NON-INVASIVE MONITORING DURING ANAESTHESIA
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This article deals with the rationale and techniques for non-invasive measurement and monitoring by which anaesthesiologists monitor organ function during anaesthesia care. The descriptions of the technologic and scientific principles used in monitoring devices have been simplified for clarity.

Human beings and machines
The best and main monitor in the operating room is always the anaesthesiologist. An anaesthesiologist could monitor whole of the patient’s condition and follow the course of the surgery, anticipating problems and correcting them as and when they occur. The vigilant anaesthesiologist continuously obtains subjective and objective information from the anaesthetized subject. Subjective monitoring depend on the anaesthesiologist’s senses (visual, tactile, auditory, ‘sixth sense’) and the experience. By contrast, even the most sophisticated electronic monitors are inherently limited. They can monitor only one aspect of the patient’s condition. They require electrical power, need regular maintenance, occasionally develop faults and are prone to error. Their advantage is that, they do not succumb to stress, boredom, fatigue, and distraction.

However, it is not possible for the anaesthesiologist to be completely vigilant at all times. Thus, the monitors do not ‘replace’ the anaesthesiologist, however, extend their range and sometimes increase their accuracy. They may also free the hands of the anaesthesiologist to perform other important tasks (maintaining airway, preparing drugs, etc.) and may be the only way of observing inaccessible patients during MRI or CT scan.

The interface problem
The interface of patient and monitoring equipment is often the major limiting factor in the collection of good quality, reliable data. Movement artefact and limitation of mobility are the two major factors affecting the quality of non-invasive monitoring. However, these problems are minimized during general anaesthesia. Non-invasive monitoring are in general, simple, quick and safe, but suffer from a relative lack of accuracy and quality.

Commonly employed non-invasive monitors

Monitoring of the respiratory system
A. By anaesthesiologist (clinical)
B. By machines: Pressure and flow; Gases and vapours (O₂ and CO₂); Gas analyzers: (infrared spectrometry, paramagnetism, Galvanic and polarographic cells, mass spectrometer, Raman spectrometry, other methods for tidal volume).

Monitoring of the cardiovascular system
A. By anaesthesiologist (clinical)
B. By machines: Precordial and oesophageal stethoscope, electrocardiogram, pulse oximetry, non-invasive blood pressure (automated), sphygmomanometer, continuous non-invasive finger blood pressure measurement.

Monitoring the depth of anaesthesia
A. By anaesthesiologist (clinical signs)
B. By machines: Electroencephalogram, auditory evoked potentials, bispectral index, oesophageal contractility, frontalis EMG.

Monitoring of the neuromuscular system
A. By anaesthesiologist (clinical)
B. By machines: Evoked responses; Nerve stimulation, electrical stimulation, magnetic stimulation, single twitch, train of four, tetanus, post-tetanic count, double burst stimulation.

Temperature monitoring
A. Core temperature
B. Types of thermometer
C. Sites of monitoring: oesophageal, nasopharyngeal, tympanic membrane, rectal, bladder.

Monitoring of Renal Function
Estimation of urine output can be a useful guide to intravascular fluid volume. Monitoring of urine output also permits early detection of haemoglobinuria, an initial sign of haemolytic transfusion reactions.

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Discussion in this article is limited to clinical monitoring by the anaesthesiologist and the other non-invasive monitoring techniques, which are not dealt separately in this issue.

**Monitoring of respiratory function**

**Clinical monitoring**

The importance of a clear airway and adequacy of ventilation can never be over emphasized in the practice of anaesthesia, because most of the accidents result from failure to ensure them. Simple things like proper movement of the chest wall bilaterally, sounds of gurgling etc. are useful guides. The reservoir bag is a very useful monitor; a great deal can be derived both from watching the reservoir bag movement and from squeezing it as is tabulated below.

