

Anaesthesia — “A Modern Concept”

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On October 16, 1846 at the Massachusetts General Hospital, Thomas Morton gave the first successful public demonstration of general anaesthesia. He anaesthetised Edward Gilbert Abbot, so that John Warren could remove a vascular tumour from the left side of his neck. Warren then uttered the famous words, “Gentlemen, this is no humbug.” From that moment, the use of ether anaesthesia spread around the world and surgery was revolutionised. Thus, Thomas Morton is commonly honoured as the “discoverer of anaesthesia” and October 16, 1846 as the date of the birth of anaesthesia. Unfortunately, this is not true and simply confirms that those who publish first are most likely to have their ideas adopted. Once a fiction is established, it is difficult to reverse. The real honour of discovery belongs to Crawford Long who, on March 30 1842, gave the first successful ether anaesthetic in Jefferson, Georgia. Unfortunately for him, Long did not publish his results until 1849 and history barely records his efforts, although his statue stands in Washington’s Capitol building as one of Georgia’s two most famous people.

As an aside, Crawford Long also submitted the first anaesthetic bill in history. He charged \$2.00 for the surgery, which he also performed, but only 25 cents for the anaesthetic. So started the historical imbalance between surgical and anaesthetic fees which exists to this very day. Perhaps Long really does deserve little honour!

Oliver Wendell Holmes first coined the term “Anaesthesia” in 1846 as a single word to apply to the newly described state. The Professor of Anatomy and Physiology at Harvard, Holmes is better known as a humorist and poet. Soon after this, in 1847, Plomley¹ described three stages of anaesthesia in a letter to the *Lancet*. He wrote, “I have breathed the ether on several occasions, and think its effects may be divided into three stages or degrees, the first is merely a pleasurable feeling of half intoxication; the second is one of extreme pleasure, being similar to the sensations produced by breathing nitrous oxide, or laughing gas; ... The third stage, the only one, I think, for performing operations in, is one of profound intoxication and insensibility.” Later that same year John Snow, the first physician anaesthetist, wrote, “I shall divide the effects of ether into five stages or degrees; premising, however that the division is, in some measures, arbitrary — that these different degrees run gradually into each other, and are not always clearly to be distinguished.”² The concept of “depth of anaesthesia” was born from Snow’s ideas.

Arthur Guedel was a young doctor who served with the American forces in World War I. He was put in charge of the anaesthetic services for the US Army in Vosges,

France. As there were few doctors involved, it was necessary for non-professionals to give ether anaesthesia and Guedel provided supervision by rounding between the hospitals on a bicycle! To ensure the safe administration of ether, he devised a system for checking on the patient's condition. After his return to the US, Guedel published his first article on the "Signs and Stages of Ether Anesthesia" in 1920,³ followed by a book in 1937.⁴ His vertically oriented tables fitted neatly with the concept of "depth", with a progression from awake, through stages of anaesthesia and, finally, to death. The stages were described by a series of observations based on breathing, muscle relaxation, pupils, lacrimation and eyelid reflexes.

Artusio in 1954⁵ refined this further, describing three planes of Stage 1 of ether anaesthesia (Table 1). He referred to Plane 3 as "Amnesia Wakefulness". Cardiac surgery could be performed whilst patients were in this state!

Table 1
Planes of stage 1 of ether anaesthesia

Plane 1	No Analgesia	No Amnesia
Plane 2	Partial Analgesia	Total Amnesia
Plane 3	Total Analgesia	Total Amnesia

In 1950, Rees and Gray⁶ published their seminal paper in which the famous "triad of anaesthesia" was described. This was said to consist of narcosis, relaxation and analgesia. The concept is still taught today and anaesthetists commonly refer to giving patients "analgesics" during an anaesthetic. Interestingly, the concept was mentioned as an aside in the paper, which was about the anaesthetic effects of methyl-n-propyl ether. The sole reference to the "triad" was a single sentence, "It might, however, give the drug a certain value in a balanced anaesthetic when a relaxant is used to complete the triad of relaxation, narcosis and analgesia". There is no discussion around this concept, and I can find no other reference to it, until another paper by Gray and Rees in 1952.⁷

They start this paper by saying, "There has been widespread support for the concept which views anaesthesia as a triad", although they provide no references to support this assertion. In the paper, they described the "Liverpool Technique" combining the use of a muscle relaxant, nitrous oxide and hyperventilation. The conclusion suggests: "The time has come, in our opinion, to substitute for the triad principle of anaesthesia outlined at the beginning of this paper a tetrad, which can be regarded as a pyramid which has a base apnoea upon which are constructed the sides of the pyramid — narcosis, relaxation and analgesia." Whilst the "triad" and the "Liverpool Technique" became popular, the "tetrad" does not appear to have resonated with the anaesthetic community; this is the only reference to the "tetrad" I could find.

