The anaesthetic machine

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Abstract

In 1917, Dr Henry Edmund Gaskin Boyle OBE developed his continuous-flow anaesthesia machine, the design of which is the forerunner of all modern anaesthetic machines. This prototype has undergone significant changes to increase the efficiency of anaesthesia and patient safety. Gases (oxygen, nitrous oxide and air) arrive at the machine via the hospital's piped medical gases and vacuum system via colour-coded tubing. Cylinders attached to the back of the machine provide a back-up supply. Cylinder gases pass through pressure-regulating valves into the 'back bar' of the machine, but pipeline gases are supplied at 'back bar pressure' of 4 bar. From the back bar, gas flow rate is set using a needle valve that regulates flow into the flowmeter of which Rotameter™ is one trademarked example. Rotameters are fixed pressure, variable orifice flowmeters which are accurate to within ±2.5%.

Many modern anaesthetic machines have electronic gas mixers rather than conventional rotameters. The gases then pass through a vaporizer where volatile anaesthetic is added to the fresh gas flow. This mixture is delivered, via the common gas outlet, to a patient breathing circuit, nowadays usually a 'circle system'. This contains a carbon dioxide absorber to stop patients re-breathing and allows higher efficiency than other systems. Waste gases are scavenged from the circle. Monitoring, ventilators and suction apparatus are mounted on the machine. The anaesthetic machine should be thoroughly tested prior to use.

Keywords Anaesthetic machine; electronic gas mixing; gas; pressure-relief valve; rotameter; scavenging

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Learning objectives

After reading this article, you should be able to:
- describe the path that anaesthetic gases take from the hospital supply to the patient, and explain how they are removed from the theatre environment
- list the safety features built into the anaesthetic machine to prevent a hypoxic mixture being delivered to the patient
- describe the ways in which modern anaesthetic machines have been adapted to improve efficiency and safety

In 1917, 'Cocky' Boyle developed a machine designed to deliver anaesthesia. Current anaesthetic machines in use in the UK are all developed from his original design[1] and are influenced by his left hand dominance. The basic principle involves supplying pressurized gas to the anaesthetic machine, which regulates the pressure prior to passing through a vaporizer for the addition of a volatile anaesthetic. The gas mixture is then delivered to the patient via a breathing system.

Power supply

Modern anaesthetic machines are connected to an electrical supply to power the ventilator and integrated monitors. Before use, the machine must be connected directly to mains electricity and switched on. In the event of power failure, modern machines often contain a back-up power source, and the charge status of the battery is checked as part of the machine 'self-test'.

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Gas supply

Gases are required to provide continuous-flow anaesthesia. These are delivered to the machine either from a piped supply or from cylinders.

Piped gas supply

Hospitals' piped medical gases and vacuum (PMGV) systems supply gases. The PMGV oxygen supply comes either from a cylinder manifold or from a vacuum-insulated evaporator (VIE), a large device for storing liquid oxygen. Banks of cylinders are used to supply nitrous oxide and air although some hospitals use a compressor for the latter. Some hospitals now use oxygen concentrators to provide their piped supply. These gases are delivered to a terminal outlet (Schrader valve) that has a collar specific for each gas; they are also individually labelled and colour-coded.

Delivery of piped gas to the machine

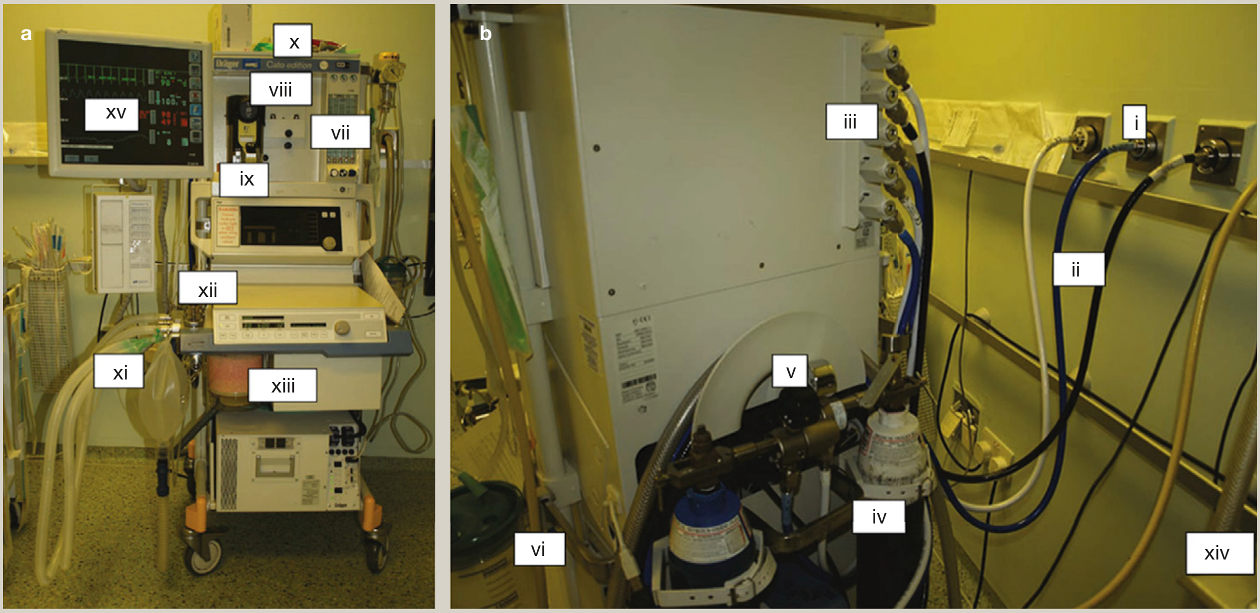
Flexible hosing links the piped supply to the machine, where it is connected with a non-interchangeable screw thread (NIST) connection.

