Anaesthesia Monitoring Techniques

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Depth of anaesthesia

Most anaesthetics are given without monitoring the effect of the anaesthetic on the target organ. Depending on the stimulus, there is a depth of anaesthesia at which the patient becomes aware. The incidence of awareness or recall during general anaesthesia is about 1/500.

Historical methods

Clinical assessment uses autonomic signs such as pulse, blood pressure, sweating and lacrimation to predict anaesthetic depth. However, autonomic functions are not affected by depth of anaesthesia only, and patients with autonomic neuropathy will not react as predicted.

Tourniquet – Tunstall described inflating a tourniquet to the upper arm above systolic pressure before induction of anaesthesia. This prevents neuromuscular agents reaching the forearm muscles, and the patient's arm moves if anaesthesia is too light. This method is unsuitable for routine use because it indicates awareness once it has occurred, and the time for which the tourniquet can be inflated is limited by neuronal ischaemia from compression.

Electroencephalogram (EEG)

Recording the electrical activity of the brain provides information on depth of anaesthesia. However, the equipment is expensive and skilled operators are required to obtain useful information. Different drugs have varying effects on the EEG. Hypotension, hypoxia, metabolic encephalopathy and cerebral oedema can all depress EEG signal output.

The EEG detects voltages of 1–500 µv. It comprises α, β, θ and δ waves. With increasing depth of anaesthesia there is a progressive increase in signal amplitude and a reduced frequency (burst suppression). The EEG is non-invasive and presents cortical electrical activity derived from summated excitatory and inhibitory postsynaptic activity that is paced by subthalamic nuclei. Fourier analysis is used to separate the raw EEG into a number of component sine waves. The derived parameters, spectral edge frequency and median frequency describe the entire EEG as a single value. Spectral edge frequency is a single value representing the frequency below which 95% of the total power is present. The median frequency is the point at which 50% of the power lies above and below this value. Median frequency has been shown to control closed loop feedback of intravenous drug administration, but no studies have demonstrated the usefulness of spectral edge frequency.

Bispectral index (BIS) is a derived variable that uses information on EEG power and frequency, and includes information derived from the mathematical technique of bispectral analysis (Figure 1). BIS records a state of the brain and not the effect of a particular drug. BIS gives a numerical value and the data are generated over 30 EEG recordings, with the average updated every 2–5 s. A low BIS value indicates hypnosis. BIS decreases during natural sleep, though not to the level produced by anaesthetic drugs.

Evoked potentials

Cortical evoked potentials to auditory, visual or somatosensory stimuli are suppressed in a dose-dependent manner by anaesthetic agents, and correlate well with peroperative wakefulness, awareness and explicit and implicit memory. Voltage potentials are small (1–2 µv) compared with background electrical activity (> 100 µv). Evoked potentials are generated using repeated stimuli, and the electrical responses pre- and post-stimuli are averaged so that only the electrical activity corresponding to the generated stimulus is analysed.

The evoked response is divided into early, mid-latency and late cortical waves. Early waves originate in the brainstem and are unchanged by anaesthesia. Mid-latency waves (40–60 ms post-stimulus) are highly influenced by increasing depth of anaesthesia, particularly the Pa and Nb waves. Anaesthetic agents increase latency and decrease amplitude in a dose-dependent manner. The correlation of mid-latency auditory evoked potentials to depth of anaesthesia approaches that of BIS.

The late cortical response (50–100 ms post-stimuli) reflects activation of the frontal cortex but is heavily influenced by attention, sleep and sedation.

1 Bispectral index (BIS) monitor. **a** Electrodes. **b** Display screen showing digital and analogue recording of BIS. *Photograph courtesy of Aspect Medical System Inc.*

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Neuromuscular blockade

Neuromuscular blockade is monitored during surgery to guide repeated doses of muscle relaxants and to differentiate between the types of block. All techniques for assessing neuromuscular blockade use a peripheral nerve stimulator (PNS) to stimulate a motor nerve electrically. The PNS generates a standard electrical pulse, which should be:

- supramaximal to ensure recruitment of all available muscle units
- a square wave of short duration (0.1–0.2 ms) with uniform amplitude (10–40 mA).

The muscle response can be assessed by visual and tactile methods, electromyography, acceleromyography and mechanomyography. Visual observation and palpation of the contracting muscle group are the easiest but least accurate methods of assessing neuromuscular block from PNS stimulation.

Electromyography uses electrodes to record the compound muscle potential stimulated by the PNS. Typically, the ulnar nerve is used and the electrodes are placed over the motor point of adductor pollicis. A drawback is that small movements of the hand can change the response by altering the electrode geometry.

