Monitoring During Anaesthesia and Recovery

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To ensure optimum patient safety certain core standards of monitoring should be used during anaesthesia and recovery. It provides information that facilitates early recognition and management of critical incidents. Experienced and vigilant anaesthetist is the most important monitor. However it is impossible to prevent all adverse events, as human error is inevitable. Appropriate monitoring gives an early warning and it reduces the consequences of critical incidents.

Association of Anaesthetists of Great Britain and Ireland has produced guidelines for minimum standards of monitoring during anaesthesia. An anaesthetist with appropriate experience should be present throughout general anaesthesia. Anaesthetist should make frequent observation of clinical parameters, parameters from the monitoring equipment and should undertake appropriate timely interventions. All anaesthetic equipment should be checked before use according to the manufacturer’s instructions. Alarm limits should be set at appropriate values for individual patients. All alarms should be enabled during anaesthesia and recovery.

During general anaesthesia inspired oxygen concentration, peripheral oxygen saturation (pulse oximetry), expired carbon dioxide concentration (capnograph) and electrocardiogram (ECG) are monitored continuously. Blood pressure and vapour concentration should also be monitored. In a ventilated patient ventilatory parameters such as tidal volume, minute ventilation and airway pressures should be monitored. Core temperature, invasive blood pressure, central venous pressure, cardiac output, neuromuscular block, blood loss and urine output monitoring is dictated by the nature of surgery and physical status of the patient. The following monitoring should be established during induction of anaesthesia.

- Pulse oximeter
- Blood pressure
- ECG
- Capnograph

During local anaesthesia and sedation continuous ECG, pulse oximetry, non-invasive blood pressure and respiration should be monitored. In addition a verbal contact should be maintained throughout the procedure.
Clinical monitoring

Despite the advance in technology, clinical monitoring plays a vital role because the machines used to provide information can fail at some stage. Information provided from the machines should be confirmed by clinical means. It includes extensive monitoring of the anaesthetic machine and equipment, close observation of the patient and the events in the operating theatre. Depth of anaesthesia may be monitored by clinical parameters such as movements, lacrimation, sweating, increase in heart rate and blood pressure. Cardiovascular parameters may be monitored by feeling peripheral pulses, capillary refill and auscultating the heart sounds. Respiratory parameters are monitored by observing chest movements, movement and feel of reservoir bag, auscultating lung fields and by observing the colour of lips and nail beds for cyanosis.

Monitoring with special equipment

In recent years, monitors have become popular due to the advance in technology. They provide additional information and free the anaesthetist’s hand to perform various other tasks such as preparing drugs, administration of drugs and writing notes.

Pulse oximeter

Pulse oximeter was developed in early 1970s by Aoyagi in Japan. It is the greatest advance in the patient monitoring. Its’ documented benefit in improved patient safety led to the widespread use of this technology in anaesthesia. It gives a value of oxygen...
saturation of the haemoglobin in the arterial blood. It is a simple, reliable and continuous non invasive method of detecting hypoxaemia.

Pulse oximeter probe consists of two light emitting diodes and a photo-detector. One of the photo-detector emits light at red region (660 nm wave length) and other at infrared region (940 nm wavelength). De-oxyhaemoglobin (reduced Hb) absorbs maximum light at red region (660 nm wavelength). At 940 nm absorbance of oxyhaemoglobin is greater than de-oxy haemoglobin. There is a microprocessor in the main unit with an inbuilt algorithm in which the ratio of absorption at red region to infra-red region corresponds to an empirically found saturation value. It produces a waveform of pulsatile flow. It also displays the heart rate derived from the pulse waveform. Pulse oximeters are accurate in the range of saturations of 70 – 100% (+/-2%).

In the following situations pulse oximeter may not be accurate.
- Presence of abnormal haemoglobins such as carboxy haemoglobin and methaemoglobin.
- Anaemia (below 8g/dl)
- Dyes like methylene blue leads to false low reading
- Reduced peripheral circulation due to vasoconstriction (hypovolaemia, hypotension, cold) or peripheral vascular disease results inaccurate reading.
- Venous congestion may result in low readings.
- Bright ambient light can affect the accuracy of pulse oximeter.
- Motion artefacts such as shivering or seizure activity can result in inaccurate reading.
- Presence of nail varnish may cause falsely low readings.