### The reservoir bag

<table>
<thead>
<tr>
<th>Observation</th>
<th>Interpretation</th>
<th>Possible causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does not fill</td>
<td>No gas</td>
<td>• Disconnection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Low fresh gas flow into circle system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fresh gas failure</td>
</tr>
<tr>
<td>Bulging</td>
<td>Gas outflow obstruction</td>
<td>• Expiratory valve closed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Valve stuck</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Faulty scavenging</td>
</tr>
<tr>
<td>Pulsation synchronous with heart beat</td>
<td>Airway clear</td>
<td>• Apnoea with cardiac pulsation</td>
</tr>
<tr>
<td>Small movement and little patient effort</td>
<td>Respiratory depression</td>
<td>• Vapours and anaesthetic drugs</td>
</tr>
<tr>
<td>Small movements with obvious patient effort</td>
<td>Obstruction</td>
<td>• Anywhere between alveolus and bag</td>
</tr>
<tr>
<td>Easy to squeeze</td>
<td>Leak</td>
<td>• Valve open</td>
</tr>
<tr>
<td>Refills slowly</td>
<td></td>
<td>• Bag leak</td>
</tr>
<tr>
<td>Difficult to squeeze</td>
<td>Reduced compliance</td>
<td>• Endobronchial intubation</td>
</tr>
<tr>
<td>Refills rapidly</td>
<td></td>
<td>• Relaxants wearing off</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Surgeons leaning on chest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Steep head down</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Diaphragm packed/splinted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pneumothorax</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pulmonary oedema</td>
</tr>
</tbody>
</table>

### Pressure and flow

In spontaneously breathing patient, observation of reservoir bag confirms an adequate tidal volume. Similarly during hand ventilation, disconnections and airway problems are immediately obvious. But, when ventilation is taken care of by machine, the potential for mishap is great and thus it is mandatory to monitor the airway pressures and preferably the expired tidal volume as well.

Ventilator disconnect alarms are among the cheapest and most useful monitors. They simply check over and over that ventilation is still occurring. In the simplest devices, the alarm sounds if during a 10 second interval the airway pressure fails to reach the preset threshold (commonly 7-10 cm H₂O). More complex alarms allow the apnoea time and airway pressure limits to be varied.

**Gases and vapours**

This is a major advance in monitoring the concentration of individual gases breathed in and out which can only be measured by machines which the chart below delineates.

### Gas and vapour monitoring

<table>
<thead>
<tr>
<th>Gas constituent</th>
<th>How measured</th>
<th>Why measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>Infrared spectroscopy</td>
<td>Tracheal tube position</td>
</tr>
<tr>
<td></td>
<td>Mass spectroscopy</td>
<td>Visual indicator of gas exchange</td>
</tr>
<tr>
<td></td>
<td>Raman spectroscopy</td>
<td>Adequacy of ventilation</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Paramagnetism</td>
<td>Adequate oxygen in mixture</td>
</tr>
<tr>
<td></td>
<td>Chemical</td>
<td>In low flow systems, increasing oxygen</td>
</tr>
<tr>
<td></td>
<td>Fuel cell</td>
<td>Oxygen suggests driving gas is contaminating</td>
</tr>
<tr>
<td></td>
<td>Polarographic</td>
<td>Breathing system</td>
</tr>
<tr>
<td></td>
<td>Mass spectroscopy</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Mass spectroscopy</td>
<td>Accumulates in low flow systems</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>Infrared spectroscopy</td>
<td>In low flow systems, concentration unpredictable</td>
</tr>
<tr>
<td></td>
<td>Mass spectroscopy</td>
<td>Too high, suggests oxygen too low</td>
</tr>
<tr>
<td></td>
<td>Raman spectroscopy</td>
<td>Too low, suggests contamination of breathing system</td>
</tr>
<tr>
<td>Anaesthetic vapours</td>
<td>Infrared spectroscopy</td>
<td>Guard against awareness (especially in low flow systems)</td>
</tr>
<tr>
<td></td>
<td>Mass spectroscopy</td>
<td>Avoid accidental overdose</td>
</tr>
<tr>
<td></td>
<td>Raman spectroscopy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Piezo absorption</td>
<td></td>
</tr>
</tbody>
</table>

Pulse oximetry and capnography which are accepted and used universally are discussed in detail elsewhere in this issue.

