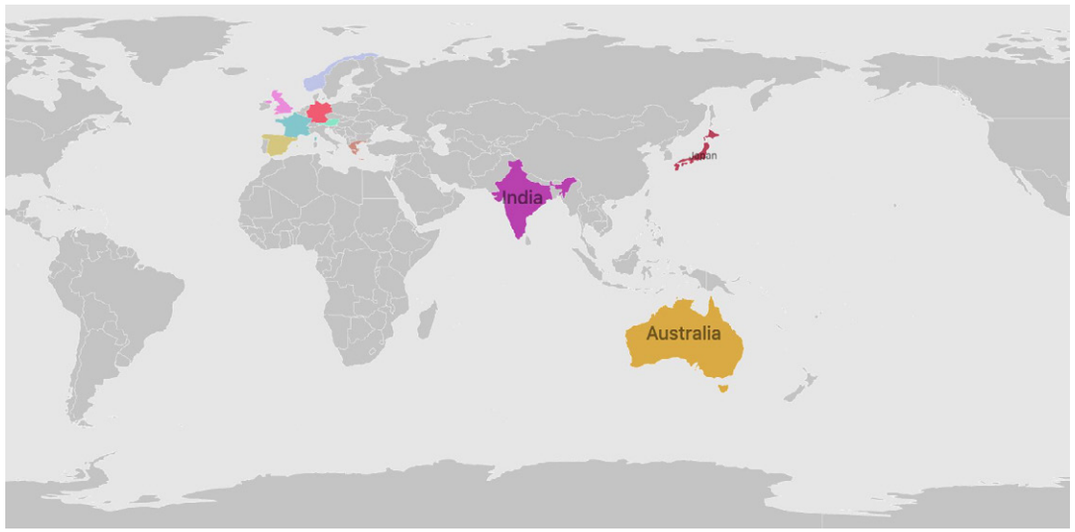
classes of antibiotics, antihypertensives, lipid-lowering medications, anticoagulants, and antidepressants, there are numerous individual medications available. On this basis, when a shortage of one medication used in anaesthesia occurs, there is unlikely to be readily available or commonly utilised alternatives.

The TGA advises that more than 90 per cent of medications in Australia are imported from overseas; we have been unable to estimate the percentage of drugs imported in New Zealand. Table 1 and Figure 1 show examples of commonly used anaesthesia medications on the Sir Charles Gairdner Hospital formulary in 2025 and their place of manufacture.

Table 1. Common anaesthetic therapeutic agents and country of origin

Medication	Brand name	Place of manufacture
Fentanyl	Sublimaze	Greece
Lignocaine/lidocaine	Lidocaine Lumacina	Western Australia
Lignocaine/lidocaine	Xylocaine	France
Morphine	DSBL Morphine	Germany
Propofol	Diprivan	Austria
Propofol	Fresofol	Austria
Remifentanil	Remifentanil-AFT	Spain
Rocuronium	Rocuronium Bromide Medsurge	India
Ropivacaine	Ropivacaine Kabi	Norway
Suxamethonium	Suxamethonium Juno	United Kingdom
Vecuronium	Vecuronium Sun	India

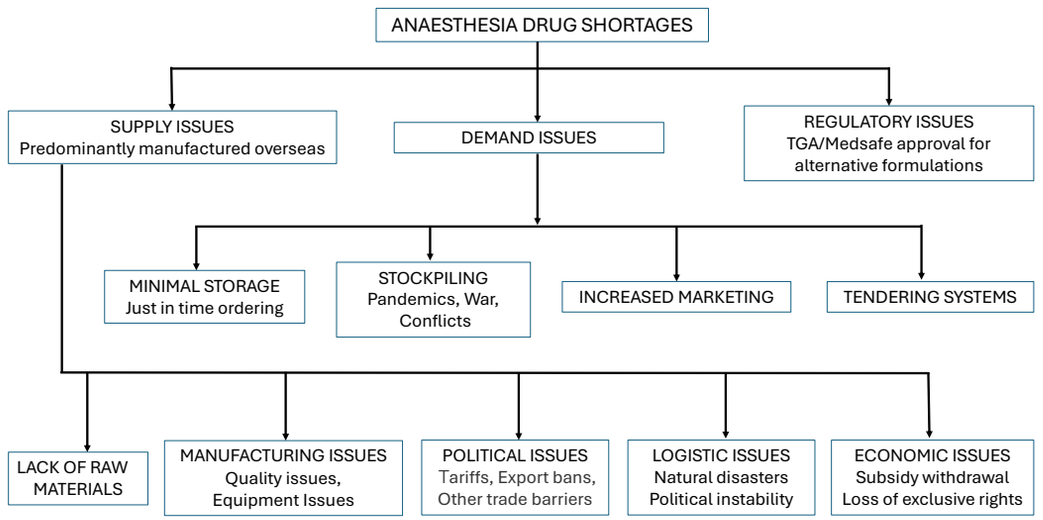
Figure 1. Map of countries manufacturing common anaesthetic therapeutic agents for Sir Charles Gairdner Hospital



WHY DO MEDICATION SHORTAGES OCCUR IN AUSTRALIA AND NEW ZEALAND?

A complex interplay of factors drives medication shortages in Australia and New Zealand. As illustrated in Figure 2, these shortages can be broadly classified into three main categories: supply issues, demand issues, and regulatory issues.

Figure 2. Anaesthesia drug shortages



Adapted from Shukar et al. (2021)[2]

Supply issues

Supply chain disruptions are a predominant cause of medication shortages, with several factors exacerbating the issue. Manufacturing issues, including production quality, equipment malfunction, and lack of raw materials, made up 63 per cent of the reasons for all drug shortages in Australia in 2023.[3] Other reasons include business and logistical issues.

Political issues, including export bans, trade barriers, and more recently the consideration and introduction of tariffs, may also contribute to a lack of drug supply. Although not affecting Australia and New Zealand, political pressure was demonstrated regarding the availability of COVID-19 vaccines in some countries.

Australia and New Zealand are geographically isolated and rely heavily on international suppliers. More than 90 per cent of prescription medications used in Australia are imported, increasing its susceptibility to shortages when global supply chain disruptions occur, either due to political instability or natural disaster.[4] Supply chain resilience will be discussed in further detail later.

Demand issues

Fluctuations in market demand can also drive medication shortages. Just-in-time inventory practices are common in Australia and New Zealand, justified by the reduction of expenses required to maintain stock levels and a reduction in wastage as a result of shelf life not exceeding expiry dates. This practice does not allow for unexpected increases in demand, contributing to supply gaps, particularly for essential medications.[1] Government-subsidised pharmaceutical provisions (the Pharmaceutical Benefits Scheme (PBS) in Australia and Pharmac in New Zealand, respectively) influence medication demand patterns. When medications become subsidised, demand can spike, leading to shortages if supply adjustments are not made. Furthermore, global competition for limited drug supplies means increased international demand may divert stock, worsening local shortages. This was evident during the COVID-19 pandemic when widespread medication stockpiling led to critical shortages.[5]

With respect to tendering issues, hospital annual drug usage data is used to negotiate the best price for future years' medication supply tender. Any change in brands or sponsors may see a situation where new suppliers are not able to meet demands at the local level for a period of time. Similarly, any change in usage after a tender process is awarded to a new supplier may result in a shortage as stress-testing the capability of that new supplier to meet increased demands may not have been established.

