and preserve the integrity of the eighth nerve during posterior fossa surgery, as well as brain stem function during operations on aneurysms of the vertebral basilar artery system.

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Monitoring the lung

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With induction of anaesthesia and its attendant alterations in gas exchange, the anaesthetist monitors lung function using instruments that must not only measure but warn. Measurement and warning are not necessarily synonymous and the latter function is often assumed by the anaesthetist. Thus, all mechanical and electronic methods are supplemental to physical examination, i.e., *inspection, palpation, percussion* and *auscultation*. The use of a precordial or oesophageal stethoscope is a mandatory intraoperative monitor; the risks are nil, the benefits enormous. But, just as the presence of electrical cardiac activity does not guarantee systemic perfusion, neither does the presence of breath sounds guarantee adequate alveolar gas exchange. Thus ancillary techniques and instrumentation have been developed to monitor both carbon dioxide and oxygen exchange.

Carbon dioxide

Inspection of the reservoir bag permits an estimate of minute volume (VE) in spontaneously breathing subjects. However, anaesthetic circuits or faulty valves which permit rebreathing, can mislead the clinician. The fundamental equation of factors that determine alveolar CO_2 concentration has been described.[1] Since anaesthesia can produce respiratory depression and rebreathing of CO_2 can be highly variable, the use of qualitative monitors of spontaneous ventilation, such as respiratory rate, tidal volume, movement of reservoir bag, chest-abdominal movement, the stethoscope and transthoracic electrical impedance measurements, are unreliable substitutes for measurement of alveolar or arterial PCO_2. End-tidal CO_2 can be monitored using an infra-red capnograph or mass spectrometer. However the end-tidal CO_2 to arterial PCO_2 gradient increases in patients with pulmonary disease, making this monitor unreliable in the high-risk group. Transcutaneous CO_2 monitoring ($TcPCO_2$) has limitations, but may be useful in specific cases.

Oxygen

Minor alterations of $PaCO_2$ are usually benign; however, this is not true for PaO_2. Potential causes of hypoxaemia are:

1. decreased FiO_2
2. decreased alveolar ventilation (VA)
3. increased V/Q mismatching
4. any right to left shunt
5. decreased PvO_2 in – anaemic states
   – low cardiac output states
   – increased VO_2 conditions.

FiO_2 should always be monitored with a properly calibrated oxygen analyser in the inspiratory limb of the breathing circuit. Future design improvements[3] will improve FiO_2 monitoring and reduce the incidence of hypoxic gas delivery due to human error or machine mulfunction.

The most frequent cause of decreased VA induced hypoxaemia is a disconnection during mechanical ventilation.[4] Anaesthetic ventilators should only be used in conjunction with low-

pressure disconnect alarms, although such threshold alarms are not failsafe.[5] Low-flow techniques with standing bellows[6] also assist monitoring for circuit leaks. A high-pressure monitor (e.g., Norrie "pop-off" valve) detects and warns of airway obstruction. This is more useful than the airway pressure manometer which does not serve the warning function.

The last three causes of hypoxaemia can be detected only by monitoring arterial or tissue PO_2. Three techniques are available:

1. transcutaneous oxygen analyzers ($TcPO_2$)
2. intra-arterial PO_2 sensors
3. oximetry

All three techniques have inherent limitations. $TcPO_2$ detects capillary PO_2 but has limited usefulness in underperfusion and obese states and needs a 30–45 minute warm-up.[7] Intra-arterial PO_2 sensors[8] are expensive, invasive and are altered by temperature, blood flow rate and N_2O concentration. Pulse oximetry,[9] a non-invasive routine monitor of oxyhaemoglobin saturation, is the most likely of the three techniques to be adopted routinely.

In conclusion, current technology provides reliable, versatile techniques to monitor lung function. However, some factors are so vital to patient survival that they should always be monitored, i.e., inspired oxygen concentration, airway pressure and disconnect alarms.

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Monitoring the heart

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Monitoring the heart may be considered from two aspects: (1) the function and (2) perfusion and oxygenation.

Cardiac function

The function of the heart is to generate sufficient pressure and flow to perfuse the body organ systems, including itself. Although pressure monitoring today is not difficult, measurement of organ flow remains a critical problem. Unless the patient is at relatively high risk, most practitioners are unwilling to accept the morbidity and (rare) mortality associated with the placement of a thermodilution pulmonary artery (PA) catheter. Various attempts at noninvasive monitoring of cardiac output have met with limited success. Analysis of arterial pulse contours and measurement of thoracic impedance have serious limitations of quantitation, although both give valuable information in terms of trends in cardiac output. Use of more sophisticated, complicated and expensive devices is possible, but may be cost-limited. The various types of ultrasound, including echocardiography and Doppler flow analysis can quantitatively measure the pumping function of the heart. However, for access to meaningful information, rather complicated com-