**Monitoring of cardiovascular functions**

**Clinical observations**

Continuous or intermittent palpation of an accessible peripheral artery is part of the qualitative clinical assessment of circulatory homeostasis. The adequacy of cardiac output and thus perfusion can also be reasonably well assessed from the simple habit of regularly palpating the arterial pulsation. Likewise, inspection of neck vein may suggest low, normal, or high central venous pressure. Auscultation of the heart, especially by attaching the chest piece of stethoscope over precordium is also useful.

Much simpler however, highly informative are the observations of skin and mucous membranes. Examples are: whether patient looks well perfused, pale, or cyanosed; the capillary refill; the colour of conjunctivae; and tissue turgor; the rash of anaphylactoid reactions. Therefore, whenever possible a portion of the patient should be exposed to permit such essential monitoring.
Electrocardiogram monitoring which is a time tested, popular monitoring technique is discussed elsewhere in this issue.

**Blood pressure**

Although adequate tissue delivery of oxygen is the *sine qua non* of cardiopulmonary homeostasis, the primary variable continuously sensed and regulated by the body’s homeostatic mechanisms is not systemic or individual organ blood flow but rather blood pressure. There exists a critical systemic arterial pressure below which perfusion of vital organs is compromised and cardiopulmonary homeostasis is lost. Therefore, measurement of systemic arterial blood pressure, an indirect indicator of circulatory well-being, is one of the several clinical monitoring elements necessary for safe conduct of anaesthesia. In most patients, intermittent non-invasive monitorings are sufficient. Non-invasive techniques usually provide good estimates of systolic blood pressure, but less accurate diastolic and mean arterial pressure.

Measurements of arterial blood pressure are greatly affected by the sampling site. As the arterial pulse moves peripherally through the arterial tree, wave reflection distorts the pressure wave form, leading to an exaggeration of systolic and pulse pressures. For example, radial artery systolic pressure is higher than aortic systolic pressure because of the former’s more distal location. In contrast, radial artery systolic pressures are often lower than aortic pressures following hypothermic cardiopulmonary bypass because of a decrease in hand’s vascular resistance. Within the aorta, the pulse wave form is broad, becoming thinner and taller as it moves distally.

**Non-invasive blood pressure monitoring**

Methods used depend on the principle that arteries are elastic and can be occluded by inflatable cuff with pressure greater than that of the systolic blood pressure. The degree of occlusion can then be detected by some means. Hence, application of cuff correctly on the skin (snugly fitting) with the cuff lying over the artery is very important. If the cuff is too narrow, the pressure transmitted to artery would be less than within the cuff and that would provide falsely high readings. In obese patients, the cuff may slide down over the elbow. Thus, the auscultatory method provides unreliable readings.

**The Sphygmomanometer**

The traditional Riva Rocci method of indirect measurement of arterial pressure remains a basic but standard method for use in many anaesthetic settings. Although it is a bit cumbersome for routine intraoperative use however, very good for recovery areas. Pressure within the cuff is displayed by a column of mercury or an aneroid gauge. The cuff is inflated to more than 30 mm Hg above the pressure at which the arterial pulsation disappears. As the pressure within the cuff is gradually reduced, systolic pressure is detected by the presence of turbulence in the artery and this turbulence is detected by a stethoscope (Korotkoff sounds) over the brachial artery just distal to the cuff. Systolic blood pressure coincides with the onset of Korotkoff sounds; diastolic pressure is variably determined as their muffling or disappearance. Occasionally, Korotkoff sounds cannot be heard through part of the range from systolic to diastolic pressure known as diastolic gap, commonly found in hypertensive patients and can lead to an inaccurate low measurement.

**Oscillotonometer**

Arterial pulsations cause oscillations in cuff pressure. These oscillations are small if the cuff is inflated above systolic pressure. When the cuff pressure decreases to systolic pressure, however, the pulsations are transmitted to entire cuff and the oscillations markedly increase. Maximum oscillation occurs at mean arterial blood pressure, after which oscillations decrease. Automated blood pressure at which oscillation amplitudes change. A microprocessor derives systolic, mean, and diastolic pressures using an algorithm.