**Electrocardiogram (ECG)**

ECG is a surface recording of the electrical activity of the myocardium. It is recorded by connecting various electrodes through which electrical potentials are measured. ECG provides information on heart rate, rhythm and some indication of myocardial ischaemia. It doesn’t provide any indication about the adequacy of circulation.
ECG monitoring system consists of following three components
- Skin electrodes detect the electrical activity of the heart.
- An amplifier to boost the ECG signal.
- An oscilloscope displays the amplified signal.

ECG is recorded at a speed of 25 mm per second and at a standardisation of 1 cm height representing one mV of amplitude. On a standard ECG recording paper width of a small square (1 mm) represents 0.04 seconds and a large square (5 mm) 0.2 seconds. Five big squares represent a time scale of 1 second and 300 big squares represent a time scale of 60 seconds or one minute. Hence if the rhythm is regular, heart rate can be calculated by dividing 300 by number of big squares within one cardiac cycle (between two consecutive R waves).

The lead system: There are 12 conventional leads, 6 in frontal plane (I, II, III, aVR, aVL, aVF) and 6 in horizontal plane (V1-V6). The heart is situated in the centre of the electrical field which it generates. The electrical intensity diminishes as the distance increases from the centre. The lead axes from three standard leads (lead I, II & III) form a triangle known as an Einthoven triangle. In routine practice, monitors with three limb leads are used. Three electrodes are placed as follows
- one on the left arm (LA), usually colour coded as yellow
- one on the right arm (RA), usually colour coded as red
- and one on the left leg (LL), usually colour coded as green or black.

For convenience, during intra-operative monitoring left leg electrode is often placed over the left side of chest, near the apex beat.

Figure 4.3 Standard lead axes forming the Einthoven triangle.

Lead I measures the potential difference between the right arm electrode and the left arm electrode. Lead II is derived from negative electrode on the right arm and positive electrode on the left leg, measures the potential difference between right arm and left leg electrode. It is usually the best lead for detecting rhythm disturbances. Lead III measures the potential difference between the left arm and left leg. For detecting ischaemic changes, ST segment should be monitored in appropriate leads. The ST segment changes in lead V1-V4 usually monitor the left anterior descending artery territory, V4-V6 circumflex artery and lead II, III, aVF monitor the right coronary artery territory. When only bipolar leads are used then a modified V5 lead may be used for detecting ischaemia. CM5 is a modified V5 lead where the right arm
electrode of lead I is placed over the manubrium sternum, left arm electrode is placed over the left anterior axillary line in the 5th intercostal space and ground electrode is placed on the left shoulder.

Table 4.1 Electrode positions for limb leads, augmented leads and modified CM5 lead.

<table>
<thead>
<tr>
<th>Lead</th>
<th>RA</th>
<th>LA (positive)</th>
<th>LL (positive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>RA (negative)</td>
<td>LA (positive)</td>
<td>ground</td>
</tr>
<tr>
<td>II</td>
<td>RA (negative)</td>
<td>ground</td>
<td>LL (positive)</td>
</tr>
<tr>
<td>III</td>
<td>Ground</td>
<td>LA (negative)</td>
<td>LL (positive)</td>
</tr>
<tr>
<td>aVR</td>
<td>RA</td>
<td>ground</td>
<td>ground</td>
</tr>
<tr>
<td>aVL</td>
<td>ground</td>
<td>LA</td>
<td>ground</td>
</tr>
<tr>
<td>aVF</td>
<td>ground</td>
<td>ground</td>
<td>LL</td>
</tr>
<tr>
<td>CM5</td>
<td>manubrium</td>
<td>V5</td>
<td>ground</td>
</tr>
</tbody>
</table>

In a normal ECG P wave represents the atrial depolarisation, QRS complex ventricular depolarisation and T wave represents ventricular repolarisation. The P-R interval represents the time taken for the depolarisation to travel from SA node to the ventricles (via AV node and bundle of His-Purkinje system). QRS duration represents the time taken for depolarisation to travel through bundle of His-Purkinje system and ventricular muscles.

