Editorial

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Depth of general anaesthesia monitors

INTRODUCTION

Anaesthetic depth is the degree to which the central nervous system (CNS) is depressed by a general anaesthetic agent, depending on the potency of the anaesthetic agent and the concentration in which it is administered. Arthur Ernest Guedel (1937) described a detailed classification of anaesthetic state based on the use of a sole inhalational anaesthetic agent diethyl ether. The signs of this classical Guedel's classification depended on the eyelash reflex, respiration, eyeball movements, pupillary size, and muscular movements among others.

Though the action of general anaesthesia (GA) drugs on the cortex and the thalamic area of brain leading to loss of consciousness is well known, the exact mechanism by which these drugs produce anaesthetic state is not really well understood. A successful GA is defined as a reversible triad hypnosis, analgesia, and abolition of reflex activity. In a balanced anaesthetic technique that uses multiple drugs, the classical stages of anaesthesia are concealed.[1] An inadequate GA can lead on to intraoperative awareness with or without recall, while overdosage results in delayed recovery and possible postoperative complications.

When the anaesthetic state was produced by one drug with relatively low specificity of action, the depth of anaesthesia was actually equated with the depth of CNS depression.[2] Therefore, a single index reflecting CNS depression in general could be used as a measure of anaesthesia.

Awareness during general anaesthesia

An unintended intraoperative awareness can occur during GA when a patient becomes cognizant of some or all events during surgery, and may have recall of those events. It may be due to several reasons, the patient is unable to communicate with others.

Awareness during anaesthesia may be explicit or implicit memory. Explicit recall involves the memory of events and speech and may result in a significant psychological sequel. Implicit memory occurs where no recollection of events exists, but patient's behavior may be modified by information received during anaesthesia. The reported incidence of intraoperative consciousness or explicit memory recall, varies from 0.2% to 2%.[3]

Anaesthesia awareness is under-recognized and under-treated in most health care organizations, because it is clinically difficult to recognise intraoperative awareness.[4] The physiologic responses to awareness may include hypertension, tachycardia, or movement of limbs, the presence of sweating and lacrimation. But in modern-day anaesthesia practice, they are often masked using drugs like muscle relaxants, beta-blockers, or calcium-channel blockers, etc. Hence, the incidence of awareness during anaesthesia with or without recall may be much higher. The common complaints include auditory recollections (48%), inability to breathe (48%), and pain (28%) and unidentified number of post-traumatic stress syndrome.[5]

The key anatomic structures of the CNS that contribute to the state of consciousness are the brain stem, pons, thalamus, and cortex with their connecting neural pathways.[6] It is generally believed that administration of at least 0.5 minimum alveolar concentration of any volatile anaesthetic agent should prevent awareness during GA.[7] Failure to adjust the adequate depth can be due to interindividual variations in drug requirements and also varying degree of pain intensity

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during a specific surgical procedure. This can result in either overdosage or underdosage with both volatile and intravenous anaesthetic techniques.[8]

Mechanism of action of general anaesthesia and electroencephalogram

The drugs used for GA can be either intravenous (IV) agents like propofol or volatile agents such as sevoflurane and they produce their actions by modulating the permeability at synaptic transmission level of CNS. These drugs affect the lateral temporo-parieto-occipital junction and the mesial cortical core and finally cause unconsciousness by disrupting cortical integration and cortical information capacity.[9] Induction of GA also inhibits the excitatory arousal pathways originating in the brain stem and pons which are involved in maintaining cortical arousal and form the so called ascending reticular formation.

These GA drugs being apolar, cross the blood-brain barrier, and interact receptors causing neuronal hyperpolarisation and increased inhibition or decreased excitation.[10] They potentiate the activity of inhibitory gamma-amino butyric acid type A receptors in the brain, resulting in decreased electroencephalogram (EEG) activity. The low voltage, high frequency wakefulness pattern of EEG changes to the slow-wave EEG of the deep sleep, and then an EEG burst-suppression pattern.[11] There isgeneral reduction of EEG activity during anaesthesia, which is proportional to the dose of GA drugs administered. Physiological conditions such as age, race, gender, hypothermia, acid-base imbalances, hypoglycemia or cerebral ischemia have a significant effect on the raw EEG. A few well-known sources of electrical interference like electrocautery, pacemakers, or warm blankets can distort EEG tracings, though EEG activity is not actually affected. However, the drugs like ketamine, xenon and nitrous oxide produce anaesthesia by interacting with other brain receptors, mainly, but not exclusively, inhibiting excitatory *N*-methyl-D-aspartate brain receptors.

