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Monitoring depth of anaesthesia

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The phrase 'depth of anaesthesia' is widely used but poorly defined. A useful concept of depth is that of a continuum[1] balancing anaesthetic-induced artificial disruptions of normal brain function leading to hypnosis, against sensory stimulation leading to consciousness. Anaesthesia is not physiologically the same as natural sleep, and has more in common with hibernation.[2]

Awareness during surgery happens (awareness during anaesthesia is an oxymoron). Failure to deliver adequate levels of anaesthesia is the cause of awareness. Equipment failure is an obvious cause of inadequate anaesthesia, but poor judgement regarding the amount of anaesthetic required to counteract the stimulating effect of noxious surgical procedures is probably the most common cause. The incidence of awareness with explicit recall has been reported as 1:500 elective procedures,[3] although awareness with pain has a much lower incidence. As the incidence of other adverse events falls, the perceived importance of awareness rises; awareness has become a 'silly season' story in the press, and has been the subject of medical drama (e.g. 'Chicago Hope'). Awareness may lead to litigation, but closed-claim procedures make it difficult to estimate its true incidence. It is impossible to test whether adverse surgical outcome has arisen due to awareness without subsequent recall. However, post-traumatic stress disorder is a potential consequence for any patient experiencing intra-operative awareness, and the treatment strategy for these patients has been compared with that for the victims of torture. Patients presenting with a history of awareness should be offered counselling.

Transient awareness does occur in spontaneously breathing subjects, even though movement and communication should be possible, but the potential for prolonged awareness with pain is greatly enhanced during competitive neuromuscular blockade. The use of the IFT, where a tourniquet prevents paralysis so that the patient can signal awareness, has revealed that a high proportion of patients subject to high dose opioid 'anaesthesia' are still capable of communicating during surgery. However, the IFT is a research tool and is not widely employed during routine anaesthesia. One reason is the need to identify cognate responses from the patient indicating true awareness, and not just an orientation response to ones name, or a spinal reflex to a noxious stimulus, which can be retained at high levels of anaesthesia. It should be noted that the tourniquet has to be deflated at regular intervals to prevent ischaemic damage or nerve block. The presence of the tourniquet prevents the use of one arm for IV infusion.

Given that awareness does occur, how can it be prevented? Vigilance is the best advice. Unexplained changes in subjective estimates of light anaesthesia e.g. mean pulse rate, BP, tears, and sweating may be signs of awareness in patients subject to competitive neuromuscular blockade. However, these signs are not reliable, and it has been shown that the anaesthetic records of patients who have exhibited awareness cannot be distinguished from normal patients when scrutinised by blinded senior anaesthetists.[4]

Detection of awareness gives the anaesthetist one course of action i.e. reassure the patient, minimise noxious stimuli, and restore the correct level of anaesthesia as soon as possible. Although some agents are reported to cause retrograde amnesia, they are not licensed for that use and they are not reliable.[5] The mechanisms of memory, especially those involving the amygdala, make it far more likely that a painful event or remarks directed personally at the patient will be recalled, so good analgesia and prevention of derogatory comments such as 'this one is a beached whale' will help.

Objective depth of anaesthesia monitoring by a dedicated monitor or add-on to existing equipment, used properly, can potentially help to prevent awareness. The ideal monitor would meet a number of criteria (Simons, 1989) including:

(1) Indicates the stage during light anaesthesia preceding conscious awareness;

(2) Closely reflects changing concentrations of anaesthetic agents;

(3) Sensitive to stimuli of different modalities, especially surgical stimulation;

(4) High temporal resolution with real time presentation of results;

(5) Able to stage the depth of anaesthesia for all anaesthetics on a common scale.

A number of technologies have been introduced with varying degrees of utility. Monitors that are widely considered as obsolete are the ABM and lower oesophageal contractility, which are no longer commercially available. The ABM (Datex) combined processed EEG and fEMG on a single display, but it

was left to the anaesthetist to identify significant features. LOC monitoring employed a tube placed in the oesophagus to measure SLOC and PLOC contractions, which declined in frequency during anaesthesia. Correctly establishing and interpreting LOC was technically demanding.

Electromyography of facial muscles is the basis of FACE (Patient Comfort Inc.). EMG of the frontalis muscle is particularly resistant to competitive neuromuscular blockade, and was the basis of the ABM monitor. Alone, fEMG is a poor index of anaesthetic depth, since it is only seen at light levels of anaesthesia associated with gradual induction and the moment of recovery, when the patient visibly frowns. FACE looks at other facial EMG signals in addition to fEMG, and reflects outflow from facial nerves originating at the pons of the brainstem.

The EEG is recorded using low-impedance scalp electrodes. The EEG ranges from 2 to 200 microvolts in amplitude, and ranges from 0.1 to 40Hz frequency. Due to its small size, special care has to be taken with electrode design and placement to minimise contamination by electrocautery. The spectral edge frequency is a statistical description of EEG power, originally defining the highest frequency at which significant EEG activity was seen, which was subsequently modified to 95% (SEF 95) or 90% (SEF 90) upper frequency. SEF appears to vary in its effectiveness between anaesthetic procedures. SEF is available in a number of monitors, including the pEEG (Dräeger).