While Australian law bans the advertising of prescription medications to the general public, New Zealand

(and also United States) law does allow it. Globalisation and the ability to obtain information online may expose Australian patients to advertising as well, and there may be situations in which patients specifically request certain types of medications and, relevant for anaesthetists, analgesics.

Regulatory issues

Regulatory constraints also contribute to drug shortages. Strict compliance requirements ensure medication safety and efficacy, but can slow down production adjustments in response to shortages.[2] Lengthy approval processes for alternative suppliers and generic drugs delay market entry, limiting the ability to compensate for disruptions. Additionally, procurement policies within publicly funded healthcare systems may restrict flexibility in sourcing alternatives, further compounding supply challenges.[2]

While the factors outlined above provide reasonable explanations for medication shortages, there is an argument that these shortages are not inevitable but rather a consequence of market failures that can be alleviated.[1] These market failures include inefficiencies in production, prioritisation of cheaper drugs over higher-priced brand-name drug manufacturers, and the growth of generic manufacturers (with inconsistent quality standards) over brand-name medications. While generally ensuring lower-cost acquisition of drugs, the resulting smaller pharmaceutical market renders the system unable to compensate when medication production issues occur. Compounded by strict regulations in Australia and New Zealand, this may result in the unavailability of the drug at any price.

CONSIDERATION OF SUPPLY CHAIN RESILIENCE

In any system, there are two distinct properties: stability and resilience, with resilience being the ability of systems to experience disturbance and maintain their functions and controls, and stability being the capacity of systems to return to an equilibrium state after a temporary disturbance.[6] By their inherent variability, the health and hospital systems should be expected to be innately unstable, responding to both short-term and seasonal variability as part of their usual business, yet in most circumstances, business continues as usual despite these variations, indicating a reasonable level of stability. However, in situations of critical medication shortages, resilience may be severely limited. Relevant to anaesthesia, important properties of resilience are firstly the amount of change that a system can undergo while retaining the same controls on structure and function; secondly, the degree to which the system can organise itself without disorganisation or force from external factors; and thirdly, the degree to which a system develops the capacity to learn and adapt in response to disturbances.[6] The recent pandemic and recurrent medication shortages have demonstrated that many hospitals and health services may not have fully considered the concepts of resilience. Although limited in scope, the section on mitigating strategies discusses ways in which anaesthesia departments can strengthen resilience.

Despite the critical nature of medication supply, the TGA has only required mandatory reporting of medicine shortages since 2019. Depending on the impact of the shortage, the TGA must be informed within 2-10 days. With the common local practices of just-in-time inventory stock supplies, there remains a significant risk of shortages despite mandatory reporting.

Although medication shortages have become relatively more visible to anaesthetists since the COVID-19 pandemic, medical product shortages have been an ongoing issue in healthcare.[7] As succinctly stated by Miller et al., “all product shortages endanger patients due to delays in care, rationing or denial of care, the use of substandard products, or heightened risk of error when using replacement products – risks that extend to increased mortality”, and are therefore of significant concern to both anaesthetists and other clinicians.[8] They also classify supply chain vulnerability in terms of two main areas, firstly threats to manufacturing, and secondly threats to local availability, the second area being of particular relevance to the geographically isolated region of Australia and New Zealand.

Threats to manufacturing are not unique to medical products, and examples from other industries demonstrate that a lack of resilience is widespread. For example, the 2011 Thai floods caused the suspension of computer hard disk manufacturing in a geographical area where more than 25 per cent of the world’s hard drives are manufactured, affecting nearly all personal computer manufacturers. This example of geographically concentrated manufacturing is not unique – approximately 65 per cent of the world’s medical gloves are supplied from Malaysia, which was affected by lockdowns during the COVID-19 pandemic. The limited number of manufacturers for many anaesthesia medications also puts the specialty at risk, because if one firm is affected by disruptions or issues related to manufacturing quality, the consequences may be

significant to the global supply. This was seen in the United States concerning propofol, when two of the three suppliers withdrew from the market in 2009-10.[9] Disruptions caused by a lack of raw materials are not limited to just the medication itself. Shortages may also affect medication packaging (like ampoules), sterilisation, labelling, shipping, or various other key components in the chain from manufacturing to point of care utilisation.

In 2021, images of the container ship *Ever Given*, which ran aground in the Suez Canal, and the backlog of vessels waiting to transit the canal, made worldwide news. They highlighted the downstream effects of a single incident on global supply. Both natural disasters and human-caused incidents may affect local availability of medications as a result of disruption in transportation processes. External factors such as trade sanctions and export bans may also threaten availability.

THE IMPACTS OF MEDICATION SHORTAGES ON ANAESTHESIA

As alluded to above, the specialty of anaesthesia is at particular risk as a result of limited drug choices within specific and essential classes of medications. Australian and New Zealand anaesthesia deservedly enjoys an unrivalled reputation for safety, which in part must be due to the training and regulation of its practitioners.[10] An extensive review of medication errors showed that no anaesthesia medication class (with the exception of opioids, which are also administered in a ward setting) are in the top ten classes for medication issues.[11] However, this may be compromised by the necessity to change medications in the presence of medication shortages, when unfamiliar medications or formulations are required to be used, or different techniques are considered.

The implications for anaesthesia practice have been clearly identified and potentially affect patient care and safety.[12] The most obvious issue is the lack of familiarity with substitutes, including dosing, pharmacokinetics, and clinical side effects. Differences in potency, or when the same drug is being presented in a different format or concentration, may lead to medication errors and adverse clinical events. It is interesting to note that government-endorsed strategies in times of medication shortages, such as ampoule sharing, may contravene accepted practice guidelines.[13,14] A practitioner’s preferred technique may need to be altered, even though the clinical outcome may be just as good. An example would be the use of a regional technique over general anaesthesia. Given that anaesthetists work as part of a team, there are also potential issues inherent within the team structure, including communication errors and potentially increased stress.