Acceleromyography – acceleration of a distal digit is directly proportional to the force of muscle contraction (because force equals mass times acceleration), and therefore inversely proportional to the degree of neuromuscular block. The transducer uses a piezoelectric crystal secured to the distal part of the digit measured and the PNS provides the electrical stimulus. Accurate and stable positioning of the digit is important for accurate results.

Mechanomyography uses a strain gauge to measure the tension generated in a muscle. A small weight is suspended from the muscle to maintain isometric contraction. The tension produced on PNS stimulation is converted into an electrical signal. Mechanomyography requires splinting of the hand and is generally used for research.

Different modes of PNS stimulation

Single twitch – an electrical pulse is delivered at 1 Hz, and the ratio of the evoked twitch compared with that before muscle relaxation gives a crude indication of neuromuscular blockade (Figure 2). When 75% of the acetylcholine (ACh) receptors on the postsynaptic membrane of the neuromuscular junction are occupied by a neuromuscular blocking agent (NMBA), twitch magnitude starts to decrease. When there is 100% drug occupation, no twitch is elicited.

Train of four (TOF) – four stimuli are given at a frequency of 2 Hz, potentially eliciting 4 twitches (T1–T4). The ratio T4:T1 indicates the degree of neuromuscular block. Non-depolarizing NMBAs produce a decrease in magnitude of the first twitch compared with a pre-relaxant stimulus, and a progressive reduction in magnitude of T1–T4. The number of elicited twitches indicates the degree of receptor occupancy. Disappearance of T4, T3, T2, T1 corresponds to 75%, 80%, 90% and 100% occupancy. With recovery of neuromuscular function the twitches appear in the reverse order. Accepted values for TOF count are:

- 1 twitch for tracheal intubation
- 1–2 twitches during established anaesthesia
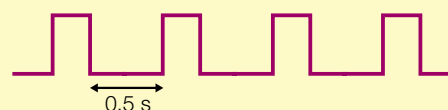
Pulse patterns

Twitch
- Single twitch
- Used with depolarizing blockade
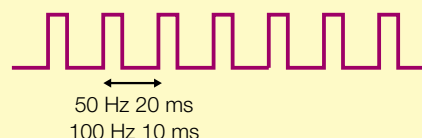- Degree of twitch depression used to calculate level of blockade

95 µs
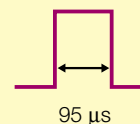
Train of four
- Four single pulses at 2 Hz
- Shows fade
- Ratio of first to fourth twitch used to calculate level of blockade

0.5 s

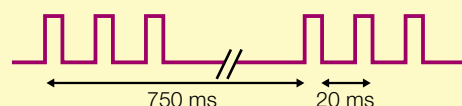#### Tetanus
- Sustained burst of pulses at 50 or 100 Hz
- Usually held for around 5 s
- Used to 'kick start' the nerve under deep paralysis


50 Hz 20 ms
100 Hz 10 ms

Double burst stimulation
- Two bursts 0.5 s apart
- Either 3 pulses followed by 2 pulses (3:2) or 3 followed by 3 (3:3)
- Used under light paralysis where train of four ratio is difficult to distinguish

750 ms   20 ms

Post-tetanic count
- 5 s tetanus followed by 20 pulses at 2 Hz
- Shows fade response earlier than train of four
- Used under deep paralysis to estimate time to recovery

Tetanus 5 s   Recovery 3 s   20 single twitches
1 s apart

2
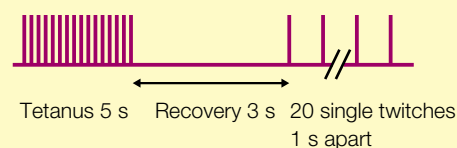
- 3–4 twitches before reversal of neuromuscular blockade is attempted.

Double burst stimulation consists of two bursts of three stimuli at 50 Hz with each triple burst separated by 750 ms. These manifest visually as two separate stimuli (T1 and T2). The ratio is related to the TOF ratio and is easier for the operator to interpret reliably.

Tetanic stimulation at 50 Hz for 5 s produces detectable fade in muscle contraction, the extent of which is related to neuromuscular block. No fade indicates no neuromuscular block. In intense neuromuscular block, TOF stimulation elicits no twitches. Post-tetanic facilitation (PTP) uses tetanic stimulation for 5 s to mobilize presynaptic ACh. Subsequent 1 Hz twitch stimulation can overcome the high concentrations of NMBAs. The number of twitches generated (i.e. the post-tetanic count) reflects the degree of neuromuscular blockade.