- Normal P-R interval is 0.12 -0.2 seconds.
- Normal QRS duration is less than or equal to 0.1 seconds.
- ST segment depression more than 2 mm represents myocardial ischaemia. and ST segment is elevated in myocardial infarction or myocarditis.

Continuous ECG monitoring should be used for all cases during anaesthesia and sedation. Knowledge of ECG is essential for appropriate diagnosis of peri-operative arrhythmias and ischaemic changes.

**Blood pressure**

Blood pressure is an indirect measure of blood flow and function of circulatory system. It can be measured non-invasively using a cuff and manometer or automated oscillometric method and invasively by placing a catheter in the peripheral artery.

**Non-invasive technique of measuring blood pressure**

An aneroid manometer or mercury type manometers (sphygmomanometer) can be used for manual measurement of blood pressure. Mercury sphygmomanometers need regular maintenance with suitable safety procedures in place for using mercury. Automated devices are increasingly used in current clinical practice. The cuff is inflated to a pressure above the expected systolic pressure and then slowly deflated at a rate of 2-3 mmHg per beat. At systolic pressure peripheral pulse appears which can be detected by palpation of radial or brachial artery. On auscultation over the brachial
artery characteristic sounds (described by Korotkoff) can be heard. These sounds are described in 5 phases. Phase I begins with the appearance of sounds and corresponds to systolic pressure; phase II, it becomes louder; in phase III there is a rise in volume; phase IV is muffling of sound and phase V is total disappearance of sounds. Phase V is accepted as diastolic pressure.

For accurate reading appropriately sized pneumatic cuff should be used. The maximal occlusion pressure under the cuff is proportional to the inflation pressure and cuff width. A too narrow cuff over estimates the blood pressure and a too large cuff under estimates the blood pressure. The width of the cuff should be 20% greater than the diameter of the arm and it should cover two-thirds of the upper arm. The arm should be supported at heart level.

In an automated device (figure 4.4), a pressure transducer measures the pressure and oscillations. A microprocessor controls the inflation, deflation and display of numerical value.

Disadvantages of non-invasive technique.

- Inaccurate in the presence of arrhythmias.
- Not possible to have continuous measurement.
- Not reliable in extremes of BP (underestimates when too high and vice versa).
- Pressure effects when used for prolonged time and frequent reading resulting in petechiae, nerve palsy.

**Figure 4.4 Automated device for measuring blood pressure**

In an automated device, a pressure transducer measures the pressure and oscillations. A microprocessor controls the inflation, deflation and display of numerical value.
Invasive technique of measuring blood pressure

The technique of invasive pressure measurement involves placing a cannula in the peripheral artery. Radial, dorsalis pedis, brachial and femoral arteries are commonly used. The system includes a cannula placed in the artery connected to a transducer (figure 4.5). In the transducer mechanical energy of movement of diaphragm due to arterial pulsations is converted into an electrical energy and displayed as blood pressure reading on the monitor. The cannula is continuously flushed with heparinised normal saline to prevent clotting.

Figure 4.5 Arterial cannula (radial artery) and transducer system.

Indications for direct arterial blood pressure measurement

- Cases where rapid blood pressure changes is anticipated as in cardiovascular disease, major blood loss, cardiac surgery, intracranial surgery and induced hypotension
- Need for frequent arterial blood gas analysis
- Cases where non-invasive blood pressure may be inaccurate: arrhythmias, morbidly obese patient

Disadvantages of invasive technique

- Arterial obstruction and distal ischaemia can occur due to thrombus, haematoma
- Bleeding
- Infection
- Accidental injection of drugs.
Capnography

It is the measurement of carbon dioxide concentration (ETCO₂) in each breath of the respiratory cycle. Capnograph displays a wave form (Figure 4.1) from which the respiratory rate and ETCO₂ can be measured. Monitoring expired carbon dioxide concentration provides useful information about respiratory system, cardiovascular system, metabolism and integrity of the breathing system. During induction of anaesthesia it is used to confirm the placement of tracheal tube. The contour and pattern of the waveform also provides additional information regarding re-breathing, airway obstruction and wearing off of neuromuscular block.