Medication shortages present ethical issues to anaesthesia practice, but as stated by Lipworth and Kerridge, they are also political issues, as “when they arise, drug shortages threaten the capacity for clinicians and governments to fulfil their moral obligations to patients and society – specifically, to provide benefit and minimise harm and to promote equity”.[15]

There is the risk of rationing, which may be defined in healthcare as the allocation of scarce healthcare resources and the use of different approaches to delivering health services and patient care, potentially withholding beneficial treatment from certain individuals or groups of people.[16] Given that there are different possible anaesthesia techniques, it may better reflect anaesthesia practice if the term “beneficial treatment” were changed to “beneficial or optimal treatment”. It is beyond the scope of this chapter to examine the discrepancies in healthcare outcomes between rural and metropolitan and Indigenous and non-Indigenous patients in Australia and New Zealand.[17,18] Concerning other medication classes, it has been highlighted in Australia that medicine shortages and discontinuations disproportionately impact certain population groups, including First Nations people and people living in remote and rural areas.[19]

Another ethical issue relates to the co-existence of the public and private health systems in Australia, and to a lesser extent in New Zealand, with different procurement practices. Some large public health systems employ procurement officers, who are responsible for medication tender and supply, which may offer an advantage over smaller private hospitals with respect to bargaining power. However, in the case of medication shortages, there may be the potential for one system to offer increased prices that may see a diversion of stocks away from the other system, and a reduction in equity in healthcare. We do note that there is no evidence of this having occurred in Australia or New Zealand. Still, the situation represents a micro-level reflection of purchasing power imbalances already seen between larger and smaller countries.

MITIGATION STRATEGIES FOR THE PREVENTION AND MANAGEMENT OF MEDICATION SHORTAGES

These strategies occur at government, health department, hospital, clinical department, and individual practitioner levels. Shukar et al. categorise changes into those of governmental policy, improvement of operations, management of current medication shortages and education, and training. Although written from an international perspective, there are many aspects in this article that are relevant to Australia and New Zealand. Anaesthetists are unlikely to be involved at many of these higher administrative levels, but mentioning these issues will allow for better transparency regarding the long chain of events, and an appreciation of the broader picture. Initiatives in government policy relate to the manufacturing and licensing of medications, the establishment of national and international guidelines, the development of advanced notification systems, the expedited review of new or different formulations of medications, and the consideration of pricing mechanisms. Improvement of operations includes increased communication among stakeholders, the introduction of medication shortage reporting and tracking systems, increased manufacturers and generic products, and increased numbers of suppliers.

Management of current medication shortages is of more interest and importance to the practising anaesthetist. Without clear guidelines on how medications are utilised during the shortage, there is the potential for both unsafe practice and issues with inequity in healthcare. Input from clinicians is required in the following areas:

1. The development of guidelines for the restriction of use.

Developing clear guidelines for medications with restricted stock should allow prioritisation for those patients and procedures where evidence has suggested improved outcomes and preservation of stock. An example would include restricting or prioritising the use of remifentanil for neurosurgical procedures and restricting its use for other procedures where other medications may be clinically suitable, such as abdominal and cardiac surgery. Another example would be ensuring that patients' fasting is kept to the bare minimum according to guidelines to reduce the amount of intravenous fluid required perioperatively.

2. Consideration of strategies to increase availability and reduce wastage.

As mentioned earlier, strategies to increase the availability and reduce the wastage of medications include using a single ampoule for more than one patient, which does not comply with ANZCA guidelines or with legislative requirements in some jurisdictions with respect to restricted medications such as opioids. When such strategies are employed, it is important that anaesthetists, in conjunction with pharmacists, set up fool-proof systems to ensure that there is no risk to patient safety as a result of these initiatives. Other strategies that may be considered include use beyond expiry dates, which again requires multidisciplinary decision making with pharmacists and administrators. It may be that to ensure equity, stock is redistributed between institutions so that supplies are available for those patients who would most benefit from these medications.

3. Consideration of an alternative medication or anaesthesia technique.

This involves substitution of the medication in short supply with alternative medications from the same class, or even considering a change in anaesthesia technique – for example, from general to regional anaesthesia.

4. Accessing unregistered medications.

Both the TGA in Australia and Medsafe in New Zealand have processes to support access to unregistered therapeutic goods from overseas markets. These may be applied for on a case-by-case basis, and an individual or group of prescribers may apply as a sponsor for importing one particular unregistered item. However, it should be noted that these medications may have different labelling, different concentrations, different formulation, or different additives from those usually available. Additional documentation and certification may also be required to use these medications, and in most instances, informed consent from patients is required.

CONCLUSION

As mentioned in the mitigation strategies section, many of the long-term strategies to reduce medication shortages are focused on interventions at much higher organisational levels than individual clinicians, clinical departments, or hospitals. In the short term, it is unlikely that there will be any improvement in the intermittent shortages recently experienced in anaesthesia practice in Australia and New Zealand. Anaesthesia departments will have to continue to prepare contingencies and strategies to enable safe anaesthesia to be administered despite medication shortages. However, safe anaesthesia practice can be maintained with appropriate strategies involving multidisciplinary teams, education, and continuous assessment of the impact of medication shortages on quality and safety.

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Back to the future: A return to point-of-care nitrous oxide cylinders

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Edited by Dr Brenton Sanderson

INTRODUCTION

Millions of litres of the anaesthetic gas Nitrous Oxide (N_2O) are currently leaking from medical gas pipeline systems around the world, including in Australia and Aotearoa New Zealand.[1-7] Most of the N_2O that a hospital buys never reaches a patient. This article will explore how such a wasteful system became ubiquitous in healthcare design and the evidence-based steps that the anaesthetic community can take to manage the problem.

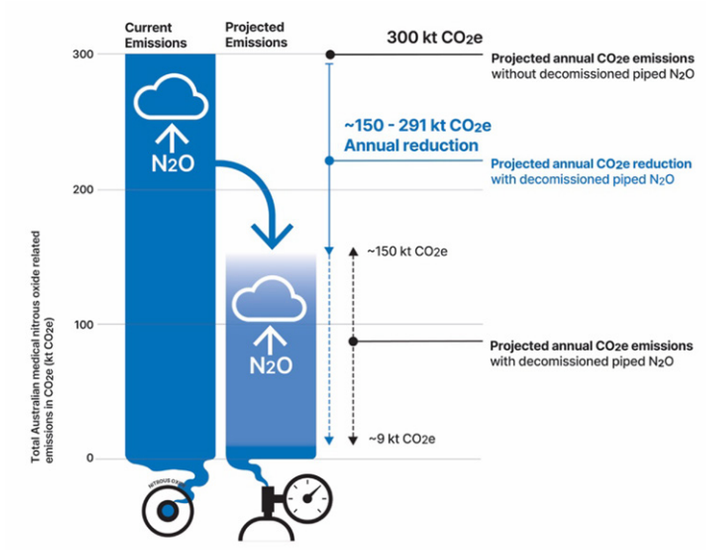
N_2O is a potent greenhouse gas, with a 100-year time horizon global warming potential 273 times that of carbon dioxide.[8] The Australian government's Health and Climate Strategy has identified reducing emissions related to N_2O as a key strategy, while New Zealand has not identified this as a government target.[9]