Cylinder gas supply

All machines must have at least two oxygen sources in case of failure of one. This second source is an oxygen cylinder housed on the back of the machine (Figure 1, iv). The standard size E cylinder is supplied at 134 bar and contains 680 litres of oxygen. Other cylinder gases, such as air and nitrous oxide, are also often present. A pin-index system is used as a safety system to ensure the incorrect cylinder cannot be attached to the machine. A Bodok seal separates the cylinder from the yoke and provides a gas tight connection. The neoprene inner of the seal is delicate and so yokes should be carefully hand tightened to avoid damage and leaks.

Pressure gauges

Colour-coded Bourdon gauges indicate the pressures of the piped and cylinder supplies. Many newer machines display numerical pressure values on their screens.



The back (**a**) and the front (**b**) of the anaesthetic machine is shown. The following are identified: (i) piped medical gases and vacuum supply, with Schrader probes inserted into the Schrader terminal outlets on the wall; (ii) colour-coded pipes; (iii) non-interchangeable screw thread; (iv) gas cylinders (oxygen on the right and nitrous oxide on the left) mounted on the back of the machine; (v) Bourdon pressure gauges; (vi) suction apparatus, connected to the hospital vacuum supply by the yellow tubing near (ii); (vii) rotameters; (viii) back bar, with empty vaporizer housing just below legend; (ix) sevoflurane vaporizer in position; (x) emergency oxygen flush; (xi) circle system (attached via the common gas outlet which is not visible); (xii) adjustable pressure limiting valve; (xiii) carbon dioxide absorber; (xiv) scavenging tubing; (xv) patient monitoring system. See the main text for further details.

Figure 1

Pressure-regulating valves

Cylinders contain gases at higher pressures than the PMGV supply so pressure-regulating valves bring the cylinder supply to an operating pressure of 400 kPa (4 bar) — consistent with the piped supply.

Oxygen failure alarm

If oxygen pressure falls an alarm must sound. Originally, this alarm was a mechanical device called a Ritchie whistle powered by the nitrous oxide supply but modern anaesthetic machines employ electronic alarms. This is checked by disconnecting the oxygen pipeline.

Gases are transported through the anaesthetic machine in nylon tubing to the back bar.

Flowmeters

Gases pass through an adjustable needle valve into flowmeters to accurately measure gas flow through the anaesthetic machine. The conventional form of a flowmeter is known as a Rotameter™.

These are constant pressure, variable orifice devices. Rotameters have a ball or bobbin which moves proportionally to the gas flow within a tapered glass tube (wider at the top than bottom). The pressure across the bobbin is fixed, as the upward flow of gas being measured is opposed by gravity acting on the bobbin. At low flows, the area around the bobbin is small due to the conical shape of the flowmeter, and it behaves like a tube. Here, flow is laminar and therefore dependent on viscosity. At higher flow rates, the clearance between the bobbin and the wall is large in comparison to the length of the bobbin. Flow at this point is as though through an orifice, which is turbulent, and therefore dependent on density. Each rotameter is calibrated for a specific gas at atmospheric temperature and pressure and is accurate to within $\pm 2.5\%$. Most machines have three rotameters, for oxygen, air and nitrous oxide.

The rotameter has several safety features:

- colour-coding of rotameter display units and needle valve control knobs for each gas
- the oxygen knob is larger and octagonal in shape and projects out further so that it is identifiable in darkness, and, in the UK, is always located to the left of the other rotameter knobs for nitrous oxide and air
- oxygen is added last to the gas mixture to prevent any being lost if there is damage to the other rotameters (Figure 2)
- the nitrous oxide is cut off in the event of oxygen failure. This is done either by a ratio-mixer valve, a chain linkage between the oxygen and nitrous oxide needle valves or electronically using oxygen analysers
- the rotameters have an internal anti-static coating of precious metal to prevent sticking of the bobbin
- the bobbins rotate to provide visual confirmation of flow.

Some modern anaesthetic machines, such as the Dräger Primus, do not have rotameters. They deliver fresh gas of a desired flow rate and oxygen concentration by the use of