In 1960, Mushin⁸ noted, "One of our commonest phrases is 'depth of anaesthesia'. We speak of getting the patient 'deeper', of getting him 'under', of getting him 'down'. All these words imply movement in a vertical direction: towards the grave." The vast majority of anaesthetists still use these terms. Virtually all medical students are taught about "depth of anaesthesia" and, as a consequence, all our surgical colleagues use the term as well. The famous "triad" is usually taught as part of this anaesthesia education as well.

Once this concept of depth had become firmly entrenched in the minds of anaesthetists, the search was on to find a measure of it. For if only we could measure

it, we could then “scientifically” deliver it! A huge range of possible “measures” have been studied, from clinical scores (PRST), EEG (and processed derivatives especially the BIS), evoked potentials (auditory mid-latency potentials being the most popular), EMG (frontalis muscles), skin vasomotor tone and lower oesophageal sphincter tone. The search continues today, with a myriad of articles published each year on “depth of anaesthesia”. A Medline search done in preparation for this manuscript, using the words “depth” and “anaesthesia”, revealed more than 350 articles published in the last ten years. Many of these strived to deliver better and better measurements of “depth”. In an erudite paper discussing the ways in which one might statistically derive a measure of depth of anaesthesia, Smith et al⁹ talk in an abstract manner of this being “judged against a gold standard indicator of anaesthetic depth”, without in any meaningful way discussing what the term might mean.

Interestingly, whilst “depth” is still the dominant paradigm (a collection of beliefs shared by scientists), a more logical way of dealing with the problem of “anaesthesia” has arisen in parallel, although this has not succeeded in supplanting the old ideas. In 1957 Woodridge¹⁰ wrote, “How deep is this patient? That question has become more puzzling as time goes by.” He suggested that there was not a single entity of anaesthesia, but that it could be broken into several components, which he called “nervous depression” of sensory, motor, reflex and mental systems. Unfortunately, at the end of this article he decided that “anaesthesia” was not even the best word and proposed that “northria” (a Greek word meaning torpor) was more appropriate and that we should all be called “Northrotists”! Whilst this may have been easier for the average patient to say and spell, it failed to have a lingering effect in our field.

Cecil Gray published the single most important article on the concept of “Depth of Anaesthesia” in 1960.¹¹ In this article, he debunked the whole concept of “depth”, in particular producing a demolition of many of the “signs” put forward by Guedel to indicate stages and planes. He proposed a modified “triad”, consisting of “narcosis” (unrousable unconsciousness), “reflex depression” (replacing “analgesia”) and “relaxation”. Amazingly, for a man so influential in this whole debate, he chose to recant his previous views in the *Irish Medical Journal*. It was almost as if he were somehow ashamed of his previous views and, whilst wishing to come clean on the issue, did not want to make it a very public retraction. Not surprisingly, I have never seen this article quoted in any article dealing with this topic! Others have written since then questioning the validity of the term “Depth of Anaesthesia”.¹²⁻¹⁷ Amongst them; Pinsker¹² suggested, “... paralysis, unconsciousness, and attenuation of stress response. This is complete anesthesia.” This view is remarkably similar to that of Gray’s, which he does not quote.

Developing this theme, Prys-Roberts¹³ stated, “There cannot be degrees of anaesthesia, nor for that matter can there be variable depths of anaesthesia. The continuing search for some method to measure anaesthetic depth resembles that for the Philosophers Stone.” Kissin¹⁴ agreed regarding the search for a single measure of anaesthetic depth. He suggested that anaesthetic action consisted of “different actions used to achieve variable goals of anesthesia”. In a paper titled “Monitoring Depth of Anaesthesia”, Schneider and Sebel¹⁵ wrote, “In the modern practice of anaesthesia, the term ‘depth of anaesthesia’ and the definition of stages are irrelevant. Anaesthesia is not ‘deep’ or ‘light’: it may or may not be adequate.” Why they then gave the article the title they did is a little harder to understand. With similar thinking to Kissin, Eger¹⁶ felt that there were two components to anaesthesia, “immobility” and “amnesia”,

suggesting that each resulted from actions at separate anatomical sites. Despite these ideas, the search continues for the measure of “depth of anaesthesia”. Kissen¹⁷ recently stated, “the term depth of anesthesia becomes irrelevant for major components taken together ... (but) it could still be relevant for each of the components measured separately”.