The strategy estimates emissions related to medical N_2O for 2020-2021 financial year in the Australian healthcare sector equates to the equivalent emissions of 300,000 tonnes of CO_2 (CO_2e), representing 20% of Scope 1 emissions, which are direct emissions that result from sources that are owned or controlled by a healthcare facility. Most of this footprint related to N_2O is likely a result of leakage and not clinical administration.[10]

The international community is acting. The United Kingdom and Ireland intend to phase out N_2O pipelines by the end of the 2026-2027 financial year and the American Society of Anaesthesiologists has called for all N_2O pipework to be decentralised.[11,12] With the support of RANZCOG and ANZCA the Australasian Health Facilities Guidelines have been updated to state that piped nitrous oxide is "not mandatory for any healthcare service and point-of-care cylinders can meet clinical requirements".[13]

Our college agrees that the climate crisis is a public health emergency and recently committed to the Australian Commission on Safety and Quality: "Working together to achieve sustainable high-quality health care in a changing climate".[14] Reducing emissions from leaked N_2O is an evidence-based opportunity to reduce harm without impacting patient care. The interim Australian Centre for Disease Control guidelines recommend "decommissioning N_2O pipelines where possible, avoiding installation of new N_2O pipelines, and instead supplying N_2O via cylinders at the point of clinical administration".[15] This adjustment has been demonstrated to reduce N_2O related emissions by up to 97%.[1,16] Our estimates, based on published literature and unpublished internal audits across Australia and New Zealand, suggest 150,000-291,000 tonnes CO_2e could be prevented *annually* across the Australian healthcare sector if piped N_2O supply was decommissioned and point-of-care cylinders were used instead (Figure 1).

Figure 1. Comparison of current and projected N_2O related emissions



Data from National Health and Climate Strategy. Current emissions represent CO_2e from Australian healthcare sector 2020-2021 financial year.[9] Projected emissions estimated from international and local published and unpublished data. Realised emission reduction will depend on the leak fraction across the Australian healthcare sector.

This article intends to be a "how to" guide to support this supply change. We aim to provide detail on existing N_2O infrastructure, outline the evidence regarding leak and provide necessary information to assist healthcare facilities in Australia and New Zealand to provide N_2O via cylinders at the point of care where necessary. We also suggest that anaesthetists review their practice to consider if N_2O administration is necessary for, and consistent with, providing the best care for their patient's current and future health.

HISTORY OF N_2O AND THE NEED FOR PIPED SYSTEMS

The discovery of N_2O in 1772 is well described.[17,18] First trialled as an anaesthetic in 1844, it was used sporadically by dentists until the widespread adoption of the drug in the late 1860s. It was then rapidly introduced into general anaesthesia, with the first records of Australasian clinical use in the 1870s.[19] It provides both sedation and analgesia with rapid onset and offset which led to its ongoing use into the 21st century as an inhaled carrier gas for anaesthesia as well as for obstetric and procedural analgesia. It remains on the 2023 version of the World Health Organization's list of essential medicines.[20]

In the mid-20th century, developments in anaesthesia such as curare, intubation, positive pressure ventilation, and muscle relaxants evolved to facilitate surgery.[21,22] Advanced centres had access to mixed Oxygen/N_2O/volatile techniques, though measurement of gas delivery and uptake was not standardised.[22]

In that era, anaesthesia circuits were typically open to semi-closed, as the absence of end-tidal gas monitoring made efficient low-flow techniques risky due to the potential for hypoxic or anoxic mixtures.[21] The introduction of halothane in the mid-1950s encouraged more economical flow rates and the uptake of exhaled gas analysers in the 1990s improved safety.

Medical gases became available in cylinders in the 1870s, a vast improvement on the original practice of preparing and storing the gas on site in ox-bladders or free standing gasometers.[23] Theatre gases were supplied by large point-of-care cylinders until the 1960s-1980s when piped or reticulated systems became more widespread.[24] The development of medical gas pipeline systems improved convenience, supply reliability, and safety through non-interchangeable screw thread (NIST) connections and sleeve index system *(SIS)* used in Australia for common medical gases.[25] Medical gas pipeline systems supplied from bulk gas sources allowed cost savings through lower gas costs per unit volume, reduced cylinder rental charges and improved logistical efficiencies.

N_2O has been commonly used as an analgesic in labour since the late 1930s, but patterns of use vary worldwide.[26,27] In Australia, 40% of labouring women use N_2O during labour.[28] It has a favourable profile and is a common first or second line midwifery initiated analgesic option, although unwanted side effects such as dysphoria and nausea are acknowledged limitations to its use in some women.[28] It is less invasive yet less effective than alternative therapies such as remifentanil PCA or epidural analgesia.[29]

N_2O is also used for procedural analgesia and sedation either in isolation or as an adjunct to other agents. It is used in emergency departments, dental clinics and procedure rooms for various interventions in both adult and paediatric populations.[29,30]

N_2O INFRASTRUCTURE

N_2O medical gas pipeline systems exist in most hospitals in Australia and New Zealand to meet the needs of birthing units, operating theatres, emergency departments, and procedure rooms. As hospitals expand and these networks become more extensive, healthcare facilities often lack updated schematics of their gas pipelines and associated wall outlets.

A N_2O medical gas pipeline system is pressurised by a dual manifold comprising one active and one inactive cylinder bank and may have a smaller reserve manifold for failures or servicing. Cylinder pressure ranges from 4600–5200 kPa and is regulated to 400 kPa before entering the main pipeline.[31,32] Supplying N_2O in this manner has allowed bulk purchasing of gas and decreased transport costs. N_2O is an inexpensive gas, costing 1-2c per litre.

In general, Australian facilities have a pure N_2O supply that is blended with oxygen at the point of care, whereas New Zealand facilities follow the UK and Ireland style, with separate pipelines for both N_2O and Entonox (50:50 N_2O:oxygen).[32]

N_2O is administered via an anaesthetic machine or a N_2O and oxygen blender, while Entonox requires only a demand regulator. Waste gas scavenging or adequate ventilation is recommended where N_2O is administered in either form. For maximum effectiveness, expired gases should be exhaled directly into a circuit connected to a scavenging system.[33,34]

N_2O PORTABLE CYLINDERS

N_2O is stored in white cylinders with ultramarine shoulders (with a Pin Index Safety System, configuration of 3,5.). These cylinders are commonly made of carbon steel but can also be made of MRI-safe aluminium. The cylinder pressure is 4600–5200 kPa at room temperature and sea level. Stored below its critical temperature, N_2O exists simultaneously in liquid and vapour phases, with respective proportions depending on ambient temperature. To mitigate the risk of cylinder rupture due to liquid expansion, cylinders are partially filled to a specified filling ratio and equipped with a pressure relief valve.[35]

N_2O cylinders are available in sizes from 900-18,000 L. The Australian, New Zealand, UK, and US cylinder sizes follow different scales and are not directly comparable. Cylinders appropriate for point-of-care use in Australia are sizes C or D and in New Zealand, sizes A or D2. There are slight discrepancies in cylinders sizes between medical gas companies and the below figures represent a guide for temperate climate areas.

