

Depth of Anaesthesia Monitors in Paediatric Anaesthesia

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There has been a resurgence of interest in depth of anaesthesia assessment. This has arisen due to a greater fear of awareness, the increased use of TIVA and the advent of new devices and technologies. What role do the new depth monitors have in paediatric anaesthesia? I will first outline the inherent limitations of the current technology, whether current monitors are in theory suitable for children, how much they have been validated in children, and finally how paediatric anaesthesia differs in its suitability for the use of depth of anaesthesia monitors.

Limitations of current monitors

Several depth of anaesthesia monitors are now available for clinical use and more are being trialled. These include the Bispectral Index (BIS), the Patient State Index, the entropy monitor, processed auditory evoked responses and ocular micro-tremor. The BIS has spawned hundreds of academic publications and has been used in millions of anaesthetics. In contrast, the entropy monitor has only resulted in a handful of publications.¹ Which monitor is better? It is unlikely one will be significantly better than any other, due to the inherent limitations in what they are trying to achieve and how.

All current monitors measure and analyse aspects of brain electrical activity. Various mathematical derivatives are then generated. These mathematical derivatives are compared to those of previously analysed records and a number allocated to each set of derivatives. The number thus generated is on a scale that equates lower numbers with periods of adequate anaesthesia and higher ones with measures of wakefulness. Often, the monitors go further to equate very low numbers with higher concentrations of anaesthetic.

It is a very important concept that these monitors do not specifically measure anything that represents consciousness or memory processing. They measure electrical activity and this is associated with some crude assessments of consciousness. Unfortunately, consciousness is a slippery thing that we have difficulty defining and even greater difficulty measuring. Thus, the monitors have never had a "gold standard" to be calibrated against. Alas, we have even greater trouble defining consciousness in infants and neonates. Some theories of consciousness would even argue that children less than 18 months of age have no state of consciousness at all!²

A further problem is that the EEG can be influenced both by degree of arousal and directly by the anaesthetic agent itself. At high concentrations of an anaesthetic, the

derived number will still go up and down with the dose of the anaesthetic, but may not vary significantly with stimulation. The patient is unconscious. Thus, the idea that consciousness is being measured is nonsense. The monitor is mainly responding to the direct effect of the anaesthetic agent on the EEG. The numbers generated have two determinants; the concentration of a particular drug (particularly at higher concentrations) and the degree of arousal (particularly at lower concentrations).

It has also been known for many years that different anaesthetic drugs can have quite different effects on the EEG.³ Ketamine, nitrous oxide, xenon, high doses of opioids and even halothane have direct EEG effects different to those of isoflurane, propofol and thiopentone. The direct EEG effects of the former anaesthetic agents make interpretation of the monitors problematic, as they have been calibrated using the latter agents. Unfortunately, ketamine and halothane are still frequently used in paediatric anaesthesia.

Even if the monitors do not measure any real entity, they are still potentially useful. The algorithms have been designed to reliably guide an anaesthetist through a typical anaesthetic. However, the algorithms are derived from adult cases and therefore are not intended to fit paediatric anaesthesia. Thus, any outcome benefit demonstrated in adults may not be applicable to paediatrics.

Could they work in theory?

The awake EEG changes with age.^{4,5} The rate of change slows as age increases, with most changes occurring in the neonatal and infant groups. The most pronounced difference is in the dominant background frequency, which increases with age. At 6 months, the dominant frequency is 5 Hz, from 9-18 months it is 6-7 Hz, at two years it is 7-8 Hz, by 7 years it is 9 Hz and by 15 years of age reaches the adult levels of 10 Hz. If a depth monitor is partly determined by the power frequency relationship, then an age related bias could occur. Young children can also demonstrate peculiar and specific EEG changes when progressing from the asleep to the awake phase. Children aged 6 months to 4 years have short bursts of 4-8 Hz activity lasting 1-5 seconds. Longer periods of 1-3 Hz activity may be seen in 3 month to 5 year olds. This activity is seen maximally at 12 months.