The Guedel's stage 3 plane 3 of GA is also known as the surgical plane of anaesthesia. An overdose of drugs can rapidly lead on to stage 4 anaesthesia resulting in cardio-respiratory arrest.[12] Hence it is essential to monitor and administer adequate dose of GA to reduce the incidence of intraoperative awareness. There are devices that can measure End-tidal concentration of volatile anaesthetic or can predict plasma concentration of IV anaesthetics devices, but they do not measure the pharmacological effects of drugs on brain activity. Hence an EEG based devices may be a good compromise for monitoring the depth of anaesthesia. It is unlikely that any single method will be found to measure the depth of anaesthesia reliably for all patients and all anaesthetic agents.[13]

The Burst suppression (BS) activity of brain represents an EEG pattern often seen during deeper planes of anaesthesia. This pattern is composed of episodes of electrical suppression alternated with high-frequency, high amplitude electrical bursts. The duration of suppression periods increases with anaesthetic depth.[14]

Auditory evoked potentials (AEP) are the responses of the auditory pathway to sound stimuli. An AEP is calculated by repeatedly applying an auditory stimulus to the patient and averaging EEG periods that immediately follow each stimulus, so that non-stimulus-related portion of the EEG is eliminated, and the specific evoked potentials are preserved.

EEG based depth of anaesthesia monitors

An EEG or AEP based monitors would enable objective, reproducible and continuous measurement of anaesthetic depth, even when the patient is fully paralysed or has lost all responses to painful external stimuli. Recent advances in the introduction of EEG-based monitors have made important contributions towards understanding of the fundamental changes in brain activity brought about by anaesthetic agents. The development of these monitors, which directly measures the state of consciousness, would also enable a safe and cost-effective anaesthetic procedure.[15]

All monitors analyse the potential fluctuations of EEG signals measured from the patient's forehead. After amplification and conversion of the analog EEG signal to the digital domain, various signal processing algorithms are applied to the frequency, amplitude, latency, and/or phase relationship data derived from the raw EEG or AEP, and a single number is generated, which is often referred to as an 'index,' and typically scaled between 0 and 100. Then the artifacts arising from eye movement, swallowing or heart activities are removed by artifact algorithm software. The facial muscle electromyogram (EMG) can also be used as the surrogate parameter. Sudden appearance of frontal (forehead) EMG activity suggests somatic response to noxious stimulation during lighter planes of anaesthesia and may give warning of impending arousal. For this reason, some monitors separately

provide information on the level of EMG activity. Because the processing, classification, and averaging of EEG derived indices needs time, there is always an inherent time delay in presentation of the results on depth of general anaesthesia (DGA) monitors. The reported time delays range from 26-106 s for the transition between EEG suppression, and the awake state for a bispectral index (BIS) monitor.[16]

Any newer DGA monitor should be able to save the amount of anaesthetics used, shorten recovery time or the length of stay in the recovery room and should produce long-term benefits like, reduced risks of awareness-related morbidity. There should be visible cost-benefit effectiveness for the patient and to the society.

The current EEG based DGA monitors have a soft sensor consisting of an EEG or AEP electrodes which are integrated with custom hardware and software to produce a dimensionless number on the scale from 0-100. This number is then used by the anaesthesiologist as a reference point for reasoning and to decide whether the level of GA is appropriate and if not, to increase or decrease the amount of general anaesthetic.[17]

The commercially available monitors

The first commercial DGA monitor Bispectral-Index Monitor or BIS®, was introduced in 1992 and later from 1999 onwards, others followed (e.g., Narcotrend, AEP-Monitor/2, Patient State Analyser (PSA), cerebral state monitor (CSM), Entropy and many more). In the last decade, the BIS monitor has established itself as standard equipment for GA monitoring. However, after rigorous testing, several drawbacks are now identified and hence the quest for an ideal DGA is still on.

BIS monitor

The BIS monitor was introduced by Aspect Medical Systems. The BIS index is a dimensionless number from 0 (isoelectricity) to 100 (awake) measured from the patient's forehead. A reading of 40-60 indicates an adequate depth of hypnosis.

Narcotrend monitor

The Narcotrend monitor (2001) records EEG from the forehead which is digitised and then subjected to extensive artefact detection and removal algorithms. Meanwhile, the monitor also calculates the surrogate EMG parameters. Narcotrend monitor has two recording modes; the one channel mode has the standard for the assessment of the depth of hypnosis during anaesthesia or sedation, and the two-channel mode for comparison of signals from the two hemispheres of the brain. The Narcotrend would have lesser problems with EMG interference than the BIS monitor.

Auditory evoked potential monitor

The first commercial monitor based on AEP was introduced by Danmeter in 2000. Later spectral EEG parameters are included in the next version of AEP Monitor 2. Along with the AEP-Autoregressive index (AAI), additional EEG parameters, the BS ratio and EMG bars are also displayed alongside the AAI. All the above parameters must be monitored simultaneously in order to ensure optimal sedation of the patient during GA. Unlike other monitors, AAI can be displayed on two scales: Either from 0+to 100, or from 0 to 60; the second scale is recommended, and the optimal anaesthesia is achieved if the index values are between 15 and 25.

PSA 4000 monitor

The Patient State Analyser 4000 (PSA) developed by the Physiometrix (2001) calculates the value of the index from four EEG channels. Patient state index, is a dimensionless number from 100 (awake) to 0 (isoelectricity). Additionally, surrogate analysis is performed by calculating BS and arousal detection parameters.