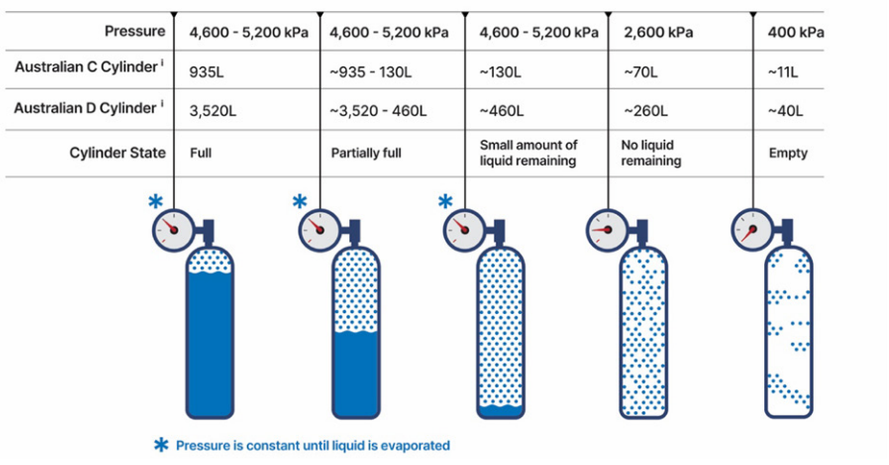
Table 1. Point-of-care N_2O cylinders in Australia and Aotearoa New Zealand

Size	Volume N_2O (L)	Weight N_2O (kg)	Water Volume (L)
Australian cylinders			
C	935	1.75	2.8
D	3520	6.6	10
E	8970	16.8	23
Aotearoa New Zealand cylinders			
A	1090	1.99	2.85
D2	3524	6.6	10

Values from British Oxygen Company.[36,37] Local and supplier variance in exact values is expected.

Determining the remaining N_2O volume in a cylinder is straightforward, and combined with advancements in knowledge regarding administration volumes, it is safe to provide point-of-care N_2O via cylinders. The gas volume is calculated from the pressure and water volume of the cylinder. Cylinder gas supply is commonly used when there is interruption to the piped N_2O supply, and cylinders of other medical gases, such as carbon dioxide, are commonplace in theatre environments.

Figure 2. Physical characteristics of N_2O cylinders



Cylinder pressure will remain stable until liquid in cylinder has been evaporated. Values from British Oxygen Company. Exact values may vary based on supplier.

HARMFUL EFFECTS OF N_2O

Environmental

N_2O is a powerful greenhouse gas, with an atmospheric lifetime of over 100 years, and is a major contributor to global warming. It also depletes the ozone layer.

The 100-year Global Warming Potential (GWP-100) of N_2O is 273 times that of carbon dioxide.[38] GWP-100 is the commonly accepted measure for understanding the impact of different gases on global warming.

Another metric reported by the Intergovernmental Panel on Climate Change (IPCC) is effective radiative forcing, and it has been recently argued in the anaesthetic literature that this may be a better metric to use when considering anaesthetic gases.[39] The debate over metrics is semantic and relates to how we should measure the global warming effect of halogenated volatile anaesthetic agents. In comparison, the evidence for environmental harm with N_2O is unanimously agreed. The radiative forcing effect of N_2O is significant due to its long stratospheric half-life and the high concentration of N_2O found in the atmosphere.[40]

Healthcare carbon emissions are considered in three “scopes”. Scope 1 refers to all direct emissions from a source that is owned by the organisation, Scope 2 refers to emissions related to energy purchased by the organization, and Scope 3 are emissions related to all products in the external supply chain.[41] Emissions related to N_2O that enter the atmosphere directly from a healthcare facility via clinical administration or leak are classified as Scope 1.

Due to the large volumes of N_2O purchased by hospitals, and its high 100-year GWP, N_2O is a significant contributor to healthcare emissions, accounting for 20% of the Scope 1 emissions of the Australian health system.[15]

Occupational health and safety

Chronic N_2O exposure has been associated with psychomotor, cognitive, hepatic and embryo-foetal adverse effects.[42,43] Both the United States National Institute for Occupational Safety and Health, and Safe Work Australia have recommended a safe occupational time-weighted average exposure standard of less than 25 ppm.[43,44]

Efforts to reduce staff exposure to N_2O in operating theatres have been successful with use of closed circuits, less frequent use, scavenging of anaesthetic gases and mandatory air conditioning standards. Australian Standards for operating theatres require 20 air changes per hour.[45] In comparison, high level exposure to N_2O has been documented in birth suites which poses a risk to staff.[34,46,47] The requirements for air changes in Australian birth suites has been significantly increased in the 2024 version of AS 1668.2, which many hospitals may not yet have implemented.[45] New Zealand follows the UK Health Technical Memorandum guidance also updated in 2024, which requires 25 air changes per hour for operating theatres, and 15 air changes per hour for birth suites.[48]

Benefit versus harm in 2025

The role of N_2O in anaesthesia has been explored thoroughly, and its routine use does not confer a benefit to patients.[49-52] Furthermore, it is known to inhibit vitamin B12, which can lead to neurologic toxicity and megaloblastic anaemia, and its use is associated with a higher risk of severe postoperative nausea and vomiting, and lower quality of recovery scores.[51] These findings, and alternative medications, have led to a widespread move away from N_2O use for maintenance of anaesthesia. This change in practice occurred before the general acknowledgement of environmental issues, and certainly before the extent of N_2O pipeline leakage was identified.[49,50,53,54] In 2025 the most common use for N_2O in operating theatres is for paediatric gas inductions and as a component of general anaesthesia for emergency caesarean sections.

N_2O outside the operating theatre has an established and ongoing clinical role for providing labour analgesia, and sedation for dentistry and paediatric procedures. Its safety profile and ability to be administered without intravenous access continues to confer significant benefits in these settings though research into alternative therapies is expanding.