There is very little systematic data about the EEG of children under anaesthesia. What is available suggests that the EEG under anaesthesia does behave differently in children compared to adults.⁶⁻⁸ Even less is known of the auditory evoked response. One study concludes that the auditory evoked responses are unreliable as a depth of anaesthesia monitor in children younger than 2 years.⁹

Validating the monitors in children

Given the theoretical basis for a difference between adults and younger patients, it would be instructive to examine the efforts made to validate these monitors in children, particularly the lower age groups. These are difficult studies to perform well, as adult measures of consciousness may be impossible to use in children. As well as it being unethical to recruit child volunteers, very young children cannot be asked to perform tasks, or be quizzed to assess word retention. Also, small children tend to awaken rapidly making definition of subtle end-points difficult.

Nevertheless, several investigators have tried to validate the BIS in children. Denman et al showed a decrease in BIS with increasing sevoflurane concentration in infants (described as less than 2 years of age) and children during maintenance of

anaesthesia.¹⁰ The BIS at various stages of anaesthesia was recorded and compared to historical adult controls. No difference was detected between age groups in BIS during emergence, induction or maintenance of anaesthesia. The study was limited, however, by the imprecise manner in which emergence was assessed and had insufficient power to compare infants with older children. Degoute et al assessed the correlation between BIS and the OAA/S scale (Observer's Assessment of Awareness/Sedation).¹¹ They compared children aged 3.5 to 13 years with adults and found no difference between BIS numbers at both loss of consciousness and return of consciousness.

In a more rigorous study, BIS was also assessed prior to awakening after a specific stimulus.¹² This compared children older than 1 year with infants aged 6 months to 1 year. In children, the number prior to awakening was similar to that described in adults. However, in infants the BIS number prior to awakening was lower. Infants also failed to show a rise in BIS as the anaesthetic concentration was lowered. These results could imply that the EEG is sufficiently different in infants to make interpretation of the BIS unreliable in this age group. The BIS should therefore be used with caution in infants and neonates.

Finally, a phenomenon known as paradoxical delta activity occurs rarely in some patients just prior to arousal and is reflected by a sudden and brief plunge in the BIS immediately prior to awakening.¹³ Paradoxical delta activity is more common in children emerging from volatile anaesthesia. This phenomenon may be related to the slow frequencies mentioned previously, which are normally seen in small children during the transition from drowsy to the awake state.

It is tempting to follow the line of some authors and insist proper validation be performed in children before clinical use of this type of monitoring.¹⁴ Another approach is to accept that good validation studies may never be performed. We do much in paediatrics using technology that has never been specifically validated in children. If well-designed studies in relevant age groups can demonstrate improvements in important clinical outcomes, then complex validation studies may be superfluous.

There is no information yet about validating the Patient State Index, entropy monitors or ocular micro-tremor in children.

Would a depth monitor be useful in paediatric anaesthesia

Having tentatively established that, in older children, at least one monitor (the BIS) corresponds with consciousness as well (or as badly) as it does in adults, what is its role in paediatric anaesthesia?

Firstly, it could be used as it is in adult anaesthesia — to guide anaesthesia delivery for optimising dose. The benefits from this are faster emergence, lower costs in drug usage and post-operative care and, possibly, reduced risks of awareness. In adults, faster emergence and drug cost savings have been demonstrated.¹⁵ However, paediatric anaesthesia is different to adult anaesthesia in both the way it is conducted and in some of the clinical goals. A rapidly “street fit” child is not always our highest priority. Techniques that save recovery time in adults may not save time in children.