It is clear that the paradigm started in 1847 is hard to break. How are we to deal with this issue in a way that will allow us to deliver anaesthesia in a logical manner?

In order to communicate we need to define some terms

The most fundamental of these is the question of consciousness. Many textbooks have been written on this topic, despite the simple statement of Rene Descartes (1596-1650), “I think therefore I am”, as a self-evident truth. William James (1842-1910), the American philosopher and leader in the philosophical movement of “pragmatism”, stated in 1892,¹⁸ “Everyone knows what consciousness is until he tries to define it”. Stanley Cobb used the definition “Awareness of environment and of self” in 1948.¹⁹

From a contrary viewpoint, Feldberg²⁰ suggested, “There is no need to define unconsciousness. We all know what it means”. I think that, for the most part, that this statement is true. We all see our family asleep each night and can usually judge if they are unconscious. Sleep is a physiological (as apposed to pharmacological) state of unconsciousness from which we can be roused. However, it must be conceded that, at its most fundamental level, the interpretation of whether or not someone is conscious is an internal one; i.e. we assume someone is unconscious when they fail to respond to some stimuli by interacting with us in a purposeful manner, for example, by opening their eyes to command. But what if a person chooses not to respond? They would then be clearly conscious, but we would not be able to determine this. We could also imagine a circumstance in which a person could be aware of themselves but not of their environment, as in a sensory deprivation tank. Also, if a person is unable to respond when paralysed, then it becomes very difficult to determine if indeed they are conscious.

The definition that I prefer to use is:

Consciousness **Awareness of one’s self**

therefore:

Unconsciousness **Loss of Consciousness**

Now whilst a person may be unconscious, it does not mean that he or she cannot be roused (made conscious) by some stimuli. Rousability is a separate, although related, issue.

Rousable **Someone unconscious can be made conscious by stimulation, e.g. talking, shaking.**

“Pain” is, in some ways, a prototypical conscious experience. Certain stimuli (noxious) will produce “pain” in the conscious person in addition to reflex responses. We can use the following definition:

Pain: **The (usually) unpleasant sensation associated with actual, potential or perceived tissue damage.**

I say “usually unpleasant” because there is that small subset of the community who finds pain pleasurable! As well, “pain” does not have to be associated with tissue damage. Indeed, as a protective mechanism, it should occur in situations before tissue damage occurs, so this can be prevented by the person’s response to the “pain”. There

are also situations where the person perceives “pain” when no actual or potential tissue damage exists, e.g. phantom limb pain or during application of an electrical current as a torture mechanism. (Provided the current is not excessive, this will produce no damage at all, e.g. a nerve stimulator’s tetanic setting). “Pain” is simply the conscious interpretation (or sensation) of these neural signals.

Analgesia: **The relief or prevention of “pain”.**
Nociceptive: **The nervous impulses associated with tissue damage. These produce “pain” (in the conscious patient) and reflex responses.**

Aims of General Anaesthesia

There are really only two aims for general anaesthesia:

1. Narcosis, or unrousable unconsciousness

Unconsciousness must surely be the first and most important aim for a general anaesthetic. However, that alone is insufficient as the patient must also be unrousable. Sleep, from which one can roused, should be clearly seen to be different. There may be times when it may not be possible or safe to achieve unconsciousness, eg during surgery for ruptured aortic aneurysm.

“Amnesia” (the failure to remember events that occurred when the patient was conscious) and “Analgesia” (as defined above) are often stated to be aims. However, these clearly imply that the patient is conscious; if we accept the first aim, then these terms have no meaning in the setting of general anaesthesia and so should not be used. We may give substances during an anaesthetic so that the patient will awake pain free, but we are not giving them as analgesics during the general anaesthetic. Opioids given during “general anaesthesia” are primarily used as reflex depressants (see later).