Bispectral Index (BIS, Aspect Medical Systems and as an additional cost option for Spacelabs, Datex, and HP monitors) is a proprietary signal processing technique combining EEG, EMG and a previously collected statistical database of patterns corresponding to the moment of recovery of response to verbal command.[6] The database was generated by looking for characteristics of the EEG identified by bispectral analysis, along with other EEG statistical descriptors, and identifying a signature associated with recovery as defined by an expert group of anaesthetists. Early, less useful, versions of BIS were based on recovery of movement, not responsiveness, and one should be careful to compare only 'like with like' when reviewing the extensive literature relating to BIS. The optimisation of the database against physiological signals is still subject to continuing commercial development. BIS is, therefore, not just a physiological monitor, but also an expert system. BIS is represented as dimensionless number from 0 (representing an isoelectric, flat EEG) to 100 (indicating wakefulness). BIS has been shown to correlate with reduction in brain metabolism associated with propofol and volatile anaesthesia in adults.[7] BIS monitors have been developed for use with proprietary EEG electrodes, which have pre-determined positions on the forehead, and are optimised for rapid skin preparation (Sensor).

Table 1 Equipment or techniques for monitoring 'depth of anaesthesia or sedation'

Name	Principle	Supplier
Clinical observations	BP, HR, pupils, tears etc.	Unreliable
Bispectral Index (BIS)	EEG, EMG and signal processing	Aspect
Fathom	Heart Rate Variability (Respiratory sinus arrhythmia)	Amtec Medical Systems
Anemon-1	Heart Rate Variability (unknown derivative)	MCSA
Patient State Index	Proprietary EEG derivative	Physiometrix, future product
FACE	Frontalis EMG	Patient Comfort Inc
pEEG	Spectral Edge Frequency	Dräeger
Isolated forearm	Left without paralysis	Research and historic interest
Anaesthesia Brain Monitor	EEG and EMG display	Datex, obsolete, historic interest
Lower oesophageal contractility	Autonomic drive altered by anaesthetics	Unreliable, limited evaluation, obsolete
Auditory Evoked Potential	EEG and signal processing	Research and possible future product

The PSI (Physiometrix) is undergoing trials and offers another proprietary EEG-based indication of anaesthetic depth.

HRV is the basis of two new monitors. Fathom (Amtec Medical Systems) employs a measurement of RSA and has been demonstrated to indicate the fall in brain metabolism associated with volatile anaesthesia.[8,9] Fathom uses a high resolution ECG, along with an indication of respiratory cycle provided by either an encoding Wright's respirometer or a chest belt, to discriminate RSA from other arrhythmias on a breath-by-breath basis. Fathom indicates the level of vagal outflow from the medulla oblongata, and has been shown to most significantly correlate with activity in the solitary nucleus.[10] Another monitor of heart rate variability, but not of RSA, the Anemon-1 (MCSA) has been described by the manufacturer as a monitor of sympathetic tone and a depth of analgesia monitor.

An extensively researched technique that may find its way into a commercial monitor is the AEP.[11,12] A computer is used to average the brain's response to repetitive auditory click stimuli. The amplitude and latency of early cortical Pa and Nb waves change with the depth of anaesthesia.

Despite the availability of dedicated monitoring (Table 1) awareness will continue to occur if the monitors are incorrectly used or ignored; the expertise of the anaesthetist is still required. It has been suggested that the use of depth of anaesthesia monitoring will reduce the level of anaesthesia required and improve recovery.[13] Whilst a persuasive argument, sudden, unexpected failure of the anaesthetic delivery system is one circumstance that no monitor can warn of. Running a patient too light will result in awakening of the patient faster than the anaesthetist can react, and so the proportion of cases of awareness due to equipment failure may rise, even though the overall incidence of awareness may fall due to monitoring.

Declaration of interest

The author is a co-inventor of Fathom and has received travel expenses from its manufacturer (Amtec Medical Systems). The author is also a member of the European Clinical Advisory Board for BIS (Aspect Medical Systems) and has received travel expenses.

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Abbreviations

ABM (Anaesthesia Brain Monitor), AEP (Auditory Evoked Potential), BP (Blood Pressure), BIS (Bispectral Index), ECG (Electro-cardiogram) EEG (Electroenchephalogram), EMG (Electromyogram), fEMG (frontalis Electromyogram), HRV (Heart Rate Variability), IFT (Isolated Forearm Technique), IV (Intravenous), LOC (Lower Oesophageal Contractility), pEEG (processed Electroencephalogram), PLOC (Provoked Lower Oesophageal Contractility), PSI (Patient State Index), RSA (Respiratory Sinus Arrhythmia), SEF (Spectral Edge Frequency), SLOC (Sontaneous Lower Oesophageal Contractility)