N_2O PIPELINE LEAKAGE

N_2O leakage was first identified in 2020 by Chakera at NHS Scotland.[55] By assessing clinical use and procurement in three hospitals, they identified system loss of 83-100% from the pipeline infrastructure. By March 2021, 15 sites in the Lothian District had reported N_2O pipeline annual losses of 84-100%.[55] In Australia, local case reports have subsequently identified large N_2O leaks in their pipeline infrastructure (Table 2) using one or more of four key methods endorsed by the interim Australian Centre for Disease Control (Text Box A).[15]

Text Box A. Leak detection methods

1. *Discrepancy method*
   An estimation method to identify the discrepancy between purchasing volumes and estimated or measured administration volumes.
2. *Cylinder weighing method*
   Tracks the reduction in weight of a cylinder in a manifold bank and compares this to administered volumes for the same period (weeks to months).
3. *Pressure testing method*
   Similar to testing that occurs as part of pipeline commissioning. Tracks pressure in a fixed volume of pipework during a period of no clinical use. Can be done in small or large segments of the reticulated system.
4. *Flow monitoring method*
   Flowmeters are installed into key sections of the system to measure flow. If installed close to a delivery device it can measure administration volumes, or if installed at the manifold it can detect a system leak.

Table 2 summarises the publications regarding N_2O leakage. Many departments in Australia and New Zealand have performed internal audits that have not been published and reached similar conclusions.

Table 2. Summary of published reports of N_2O leakage from medical gas pipelines

	Year	Method	Annual leakage (L/year)	Individual site leakage (%)	Annual tonnes CO_2e due to leak
Australian/New Zealand					
Footscray Hospital, Melbourne[6]	2021	Discrepancy	160,000	75	75
The Alfred hospital, Melbourne[4]	2023	Cylinder weighing	197,789	83.5	100
Sydney Children's Hospital at Westmead[5]	2024	Flowmeter	273,312	50	563
International					
Tenon Hospital, APHP Sorbonne Université, Paris, France[42]	2019	Discrepancy	1,191, 892	87.5	600
NHS Scotland (multi-site study)[55]	2021	Discrepancy	13,771,800	83-100	37,462
University of San Francisco California/ Providence Health (multi-site study)[1]	2022	Discrepancy		47.2-99.8	5500
Greater London Network (multi-site study)[3]	2023	Discrepancy	5,311,852	51-100	2615

How did this major problem with the N_2O pipeline system remain undetected for so long? Despite meeting all Australian Standards maintenance and testing requirements, hospitals have shown through

specific testing using a method described above that they have a significant leak. One reason behind this inconsistency is that post installation the Australian Standards only requires relatively rudimentary testing for local leaks at outlets and regulators in the clinical care environment and do not address other areas of the pipeline enclosed within the building.[25] Another issue is that the system is tested in segments with equipment disconnected, rather than the dynamic system, as a whole. This will exclude leaks occurring in at the back bar, and seals at NIST or Sleeve Index S fittings. In effect, the current standards are not appropriately sensitive.

The piped N_2O system is prone to leakage at many points, where much of it is enclosed in building walls or ceilings that is difficult to inspect, maintain and repair. N_2O molecules can escape well maintained systems through various points. Sites of leakage that have been identified include diffusing through flexible pipeline hoses that connect anaesthetic machines to the terminal wall outlet, flexible pipeline in operating theatre pendants, sections of pipeline in high-vibration areas such as near medical imaging equipment and terminal wall outlets.[6,56,57]

Current infrastructure relies on a pressurised gas system to pipe large volumes of N_2O throughout the hospital buildings, while modern anaesthesia practice uses only small volumes of the gas. Leaks of 500-1000 ml/min from a hospital pipeline can account for most of the facility's total N_2O consumption and subsequent N_2O related emissions. The financial gains of transitioning will depend entirely on the leak rate of a facility. One example, the Prince Charles Hospital in Queensland, Australia, expect a return on investment of two years after decommissioning.[58]

DECOMMISSIONING N_2O PIPELINES

Testing a pipeline for leaks can be helpful to demonstrate the issue to a healthcare service, but in our experience testing beyond the discrepancy method is arduous, time consuming and costly. Institutions can instead move straight to implementing a point-of-care cylinder solution and decommissioning their N_2O pipeline.

As of March 2025, a small number of Australian and New Zealand healthcare facilities have already decommissioned their centralised N_2O pipeline supply, with a greater number of international locations performing this evidence-based intervention (Text Box B).

Table 3. Reports of decommissioned N_2O piped medical gas systems

International sites	Sites decommissioned (n)
NHS Scotland[59]	27
NHS Wales[16]	6
Providence Healthcare[1]	25
Tenon Hospital[2]	1
Australian sites	
Prince Charles Hospital[58]	1
Broome Hospital	1
Sir Charles Gairdner Hospital	1
Modbury Hospital	1
Aotearoa New Zealand Sites	
Christchurch Public Hospital – Riverside	1
Burwood Hospital	1
Dunedin Hospital (except Birth Suite)	1

Environmental benefits reported from the decommissioning of pipeline systems are large, as would be expected given the size of the measured leaks. Across the UK, the NHS has reported a reduction of over 37,000 tonnes of carbon dioxide equivalents from piped N_2O emissions from 2018 to 2023, with no increase in portable emissions over that timeframe.[16] In the US, decommissioning by 25 hospitals across two health systems have mitigated more than 5500 tonnes of N_2O related greenhouse gas emissions annually.[1]

Unfortunately, N_2O is cheap and financial benefits of decommissioning N_2O pipelines are modest until a carbon price is considered. Though a change to point-of-care cylinders is not expensive, this lack of substantial financial savings may reduce the incentive to healthcare facilities to invest this change. As discussed, centres with high leak rates will benefit the most from this project. Financial savings will occur through decreased maintenance and decreased building costs of new buildings if N_2O pipework is excluded.

Other benefits for hospitals to consider include improved occupational safety, and the benefit of increased mobility for labouring women by having a portable N_2O supply in the birthing suites. It may also reduce the risk of patient death due to administration of hypoxic gas from a cross-over error.[60,61]

There are no reports of a hospital moving to point-of-care cylinders and increasing N_2O related emissions. There are also no reports of patient harm or near misses. Healthcare facilities can retrospectively determine the extent of the leak based on purchasing reduction over time after decommissioning.

CYLINDER BASED SOLUTIONS

Development of a resilient point-of-care solution requires three phases: assessment, establishment of portable supply, and decommissioning.

Assessment phase

Management of N_2O related emissions requires a collaborative multidisciplinary approach.[1,11] To answer five key questions (Text Box C), a working group including all major stakeholders should be assembled early (Text Box D). It is important to build an agreed shared vision and strategy with all members of the project team. A suggested goal is "to provide N_2O to necessary clinical areas in the least wasteful method possible while ensuring safety". Time and patience may be needed, particularly when there may be competing interests, such as when public-private partnerships exist with long term fixed contracts. Improving government regulation and carbon emission reduction targets would help to provide incentives to healthcare facilities in this area.

Text Box B. Questions for N_2O needs assessment

1. Where is N_2O piped to?
2. Where is N_2O required?
3. How much N_2O is purchased?
4. How much N_2O is required to supply each clinical area?
5. What equipment is required for each clinical area?