![Figure 4.6 Normal capnographic trace](image)

1. Inspiratory phase.
2. Upslope phase; onset of expiration.
3. Expiratory Plateau. ETCO₂ is the reading taken at the end of this phase.
4. Inspiratory down stroke; inspiration begins.

In healthy patients at normal physiological parameters, ETCO₂ approximates to the partial pressure of arterial carbon dioxide (PaCO₂). In normal lungs the partial pressure ETCO₂ is about 0.5 to 0.8 kPa less than the PaCO₂.

Hyperventilation, reduced perfusion of alveoli due to reduced cardiac output, reduced metabolism or pulmonary embolism leads to decrease in the ETCO₂. Increased metabolism, fever, re-breathing and hypoventilation results in high ETCO₂.

Infrared analysers are most commonly used to measure end-tidal carbon dioxide concentration. Gas molecules having two or more dissimilar atoms absorb infrared light. CO₂ has a strong absorption band at a wavelength of 4.26 µm. The amount of infrared radiation absorbed is proportional to the carbon dioxide concentration.
Monitoring of anaesthetic agent concentration

Most often general anaesthesia is maintained using inhalational (volatile) anaesthetic agents. Inspired and expired concentration of anaesthetic agent should be continuously monitored. Again infrared analysers are commonly used for measuring anaesthetic concentration.

Monitoring inspired oxygen concentration

In view of avoiding hypoxia it is important to continuously monitor inspired or expired oxygen concentration. Oxygen concentration in a gas mixture can be measured using paramagnetic technique, or a fuel cell. Partial pressure of oxygen in the blood can be measured using a Clark electrode.

Monitoring depth of anaesthesia

Depth of anaesthesia can be monitored using electro encephalogram (EEG) which involves surface recording of the electrical activities from the cerebral cortex. In practice the information is obtained from EEG is difficult to interpret and the pattern of EEG is also affected by various pathophysiological events like hypoxia, hypotension and hypercarbia. Recently Bispectral index (BIS) monitor has been used as depth of anaesthesia monitor. This monitor generates a number called bispectral index on a continuous scale of 0 to 100. 100 represents normal cortical activity and 0 represents no cortical activity. BIS values of 40-60 imply adequate depth of anaesthesia.

Monitoring neuromuscular function

This helps to assess the onset of neuromuscular block, depth of neuromuscular block and adequacy of recovery from neuromuscular block. Most often a peripheral nerve stimulator is used. The principle involves transcutaneous electrical stimulation near a nerve and assessment of muscle response by visual inspection or by palpation of the muscle.
Monitoring temperature

Body temperature usually decreases during intra-operative period. There is heat loss from radiation, convection, evaporation and respiration. General anaesthesia depresses thermoregulatory centre and most of the anaesthetic agents produce vasodilatation, facilitating heat loss. Other factors such as infusion of cold i.v. fluids, exposure of body cavity, low room temperature all can further increase heat loss. Temperature should be monitored during major surgery and in all cases where heat loss is anticipated.

Figure 4.8 Tympanic thermometer

Temperature can be measured using non-electrical thermometer such as mercury thermometer and electrical thermometers such as thermister, thermocouple and resistance thermometer. Due to the limitations and risks involved with mercury thermometer, electrical thermometers are preferred. Temperature probes that are based on the principle of thermocouple are used in clinical practice to measure temperature. Most commonly used sites for temperature measurement are nasopharynx, and tympanic membrane.

Measurement of central venous pressure, cardiac output and pulmonary artery wedge pressure are sometimes used for major surgeries and in patients with cardiovascular disease. Central venous pressure is monitored by placing a long catheter in the internal jugular vein or subclavian vein. Balloon-tipped pulmonary artery catheter is used to assess left atrial pressure and pulmonary artery pressure. Cardiac output can be measured using oesophageal Doppler or thermodilution techniques.

Further reading

Warwick Medical School- Handbook of Anaesthesia 2006

Fearnley SJ. Pulse oximetry. Anaesthesia Update, 1995 (issue 5). http:// www.nda.ox.ac.uk