The oscillometric monitors should not be used on patients being perfused with a heart-lung machine. Nonetheless, the speed, accuracy, and versatility of these devices have greatly improved and they are now preferred automated non-invasive blood pressure monitors at operation theatre. The great advantage of such a monitor is that, it frees the anaesthesiologist for other tasks. Time span after which pressure recording is required can also be set and the machine can store data to provide trends, if required. The disadvantage include that the machine frequently fail when faced with profoundly shocked patients and in those with arrhythmias.

**Continuous non-invasive finger blood pressure measurement**

Invasive beat-to-beat arterial blood pressure monitoring is considered the ‘gold standard’, as it is both accurate and reliable. However, cannulation of radial artery is associated with a risk of local infection, haematoma formation, or thrombosis. Therefore, non-invasive method providing accurate and reliable data are required.

In 1973, Penaz described the volume clamp technique whereby a continuous non-invasive arterial pressure waveform could be obtained from a finger cuff. The blood volume of the finger varies in clinical fashion with each cardiac cycle because of the attendant variation in systemic blood pressure. This variation is detectable by a plethysmograph attached to the finger. If a pneumatic
finger cuff can be inflated and deflated rapidly enough to maintain constant finger blood volume then the arterial wall has been ‘unloaded’ i.e. the cuff pressure must be equal to the intra-arterial pressure. A display of the cuff pressure should, therefore, represent the intra-arterial pressure waveform of the digit and the analysis of the cuff waveform would allow measurement of systolic, diastolic, and mean blood pressure. The principles have been embodied in the Finapres and with modifications in the Portapres.

Finger blood pressure measurement is an advance in the monitoring of patients admitted to the emergency department. However, a final comment on its use in intensive care units is not possible due to the lack of data.

Precordial and Oesophageal Stethoscopes

According to many anaesthesiologists all anaesthetized patients, especially the paediatrics should be monitored with a precordial or oesophageal stethoscope. Both the stethoscopes individually, permit the anaesthesiologist to monitor heart and breath sounds continuously. A moulded ear piece renders the device more comfortable.

**Technique:**

The weighted diaphragm of a (preferably) single-tube stethoscope may be placed over the precordium or suprasternal notch. Although the weight of chestpiece tends to maintain its position, double sided adhesives provide an acoustic seal to the patient’s skin. The stethoscope is connected to the anaesthesiologist by extension tubing.

The oesophageal stethoscope is a soft plastic catheter with a balloon-covered distal opening. The stethoscope may be passed down the oesophagus and the tip being kept at the junction of middle 1/3 and lower 1/3. This being near to the heart, thus the breath sounds and the heart sounds are more clearly audible. Although the quality of breath and heart sounds would be audible better with an oesophageal stethoscope however, its use is limited only to intubated patients. Temperature probe, ECG leads and even arterial pacemaker electrodes have been incorporated into such stethoscope. Insertion of oesophageal stethoscope is contraindicated in oesophageal varices or strictures.

**Clinical consideration:** The information provided by such stethoscopes include confirmation of ventilation, quality of breath sounds (e.g. wheezing), regularity of heart rate and quality of heart tones (muffling of reduced cardiac output).

**Monitoring depth of anaesthesia**

**Clinical signs:** The paralysed patient can only respond via the autonomic nervous system. Increased sympathetic activity with tachycardia, hypertension, pupillary dilatation and sweating are indicative of too light a level of anaesthesia.

The other non-invasive monitors which measure depth of anaesthesia viz. EEG, Bispectral Index monitor, etc are dealt in detail elsewhere in this issue.

**Temperature monitoring**

The ability to monitor body temperature is a standard of anaesthesia care. The continual observation of temperature changes in anaesthetized patients allows for the detection of accidental heat loss or malignant hyperthermia. Humans maintain their core temperature by balancing heat production from metabolism and the many environmental factors that supply heat or cool the body. Body temperature often decreases 1°C to 4°C during anaesthesia and surgery performed in cold rooms. Although this decrease is usually not serious, postoperative awakening may be delayed, and shivering, when it occurs, may increase oxygen requirements by as much as 300-400%. Intraoperative hyperthermia is less common but certainly can occur. It is usually due to overvigourous warming with heating pads or blankets, heated airway humidifiers, warm ambient temperatures, or, occasionally, development of a febrile illness and due to malignant hyperthermia. The maximum body temperature that is survivable in humans is 42-43°C, however, no such figure can be accurately stated for low temperatures. Therefore, temperature monitoring should always be done in every major surgery.