Text Box C. Working group membership

1. Project lead
2. Clinician stakeholders
   a) Anaesthesia
   b) Emergency
   c) Obstetrics
   d) Midwifery
   e) Paediatrics
3. Biomedical engineering
4. Facilities management
5. Medical gas supplier
6. Hospital sustainability officer
7. Procurement
8. Senior hospital leadership

Establishing portable supply phase: point-of-care cylinders

Implementing a point-of-care cylinder approach requires significant project management skills, but the physical work is not complex. Ongoing quality cycles will enhance this process. N2O compatible equipment must be used, including Pin Index Safety Systems and NIST or Sleeve Indexed Bayonet fittings. ANZCA PS54 provides guidance on minimum safety requirements for N_2O administration.[62]

Anaesthesia machines

To supply N_2O via an anaesthetic machine there are two options: cylinders connected directly to the back of the anaesthetic machine via an inbuilt yoke, or a portable cylinder with a 400 kPa regulator, to allow a connection similar to wall outlets, via a flexible hose with Sleeve Indexed Bayonet fittings.

1. Inbuilt N_2O yokes

Many anaesthetic machines have capacity for up to three cylinders to be connected via inbuilt yoke.[35,63] If not already in place, these can be ordered when anaesthetic machines are upgraded or can be retrofitted for $500-2500 per machine.[1]

Inbuilt yokes are familiar and N_2O is immediately available. Cylinders should be installed to the back of all machines, or high frequency use locations until review demonstrates that this is oversupply. A cylinder plug needs to be installed when a cylinder is not installed to avoid entrainment of air through imperfect seals. Cylinders stored in the open position will slowly leak, whilst closed cylinders do not.[1]

When this system is used, a low-pressure alarm will occur at 2633 kPa for GE machines, which correlates to about 70 L remaining in an A or C cylinder (see Figure 2).[64] This should give ample warning (280 minutes at 250 mL N_2O per min, or 14 minutes at 5 L N_2O per min) to allow a cylinder change.

2. Portable N_2O trolley systems

A portable N_2O system that can act as a surrogate medical gas pipeline consists of a cylinder with cart, a regulator and hosing with Sleeve Indexed Bayonet fitting (Figure 3). When required, this apparatus is wheeled into theatre and connected to the N_2O inlet at the back of the anaesthetic machine. In this system, pressure regulation to 400 kPa occurs prior to the machine via the yoke and regulator. There is an analogue Bourdon pressure gauge and no audible alarm. A D or D2 cylinder will start to depressurise once the volume remaining is approximately 460 L (Figure 2). The first audible alarm will vary between each machine, with alarms being triggered occur when the pressure reaches 180-260 kPa.[64] At this threshold, there is approximately 25 L of N_2O in a D cylinder, providing enough warning to allow for a cylinder change.

Figure 3. Portable N_2O trolley systems

Example of portable N_2O trolley system demonstrating a D-Cylinder, regulator and hosing. Photo courtesy M. O'Shea and K. Williams. The Prince Charles Hospital, Queensland.

Table 4. Comparison between inbuilt yoke and portable trolley systems for point-of-care N_2O

Portable N_2O supply	Inbuilt yoke	Portable trolley
Upfront cost	$500-2500 per machine	Minimal
Cylinder size	A/C	A/C or D/D2
Number of cylinders required	One per machine	Department dependant
Alarms	Audiovisual Cylinder Pressure Alarm 2633 kPa for GE	Audiovisual Pipeline Pressure Alarm Visual "Low" on Pressure Gauge 180-260 kPa
Volume remaining when alarm reached	70 L (C Cylinder)	18-26 L (D Cylinder)
Advantages	Intuitive and familiar Avoids flexible N_2O hose/attachments More warning of low N_2O supply	Larger capacity possible Requires active decision to employ N_2O
Disadvantages	Cylinder changeover takes about 1 minute Cylinder plugs required if cylinders no longer installed Pressure alarms set by manufacturer	Shorter warning time Extra piece of equipment in theatre environment Extra step in clinician workflow.

Non-operating theatre locations

Locations that use blenders can adapt to portable N_2O supply easily, and some require no equipment changes at all. These systems usually rely on visual pressure gauges to detect when cylinders need to be changed. This provides an opportunity to review practice and determine if N_2O blenders or Entonox cylinders would be a more suitable choice.

Emergency departments have adapted from piped N_2O without issue. Birthing units that use portable systems report excellent patient satisfaction as it allows patients increased mobility (Figure 4).

Figure 4. Portable N_2O and oxygen blender in use at Broome Regional Hospital Birth Suite

Photo courtesy of P Mareyo. Broome Hospital, WA

OTHER CONSIDERATIONS

Scavenging

Any delivery of N_2O without an anaesthesia machine must also consider how the exhaled or administered drug is scavenged. A suggested scavenging system in procedural spaces is a bassoon-scavenger (Figure 5) which can accept a volume of exhaled air while scavenging the bassoon-shaped container at a constant rate.[65] Use of a demand valve for N_2O in birthing suites can reduce the amount of N_2O wasted and can reduce exposure to other personnel in the room.

Figure 5. The Bassoon-style scavenging setup in birth suite at Flinders Medical Centre, South Australia

Photo courtesy of J Duke. Southern Adelaide Local Health Network, SA

Cylinder storage

Sufficient portable N_2O cylinders will need to be stored in an area that will be compliant with storage of an asphyxiant and medical gas systems.[25,66] A practical solution is a larger supply in an external area, with a smaller supply in a suitable internal location. N_2O is a Schedule 4 drug and is subject to national storage and administrative requirements. A dangerous goods consultant may be required to approve the designated storage areas. Supply chain disruption is a consideration for remote or more vulnerable locations.

Detecting filling status of a cylinder

As cylinders returned to the supplier are vented to the atmosphere before being refilled, the balance between returning partially full cylinders and running empty mid-case needs to be struck. While the decision to change a cylinder during theatre use ultimately lies with the anaesthetist, a system that reduces intraoperative changes is preferable and is likely to still be less wasteful than piped N_2O.

The three methods of checking the contents of a cylinder are pressure, weight and percussion. Pressure monitoring is the most straightforward, but departments need to consider the pros and cons of each and provide education.

Pressure

When the pressure in a cylinder is between 4600-5200 kPa there will be liquid remaining in the cylinder. As N_2O is withdrawn, liquid will evaporate inside the cylinder and the cylinder will cool. Only once all of the liquid contents have evaporated does the cylinder pressure drop below 4600 kPa. This occurs after 87% of the gas has been withdrawn (Figure 2).[35,67] During the vapour phase of emptying (that is, no liquid remaining), the pressure will fall linearly in the same manner as an oxygen or air cylinder according to Boyle's law. Low pressure alarms for GE anaesthesia machines are triggered at 254 kPa for pipeline or 2633 kPa for cylinders.[64]

Percussion

A percussion test is used to determine the tone change and identify the fluid level in the cylinder. Starting from the bottom, the cylinder is struck with an instrument until the tone changes from dull to resonant. This fluid level can be tracked over time.