The index of consciousness monitor

The Index of Consciousness (IoC) monitor also records the EEG with three surface electrodes attached to the patient's forehead. In addition, the IoC monitor displays EMG bar, signal quality bar and Burst Supression Ratio (BSR).

Cerebral state monitor

The cerebral state monitor (CSM) was introduced in 2004 and marketed as a low-cost DGA monitor by Danmeter A/S, Odense, Denmark. It is a portable, wireless monitor that uses the time and frequency domain analysis and shows the cerebral state index (CSI) on a 0-100 scale; and 40-60 indicates an adequate depth of hypnosis.[18] The CSM is built upon the EEG-algorithm of its predecessor AEP-Monitor/2 and uses the same electrodes. CSI can be used for detecting the depth of anaesthesia or sedation, but overlapping EEG with EMG is an important and sometimes very hazardous pitfall.

Entropy

The Entropy Module was introduced in 2003 by the Datex-Ohmeda Company. The main principle involved is that increasing depth of anaesthesia causes increase in the regularity of the EEG, which can be used to estimate the depth of anaesthesia. The signals are divided into State entropy (SE) and Response entropy (RE) based on the two frequency bands (SE-0.8-32 Hz and RE-0.8-47 Hz). Both are dimensionless numbers between 91-0 and 100-0, respectively. SE is based on EEG alone, but RE is based on both EEG and electromyography. The RE can reveal more rapid alterations in frontal cortex activity. State entropy values are resistant to sudden reactions of facial muscles, and hence SE is used to assess hypnotic effects on the brain during GA.

Additionally, the monitor performs the BS analysis and displays the Burst Suppression Ratio (BSR). The main difference from other DGA monitor is that this monitor outputs two index values. While the SE includes information only from EEG, the RE includes the EMG activity also and can be therefore used as a surrogate parameter. Consequently, the difference between indices, which is larger than 10 indicates increased muscle activity. Hence the interpretation of the results is left entirely to the anaesthetist. Compared to BIS, entropy is considered to be a more accurate and reliable indicator of the hypnotic effects of anaesthetic and sedative drugs.[19]

Limitations

BIS and entropy monitors were designed and studied to correlate EEG signals of adult patients, with anaesthetists' impressions of depth of sedation and anaesthesia across a wide range of clinical states. Because of its presence in clinical practice for over two decades, BIS monitor is used as a standard against which all other DGA Monitors are compared, though it does not necessarily mean that the BIS monitor is superior to others. The complexity of the algorithm is an important property because all the monitors have developed on their own algorithms. No DGA algorithm has been published with full technical specifications by any manufacturer, until now.

To date, no health authority has so far recommended that DGA monitors are compulsory during GA, but it should be considered only on an individual basis.[20] In its review of BIS monitor, the Food and Drug Administration observed that.[4] 'Use of BIS monitoring to help guide anaesthetic administration may be associated with the reduction of the incidence of awareness with recall in adults during GA and sedation.'

Since adult EEG, data were used to authenticate the BIS algorithm, it cannot automatically be extrapolated to young children, because the paediatric EEG pattern approaches the adult pattern only by about 5 years of age. Comparison of BIS values between adults and children suggest that following GA, BIS performs similarly both in adults and children older than 1 year. Hence studies conducted to date demonstrate that the current BIS provides useful clinical information in children, and shows promise for use in paediatric anaesthesia practice in similar ways to its use in adults.[21]

The future development of DGA monitors depend on consensus on the validation protocol on an international platform and the practice of using open-source algorithms in the design of mathematical interpretation of EEG signals during GA. But unfortunately, there is no agreement on the minimum level of performance for EEG or AEP based DGA monitors, although many validation studies have been conducted.[22] Hence, it is still difficult to compare their performance because there is no consensus on the validation methodology.

The currently available DGA monitors cannot always differentiate a sleeping patient from an unconsciousness and anaesthetized patient. They can only monitor the hypnotic component of GA but not the patient's stress level in response to nociceptive stimulus during GA.[23] Clinically the changes in heart rate and arterial pressure are used as signs of increased nociception during GA but they are neither specific nor sensitive, though the surgical stress index (SSI), the response index of nociception (RN) and the noxious stimulation response index (NSRI) can be better predictors of noxious stimulus.

CONCLUSIONS

The usage of DGA monitor in paediatric anaesthesia practice is yet to catch up. There is an urgent need to overcome the limitation of DGA monitors to measure the depth of anaesthesia produced by drugs like ketamine or nitrous oxide and others. A monitor which can measure not only the hypnotic component of GA but also the patient's stress level in response to nociceptive stimulus during GA are desirable.

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Announcement

Dr. TN Jha and Dr. KP Chansoriya travel grant

From the year 2011, the Dr. TN Jha and Dr. KP Chansoriya travel grant will be awarded to the participants from 15 states. All the states can select their candidate during their annual conference and send them with the recommendation of the Secretary. Only one candidate is allowed from each state. In case, if two states have a combined annual meet but separate as per the records, have to select one candidate from each state. If more than 15 states recommend the candidates for the award, selection will be made on first come first served basis.

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