Depolarizing NMBAs react differently to the PNS modes of stimulation. They produce equal but reduced twitches in response to single twitch and TOF stimulation (the T4:T1 ratio is 1), reduced but sustained contraction with tetanic stimulation, but do not demonstrate either tetanic fade or PTP.

Temperature

In health, body temperature is maintained at 37 ± 0.2°C. Intraoperative monitoring can be via electrical or non-electrical techniques.

Non-electrical techniques

An aneroid gauge uses the expansion of air with increasing temperature to change the size of a bellows connected to a needle. The needle moves across a calibrated scale to display the temperature.

Liquid thermometers typically rely on the thermal expansion of alcohol or mercury. The liquid is forced into a fine transparent glass tube with an appended scale. An angulation and constriction below the fine-bore tube prevents the liquid retracting into the bulb reservoir until the thermometer is shaken. A short time (2–3 minutes for mercury) is required for complete thermal equilibration between the liquid and the surrounding environment. There is a risk of poisoning if the thermometer breaks and mercury leaks.

Bimetallic strip thermometers comprise two metals with different coefficients of thermal expansion. With a change in temperature one metal changes size more than the other causing the strip to bend; this is displayed via a mechanical linkage on a temperature scale.

Chemical thermometers use liquid crystals composed of chemicals such as cholesterol esters, that change colour with temperature. Typically these scales can be accurate only to 0.5°C. They are used for monitoring skin temperature which may be markedly different from core temperature.

Infrared thermometers use the principle of black body radiation. Only the temperature of that object determines the maximal amount of radiation emitted by a body. The amount of radiation emitted by a surface (e.g. the tympanic membrane) is less than that emitted by a black body at the same temperature. The emissivity of the surface is the ratio of these radiation levels. Thus, measurement of a surface's emitted radiation combined with a pre-existing knowledge of that surface's emissivity can determine the temperature of that surface. Infrared tympanic membrane thermometers are in common clinical use.

Electrical techniques

Thermocouples use the Seebeck effect, whereby a small voltage is produced at a junction between two dissimilar metals, commonly either platinum/rhodium or copper/constantan. The temperature at the junction determines the voltage produced. There is a second junction to complete the electrical circuit. This is either maintained at a constant temperature, to provide a reference level, or has built-in compensation for the reference junction temperature, enabling the first junction to act as a thermometer.

A thermistor is a semiconductor made from tiny beads of heavy metal oxides, which can be incorporated into the tips of fine temperature probes. Electrical resistance of semiconductors decreases exponentially with increasing temperature. Thermistors require signal conditioning and calibration because resistance may alter with time. Thermistors exhibit hysteresis in that their electrical resistance is different at the same temperature depending on whether the temperature is increasing or decreasing.

Platinum wire thermometers – electrical resistance of platinum increases with increasing temperature. The increase is linear in the range 0–100°C. They are accurate to within 0.0001°C, but are fragile.

Respiration

In anaesthesia, ventilatory pattern, gas flow, airway pressure and tidal and minute volumes are measured. Only methods of measuring gas flows and volumes are mentioned here.

Gas flow can be used to derive volume. Flow is laminar or turbulent, and Reynolds number is used to predict the type of flow. Laminar flow is described in the Hagen–Poiseuille equation. Pneumotachographs measure flow by inducing laminar flow through a gauze screen. The screen produces a resistance

3 Wright's respirometer. **a** Small pointer shows accumulated volume; **b** large pointer indicates tidal volume (it can be reset each breath); **c** to the breathing sytem.

to flow and thus generates a small pressure difference on either side. This pressure difference is measured with two transducers. These convert pressure into an electrical signal, which is processed to produce a display of flow. The screen is manufactured to provide minimal resistance to respiration, and is heated to maintain a constant temperature. If the screen was allowed to cool in the gas flow this would affect the gas viscosity, altering flow characteristics of the gas and thus affecting accuracy. Warming also prevents condensation developing on the screen, which would increase resistance to flow.

Respirometers can be used to monitor expiratory gas volumes. The most common is Wright's anemometer (Figure 3). Expired gas passes through oblique slits, which creates circular gas flow in a chamber, causing rotation of a double-vaned rotor. The rotor is coupled via a set of linkage gears to a display indicator dial and needle. The respirometer measures gas volume in one direction only. Flow can be calculated by averaging recorded volumes over time. Its advantages are that no power supply is necessary, and the device is lightweight and portable. Owing to the inertia in the system it tends to overestimate higher volumes and underestimate lower volumes. ◆

FURTHER READING

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