Weight

The weight of gas remaining in a cylinder is the most accurate method of determining the volume of gas remaining. The gross, tare and net weights of all the cylinders are known, with 1 kg of liquid N_2O equivalent to 534 L at sea level and room temperature. The weight of a cylinder can be tracked over time. This method requires cylinders to be disconnected from equipment and is cumbersome if cylinders are heavy, or if multiple require weighing.

Table 5. Methods of detecting volume of N_2O remaining in cylinder

Method	Advantages	Disadvantages
Pressure	Most reliable method to detect depressurisation	Portable regulators do not have auditory alarm Pressure is constant during liquid phase of cylinder emptying
Percussion	Cylinder can remain connected to equipment Can be performed as often as required	Requires interpretation Interindividual variability No tone change once fluid evaporated
Weight	Most accurate	Requires excess equipment Requires cylinder to be disconnected from delivery device

Decommissioning pipelines phase

Decommissioning the reticulated N_2O supply can occur once a resilient portable system has been established and tested in the relevant clinical areas. Formal approval from hospital executive and the head of each affected department is necessary prior to works on the medical gas pipeline system. The following steps need to be considered and conducted by suitable personnel.

Text Box D. Steps in deactivation of central supply

1. Update the map of existing N_2O network
   a. Deactivation of N_2O alarm systems
   b. Manifold – change over alarm and line pressure alarm
   c. Isolation valve box alarms
   d. Theatre – medical gas panel alarms
2. Isolation of the N_2O supply to building
3. Vent the outlets
4. Plug the N_2O gas outlets to make them inoperable
5. Apply "decommissioned" labels to all N_2O outlets, isolation valves, manifold and emergency connection inlets.
6. Return hired manifold cylinders to supplier

Pipelines may remain in situ, but the decommissioned status must be labelled clearly at outlets (Figure 6) and the manifold to ensure the infrastructure is not inadvertently used. Purpose-built "decommissioned" fixed outlets may soon be available.

Figure 6: Decommissioned N_2O outlet

Photo courtesy M.O'Shea and K. Williams. The Prince Charles Hospital, Qld

UNRESOLVED ISSUES

Birth suite

Most N_2O clinically administered in Australia and New Zealand is delivered by non-anaesthetists to provide labour analgesia in birth suites. RANZCOG supports decommissioning N_2O manifolds, referencing internal audits demonstrating leakage. With the current evidence base it is not yet clear if birth suites would be better served by limited piped N_2O and central destruction devices, portable N_2O blenders with or without destruction or a combination thereof.[68,69] Portable N_2O is the method of delivery in Broome Hospital and reports of high patient satisfaction are encouraging. More research and education to determine the best path forward in this area is necessary. It is worthwhile noting that when asked, some patients would have changed their analgesic choice based on the environmental impact.[70]

Quaternary paediatric centres

N_2O is used by many clinicians as part of paediatric gas inductions and procedural sedation. Paediatric centres with multiple anaesthetising and procedural locations throughout the facility will require the most investment to change. Each centre will need to evaluate their usage volumes and patterns to determine the most suitable solution. There is growing consensus that N_2O is not required for successful and atraumatic paediatric gas induction.[71]

Hazards

Diversion of N_2O for use as a recreational drug of abuse is a common concern raised when considering decommissioning. Our opinion is that this risk is likely to be lower with portable supply than with piped systems. As N_2O is a Schedule 4 drug, it should be secured appropriately and records kept. Medical gas companies are obligated to ensure that delivered stock is returned. As such, there is a greater likelihood of being able to detect misuse with point-of-care cylinders than with the current unmonitored outlets. Anecdotal reports of patients and support persons self-administering N_2O from wall outlets are very common. Removing piped N_2O also reduces the risk of cross connection while, whilst rare, can result in fatalities.[60,61]

FUTURE DIRECTIONS

N_2O is becoming less relevant in anaesthesia due to the availability of faster acting intravenous and volatile agents. Challengers to N_2O in the procedural sedation sphere include intranasal agents and inhaled methoxyflurane.[72,73] Methoxyflurane has historically been used in labour and more recently as a bridge to epidural.[74]

Destruction of waste and exhaled N_2O, which reduces the environmental and occupational hazard, may be a path to ensure continued acceptability of this agent.[46] Central and portable N_2O destruction units are in use in Europe, scavenging waste N_2O at point of care or centrally.[68,69] These “nitrous cracking” devices break N_2O into N_2 and O_2, however they rely on the exhaled N_2O being scavenged to the destruction device and are unable to process gas contaminated with volatile agents.

N_2O cylinders are returned to the medical gas company with residual N_2O. Current practice, for regulatory reasons, is to vent the remaining drug in the cylinder to the atmosphere before the cylinder is refilled. In our opinion, medical gas companies have an ethical obligation to pass this waste gas through N_2O destruction units and avoid this emission event entirely.

SUMMARY

N_2O has a long and important history in anaesthesia and pain medicine but is notorious now as a greenhouse gas leaking millions of litres annually from hospital infrastructure. Health services have an obligation to control these leaks by going back to the future and implementing point-of-care cylinders and decommissioning N_2O pipelines.

Thank you to members of the Main Manifold Group for contributions and expertise.

Appendix A. Key physical characteristics of N_2O

Sweet-smelling, colourless, tasteless gas	
Molecular weight	44.01
Boiling point 1ATM	-88.5°C
Density gas 0°C 15°C 21°C Density liquid 1ATM	1.977 kg/m3 1.947 1.88 kg/m3 1227 kg/m3
1 kg liquid N_2O is the equivalent to 534 L	
Critical temperature	36.5°C
Blood/Gas coefficient	0.47
Oil/gas partition coefficient	1.4
MAC	105%
Non-flammable, but supports combustion Oxidising agent	 Oxipotential 0.6 (100% O2 = 1.0, Air = 0.21)
100-year global warming potential	273

Appendix B. Estimated cylinder requirement and emissions per episode

Based on Australian D cylinder (3520 L) and Australian C cylinder (935 L) allowing for 10% wastage

Type of episode	Estimated N_2O per episode (L) (74)	Episodes per C cylinder	Episodes per D cylinder	CO_2e (kg)	Equivalent emissions from car travel (km)
Paediatric gas induction	50	17	64	25.5	180 km
One hour maintenance anaesthesia at 500 mL/min @50%FiN_2O	15	56	213	7.65	52 km
One hour maintenance anaesthesia at 2 L/min 50%FiN_2O	60	14	53	30.6	208 km
Paediatric sedation in ED	60	14	53	30.6	208 km
Labour analgesia	500	1.6	6	255	1740 km

Conversion from CO_2e to kilometres based on 2021 average petrol passenger car in Australia (146.5 g/km)[76]

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