**Core temperature**

For clinical purposes core temperature can be measured at a number of body sites chosen for their accessibility, comfort, and safety. The best sites for determining central or core temperature are the distal oesophagus, and the tympanic membrane. Temperature at the tympanic membrane is a close approximation of hypothalamic temperature, the area of the brain controlling thermoregulation.

Each site has advantages and disadvantages. The tympanic membrane temperature theoretically reflects the temperature of blood perfusing the brain because the auditory canal’s blood supply is through the external carotid artery which is perfusing the brain. Trauma during insertion detracts from the routine use of tympanic probes. Rectal temperatures have a slow response to changes in core temperature and thus they are very unreliable. Nasopharyngeal probes are likely to cause epistaxis but
accurately measure core temperature when placed adjacent to the nasopharyngeal mucosa and a cuffed tube in the trachea prevents artificial cooling of the nasopharynx by respiratory gases. Oesophageal temperature sensors, often incorporated into oesophageal stethoscopes, provide the best combination of economy, performance, and safety.

Intraoperatively, temperature is usually measured by a thermistor or thermocouple. Thermistors are semiconductors whose resistance decreases predictably with warming. A thermocouple is a circuit of two dissimilar metals joined so that a potential difference is generated when the metals are at different temperatures. Disposable thermistor and thermocouple probes are available for monitoring core temperature.

It is useful to measure simultaneously both core and skin temperature. The difference between the temperatures indicates the degree of vasoconstriction or vasodilatation, which may help to assess the adequacy of fluid replacement of the patient.

**Urine output**

Perfusion and function of the kidney is reflected through the output of urine. Moreover, urine output indicates the renal, cardiovascular, and fluid status of the patient. Inadequate urine output (oliguria) is often defined arbitrarily as less than 0.5 mLkg⁻¹hour⁻¹, but actually is a function of the patient’s concentrating ability and osmotic load.

Urinary bladder catheterization is the only reliable method of monitoring urine output. Insertion of a urinary catheter is indicated in patients with congestive heart failure, renal failure, advanced hepatic disease or in shock. It is also a routine in some surgical procedures such as cardiac surgery, aortic or renal vascular surgery, craniotomy, major abdominal surgery or procedures in which large fluid shifts are expected. Lengthy surgeries and intraoperative diuretic administration are other possible indications.

**Monitoring of neuromuscular function**

Neuromuscular blocking drugs are extensively used in anaesthesia. Patient sensitivity to such drugs is extremely variable. Neuromuscular function of all patients receiving neuromuscular blocking agents should be monitored in view of the danger of inadequate recovery of muscle power at the end of the operation. Moreover, such monitoring also helps in assessing the blockade during rapid sequence induction or during continuous infusion of short-acting neuromuscular blocking agents. In regional anaesthesia, a peripheral nerve stimulator helps in localizing the nerve and determine the sensory blockade.

**Clinical assessments**

Neuromuscular function may be assessed clinically, at the end of the operation by asking the patient to open his/her eyes, protrude the tongue or by grip strength. A ‘sustained head lift’ for at least 5 seconds is a more or less reliable indicator that the respiratory muscles have been adequately functioning. However, these measurements can also be affected by residual anaesthetics — intravenous or inhalational, and central nervous system depressants viz. opiates, benzodiazepines, etc. These tests also require patient co-operation and may not be possible at the end of an operation.

Evoked potential measurements, which monitor the NMJ blockade, are best explained in detail, in the separate article, elsewhere in this issue.

**Conclusion**

Monitoring aims to improve the quality of care which the patient receives during anaesthesia, by increased access to physiological information. The development of methods to deliver to the anaesthesiologist further derived data — displayed on a real-time basis, in a manner which can be easily perceived and understood — should enable the anaesthesiologist further to improve the regulation of the cellular environment.

**Suggested Reading**