Similarly, there may be times in which we would wish a patient to be amnesic (during the performance of a difficult block). However, if we aim to have an unconscious patient, then amnesia is not an aim as such during “general anaesthesia”. (Of course, all drugs that produce unconsciousness will also produce amnesia in lower doses.)

Consciousness is a quantal response, one is either conscious or not. One should not confuse the difficulty in determining whether or not a paralysed patient is conscious with its quantal nature. If unconscious, then one may be either “rousable” or “unrousable”, depending on the particular stimulus. Scott and White²¹ have pointed out that many Sedation Scores are, in fact, measures of rousability. Table 2 shows a typical sedation score:

Note that the patient is actually conscious only with a score of 4 or 5. With scores of 3, 2, or 1, the patient is unconscious but “rousable”. With a score of 0, they are “unrousably unconscious” (the primary aim of general anaesthesia). What physicians and neurosurgeons mean when they speak of a “deeply unconscious” patient is that the

Table 2
Sedation score

5	Responds readily to spoken word in normal tones
4	Lethargic response to name spoken in normal tones
3	Responds only after name is called loudly and/or repeatedly
2	Responds only after mild prodding or shaking
1	Responds only after painful trapezius squeeze
0	Does not respond to painful trapezius squeeze

patient is “unrousably unconscious” and has a variable degree of reflex depression, i.e. flexor or extensor responses only. The conscious patient’s level of mentation, (e.g. oriented, alert, confused) can be assessed, but these are not measures of consciousness; rather, they are measures of higher cortical function.

Induction of anaesthesia is first and foremost about rendering the patient “unrousably unconscious”. One determines this by the same means we assess whether someone is conscious in any other non-medical setting, by talking to the patient. The common habit of trying to determine if the eyelash reflex has gone is clearly not appropriate, as not only is it a test of a reflex (and therefore unrelated to consciousness) but is also unpleasant should the patient actually be conscious.

2. Reflex Depression

Whilst a patient may be “unrousably unconscious”, this is not sufficient for general anaesthesia. The same nociceptive impulses that would have produced pain had the patient been conscious may also produce other non-conscious (or reflex) responses. Reflexes are, by their very definition, non-voluntary responses and so have nothing whatsoever to do with consciousness. Again, we should not get confused about the separate nature of the aims just because we commonly give drugs that may produce both “unrousable unconsciousness” and “reflex depression”.

Reflexes can be classified into:

Motor Reflexes, e.g. movement, coughing

Autonomic Reflexes

Cardiovascular, e.g. BP and HR changes

Neuro-endocrine, e.g. cortisol, vasopressin increases

These can be modified at any point in the reflex arc, consisting of a receptor organ, an afferent limb, central processing area (spinal, brainstem, cortical), an efferent limb and an effector organ, (e.g. skeletal or vascular muscle, heart, endocrine gland).

There is no pre hoc way of describing reflex responses; one can only say whether a response has occurred and, if so, to what degree. The reflex arc can be interfered with at any one (or more) of the points in the arc. We may very specifically block particular reflexes (e.g. neuromuscular junction (NMJ) blockers for motor reflexes or beta-blockers for HR responses) whilst leaving others unaffected. We might also use agents, e.g. opioids, which have their major effect by blocking central processing (spinal cord, brainstem).

The responses can clearly be graded, but each reflex type has different responses to different drugs and differs between patients, as demonstrated by MAC and MAC BAR.²² Sometimes, one reflex will be blocked whilst another is present, as with a patient whose BP increases with incision, but who does not move because paralysed. Some patients will cough on incision as the sole motor response. There is a multitude of reflex responses, each with its own pathway and intermediate relays and neurotransmitters. The neuro-endocrine responses, in particular, are especially varied, although not able to be measured easily at the time of anaesthesia and surgery.

Clearly, as reflex depression has nothing to do with consciousness, or lack thereof, and as we can break reflex responses into component parts, each of which can be blocked separately, it is impossible to have a single measure of all these things. Hence, there can be no such thing as “depth of anaesthesia” and, philosophically, if it does not exist it cannot be measured.

It is also now clear that the effects of anaesthetic agents in producing

unconsciousness and interfering with reflex responses, occur via differing mechanisms, with the movement responses being, to a large extent, mediated at a spinal cord level.²³ Thus, there are pharmacological as well as physiological reasons to consider reflex depression as a separate aim to unrousable unconsciousness, even if both are achieved with the one drug.