Bannister et al have evaluated the use of BIS guided anaesthesia in reducing times to emergence and discharge.¹⁶ They found that, in children aged 3 to 18 years, less anaesthetic drug was consumed, and the children awoke and were ready for discharge sooner. The time to actual discharge was, however, unchanged. In children less than 3 years of age, there was no difference in any of the outcomes. In children less than

6 months they had difficulty titrating the anaesthetic to the desired BIS number. Similarly to Davidson et al,¹² they found a lack of correlation between BIS number and low anaesthetic concentrations in this age group.

Reduction of awareness using the BIS is being evaluated at present in several large trials in the adult patient population. There is no reason to think that using the BIS would not help detect inadequate anaesthesia delivery or equipment malfunction and thus result in a reduction in awareness. It may also help detect that group of patients who are aware due to a higher anaesthesia requirement. There is, however, less evidence that this forms a significant proportion of cases of awareness. Moerman's oft quoted paper suggests anaesthesia records fail to give an indication of awareness because of poor record keeping, not because patients are frequently aware when all seems well.¹⁷

Very little has been published about awareness in children.¹⁸ In 1973, a study demonstrated an alarming incidence of 5% in 202 children aged 7 to 14.¹⁹ In 1988, two smaller studies from Liverpool of 120 children aged 5-17 and 144 children aged 5-14 reported no cases of awareness.^{20, 21} The later studies were limited by a relatively less comprehensive follow-up. Given the low incidence in contemporary adult studies, the small sample sizes of the Liverpool studies are also unlikely to give any meaningful result when comparing paediatric to adult anaesthesia.

The incidence of awareness may well be different in children, as the techniques of paediatric anaesthesia are different and there is less consistency in the pharmacokinetics and pharmacodynamics of anaesthetic agents. Small children also show greater fluctuation in haemodynamic variables, reducing their specificity in indicating inadequate anaesthesia. A child's response to the trauma of awareness may also be very different. A pain-free neonate may not be as upset by hearing the surgeon's conversation compared to the body-conscious adolescent. Children may also lack the coping strategies of adults. Clearly a lot more work needs to be done in the paediatric population before depth monitoring can be advocated as "a must" for reducing awareness in this age group.

Depth of anaesthesia monitors are also useful for total intravenous anaesthesia (TIVA). TIVA does not have the advantage of blood concentration monitoring similar to the end tidal estimates possible with volatile anaesthesia. An end organ effect monitor would therefore be more useful in TIVA. In paediatric anaesthesia, TIVA is less frequently used. One reason for this is the relatively poorly developed algorithms compared to adult TIVA.²² Use of depth monitors may encourage the development of better algorithms and increased use of TIVA in paediatrics.

Outside theatre

The use of depth of anaesthesia monitors is being advocated to monitor sedation in the ICU and the emergency departments. It is plausible that these monitors could be better suited to sedation rather than anaesthesia, as in the algorithm design there were more meaningful end-points at higher planes of sedation/anaesthesia. Numerous studies have already explored the use of the BIS for sedation, sometimes demonstrating remarkable reliability.²³

Measuring pain and sedation in paediatric ICU patients is particularly challenging. Demonstrating any improved outcome is difficult in the ICU setting. Nevertheless, there may be a role for these monitors in the paediatric ICU.²⁴⁻²⁶

Giving sedation to children for procedures in the emergency department is a controversial issue amongst paediatric anaesthetists. These children deserve effective and safe sedation and any advance in this area would be most welcome. BIS monitors are being used in paediatric emergency departments, but far more careful and extensive outcome analysis needs to be done before their widespread use can be recommended.²⁷

Conclusion

We are still far from the perfect depth monitor. Despite this, interest in measuring anaesthetic effect is likely to continue and increase. As we learn more of the neurobiology of the effects of anaesthesia and as new monitors and new applications of existing monitors emerge, we must make the effort to specifically investigate the paediatric population. Children are different; their neurophysiology and the concepts of consciousness are distinctly different to adults. New drugs and technologies often neglect children. Children may well benefit from depth monitoring but simply applying adult technology to younger patients could be useless or misleading.

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