The anaesthetic machine

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Abstract

In 1917, Dr H Edmund G Boyle developed his continuous-flow anaesthesia machine, the design of which is the forerunner of all modern anaesthetic machines. This 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 must be present to provide a back-up supply of gases. The gases pass through pressure-regulating valves into the 'back bar' of the machine. From there, gas flow rate is set using a needle valve that regulates flow into the rotameter. Rotameters are fixed pressure, variable orifice flowmeters which are accurate to within ±2.5%. Modern anaesthetic machines may have electronic gas mixers rather than conventional rotameters. The gases pass through a vaporizer where anaesthetic is added to the fresh gas flow. This mixture is delivered, via the common gas outlet, to a patient breathing circuit, usually a 'circle system'. This circulates gases and vapours and contains a carbon dioxide absorber to stop patients re-breathing carbon dioxide. Waste gases are scavenged. Monitoring, ventilators and suction apparatus are all incorporated into the machine.

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

Learning objectives

After reading this article, you should be able to:
- describe the journey that anaesthetic gases take from the hospital supply to the patient, and explain how they are removed from the theatre environment
- list all the safety features incorporated 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, Boyle developed a machine designed to deliver anaesthesia. Current anaesthetic machines in use in the UK are all developed from his original design.[1]

Power supply

Although the delivery of pressurized gas through a plenum vaporiser, even mechanical ventilation can be achieved without electrical power, modern machines incorporate an electrical supply to power the ventilator and integrated monitors. Before using the machine, ensure that it is plugged in and switched on. This also activates the pneumatic parts of the machine.

Gas supply

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

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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. Some hospitals now have oxygen concentrators to provide their piped supply. These gases are delivered to a terminal outlet (Schrader valve) that is specific for each gas; they are individually shaped, 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 of them. This second source is an oxygen cylinder housed on the back of the machine (Figure 1, iv). Other cylinder gases, such as air and nitrous oxide, are also often present.

Pressure gauges

Colour-coded Bourdon gauges indicate the pressures of the piped and cylinder supplies.

Pressure-regulating valves

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

Oxygen failure alarm

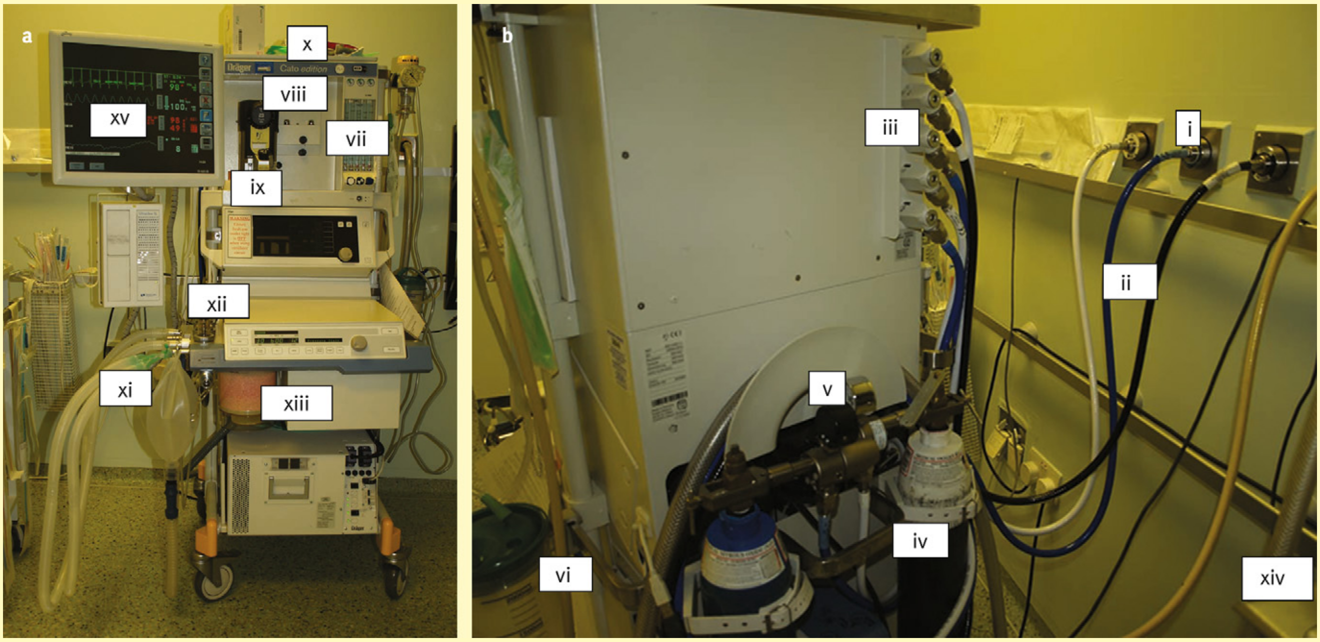
If oxygen pressure falls an alarm must sound. Originally, this alarm was a mechanical device called a Ritchie whistle but modern anaesthetic machines employ electronic alarms.

Gases are transported through the anaesthetic machine in nylon (previously copper) tubing to the back bar.

The back bar (Figure 1)

Flowmeters

Gases pass through an adjustable needle valve into flowmeters to accurately measure gas flow through the anaesthetic machine.



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

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 like 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 $+/-2.5\%$. 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

Gas flow through rotameters

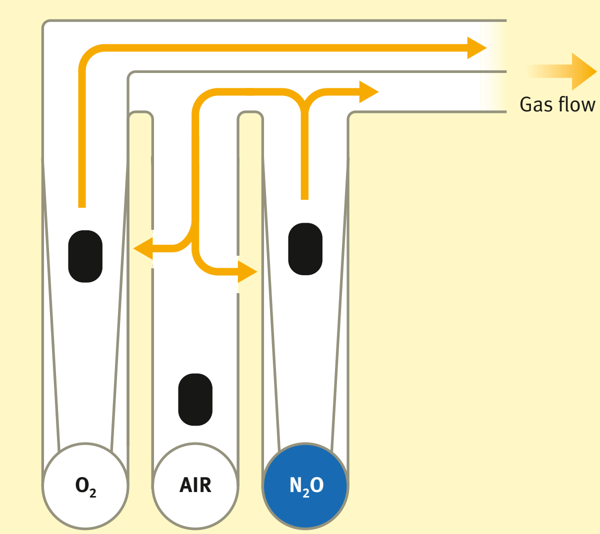


Figure 2 The oxygen is delivered to the gas mixture last to prevent a hypoxic mixture being delivered to the patient in the event of a leak from the other rotameters. If this system did not function in this way, it would be possible for oxygen to leak out of the damaged middle rotameter and nitrous oxide may then make up too large a proportion of the fresh gas flow, causing hypoxia.