Decreased Muscle Tone

The literature has got itself confused in this area. Authors often use the term “muscle relaxation” as a requirement of anaesthesia. However, what is really meant is a lack of motor response to surgical and anaesthetic stimuli (motor reflex depression). Provided a patient does not move during a procedure, then a decrease in muscle tone is not always needed, e.g. during breast biopsy. There are many occasions when a decrease in muscle tone is needed, but it is not a universal requirement. When needed it can be achieved in a number of ways. Muscle tone is a function of:

1. efferent (motor) nerve activity,
2. neuromuscular junction activity, and
3. muscle function/ mass/ resting fibre length.

We can decrease tone by interfering with one or more of these. However, we are only able to objectively measure the second mechanism, with nerve stimulators and either the force or EMG response to the stimuli, as with the Train of Four response. There are many clinical situations where the muscle tone is low without any pharmacological intervention, e.g. spinal cord injury (decreased efferent activity), myasthenia gravis (inadequate neuromuscular junction function), myopathies (poor muscle function), the cachectic patient (decreased muscle mass) and post-caesarean section (abdominal muscles lax due to loss of stretch). In these situations, no pharmacological intervention may be needed to provide the low muscle tone that surgery may require.

Clearly, we need to consider decreased muscle tone as a separate, but not always necessary, part of the anaesthetic care of the patient. It is not a part of “general anaesthesia” per se. A decrease in muscle tone is highly dependant on the mechanisms by which a particular drug achieves this and different patients will respond quite differently. One needs to think clearly as to how one might achieve a decrease in muscle tone (if indicated) and how one might monitor it. Whilst many drugs that interfere with motor reflex responses at the spinal cord level or higher will also tend to decrease efferent motor activity and, hence, decrease muscle tone (volatile agents), some (e.g. opioids), may actually increase muscle tone and cause rigidity in high doses. Depolarising and non-depolarising NMJ blockers are commonly used to achieve a decrease in muscle tone and their effects should always be monitored with a nerve stimulator.

It must be remembered that the muscle tone achieved will be a function of all the factors listed above, not just the function of the neuromuscular junction. A patient with a high P_aCO_2 may show diaphragmatic movement, even though they have barely one twitch visible in response to a TOF stimulus. The most appropriate response for the anaesthetist could be lowering the P_aCO_2 or giving opioids or other respiratory depressants, rather than just giving more NMJ blockers.

Conclusions

Consciousness is a quantal phenomenon, rousability can be graded, reflexes are quite independent of consciousness and reflexes themselves, whilst gradable, come in

a multitude of forms many of which can be individually depressed. As a consequence, there can be no single measure of “depth of anaesthesia”; this is a philosophically meaningless term and cannot possibly be measured.

As Prys-Roberts¹³ wrote, “the search for a measure of Depth of Anaesthesia is the modern day equivalent of the search for the Philosopher’s Stone”. Those who keep up with the latest literature will know that the Philosopher’s Stone was destroyed by Professor Dumbledore to prevent the evil Lord Voldemort from acquiring it (Harry Potter and the Philosophers Stone, 1997). With the stone gone, it is time for us to abandon the long lived and futile search for it and the related depth of anaesthesia.

1. As Gray wrote¹¹ in 1960 (and was ignored):

“I suggest that these concepts ‘stages of anaesthesia’ and ‘depth of anaesthesia’—no longer serve any useful purpose and should no longer be taught. I believe that they should be relegated to the museum, already crowded, for outworn concepts ...”

2. One should therefore describe the patient in terms of the aims described above.

3. General Anaesthesia can thus be defined as: **A reversible iatrogenic state characterised by unrousable unconsciousness and reflex depression.**

By logically dealing with every general anaesthetic in this way, one can then deal appropriately with the management of each patient. By ensuring that the patient remains unrousably unconscious and their reflex responses are depressed (usually so they don’t move and their BP and HR are within acceptable limits) and by considering these as separate issues (even if managed with a single agent), one can optimally manage each general anaesthetic. If a decrease in muscle tone is needed it also should be thought of in a logical way, but not be considered part of “general anaesthesia”, rather just another part of the intraoperative management of the patient, just as is keeping them warm or cold and well hydrated. It is time to abandon the old paradigm and embrace the new.

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