CONTINUOUS FLOW ANAESTHETIC APPARATUS - THE BOYLE'S MACHINE

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Continuous flow anaesthetic machines date back to the first availability of compressed gases, and despite numerous modifications the modern apparatus retains many of the features of the original Boyle's machine, a British Oxygen Company trade name in honour of the British anaesthetist H E G Boyle (1875- 1941). This article describes the basic principles of continuous flow apparatus and will be followed in the next edition of Update by a description of anaesthetic circuits.

Basic Design: Pressurised gases are supplied by cylinders or pipelines to the anaesthetic machine which controls the flow of gases before passing them through a vaporiser and delivering the resulting mixture to the patient via the breathing circuit.

Medical gas supply.

Cylinders: Anaesthetic gas cylinders are made of molybdenum steel and should be regularly checked by the manufacturer for faults.

Different gases are supplied at specific pressures. The standard E size oxygen cylinders attached to anaesthetic machines are supplied at 134 bar pressure and contain 680 litres of oxygen.

During compression nitrous oxide becomes a liquid, which then evaporates to form a gas as it is released. This process causes cooling of the cylinder. The pressure in an E size nitrous oxide cylinder is 44 bar which releases 1800 litres of nitrous oxide during use. Unfortunately there is no international colour coding system for the contents of anaesthetic gas cylinders (or pipelines). In the USA oxygen is supplied in green cylinders, in the UK the cylinders are black with white shoulders and in Germany they are blue. Under circumstances where the supply of oxygen is unreliable the only true method of identifying the contents of an oxygen cylinder is to use an oxygen analyser.

In order to ensure that the correct cylinder is attached to the yoke of the anaesthetic machine a series of pins on the machine yoke is made to fit an identical pattern of indentations on the cylinder. This is known as the pin-index system. It is not foolproof, however, as the pins may be deliberately removed allowing the wrong cylinder to be fitted to the machine.

A small metal and neoprene seal (Bodok Seal) ensures a gas-tight fit between the cylinder and anaesthetic machine yoke. Under no circumstances may oil or grease be used as a seal; the pressurised gases give off heat as they are released from the cylinder and may cause explosions if oil is used. Before attaching a full cylinder to the machine briefly open and close the cylinder valve to clear any dirt from the port.

Anaesthetic machines operate at 4 bar pressure and therefore the compressed medical gases in cylinders pass through reducing valves to bring the gas pressure to a constant 4 bar. Non-return valves prevent empty cylinders still attached to the machine from refilling from fresh cylinders. Until recently cylinders of cyclopropane and carbon dioxide were also commonly found on anaesthetic machines. Cyclopropane is now rarely used and carbon dioxide should only be attached if the anaesthetist wants to use it for a specific reason.

Pipeline Supply: Larger hospitals supply medical gases from a central store via pipelines in the floor and walls. The central store may be a bank of large cylinders, or in the case of oxygen, a large insulated tank of liquid oxygen maintained at approximately minus 165 degrees centigrade. The piped medical gases are delivered to specific ports located in the wall of the operating theatre and anaesthetic room. Non-interchangeable spring loaded valves (Schraeder Valves) are inserted into the wall ports and connect to the anaesthetic machine via flexible but non-crushable tubing. The valves are specific for each gas and the tubing is colour coded and permanently bonded to the individual valve.

The pressure in anaesthetic gas pipelines is 4 bar (the same as the working pressure of the anaesthetic

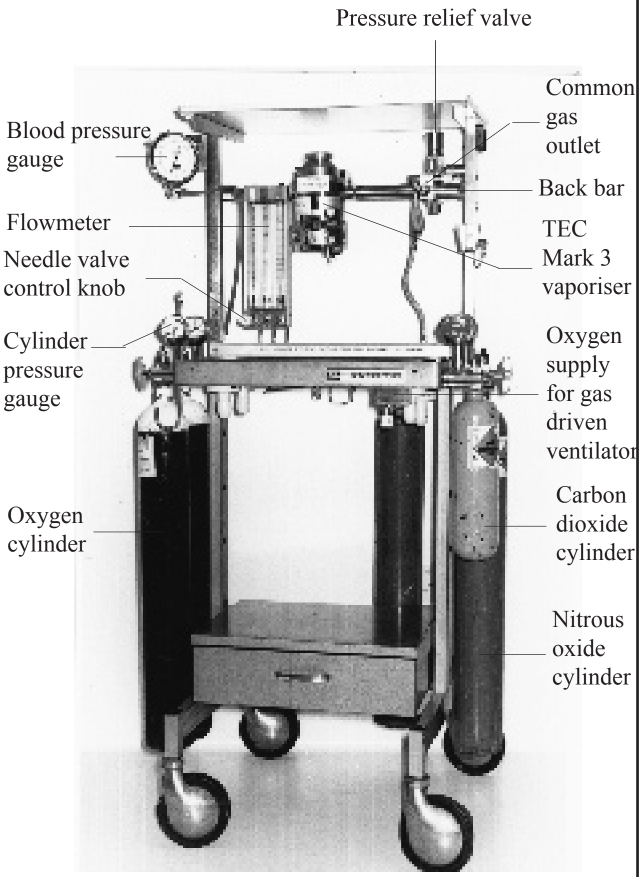

Fig.1. BOC Boyle International Continuous Anaesthetic Machine

machine). All anaesthetic machines, including those on pipeline gases, should have reserve gas cylinders attached, but turned off.

Flow meters: The gases from both cylinders and pipelines flow through narrow steel tubing to the rotameters where the flow rate of the gases is controlled by a needle valve. The flow rate of the individual gas is shown by a float or bobbin in a vertical glass tube. These tubes are individually calibrated by the manufacturer and are not interchangeable. The control knob for oxygen is larger and different in shape to the nitrous oxide control. In the UK, the left rotameter is oxygen whilst in the USA oxygen is on the right!

After the gases have passed through the rotameters the different gas tubes are joined together with oxygen added last so that the chances of an hypoxic mixture resulting from a leak of gases is minimised. Many machines now also link the flow of nitrous oxide to that of oxygen to ensure that a minimum of 25% oxygen will always be delivered.

Vaporisers: A volatile anaesthetic agent is supplied as a liquid and then vaporised (evaporates into a gas) before being mixed with the anaesthetic gases. Vaporisers are generally fitted on the "back bar" of the machine. Modern vaporisers are agent specific and automatically compensate for the temperature drop as the anaesthetic liquid evaporates. Some have a special filling system to ensure that they are filled with the correct agent. Although more than one vaporiser may be fitted to the machine, most back bar systems prevent more than one vaporiser from being used at any one time. Back bars may be equipped with systems such as the "*Selectatec*" mechanism which allow vaporisers to be easily exchanged between machines.

Unlike the Boyles bottle where a large proportion of the gas is passed over or bubbled through the volatile anaesthetic agent, modern continuous flow vaporisers split off a small proportion of the gas flow and completely saturate it with the volatile agent. These are known as "plenum" vaporisers, have a very high internal resistance and can only be used with pressurised medical gas supplies. All these vaporisers must be correctly attached to the anaesthetic machine with the back bar locking mechanism fully engaged to avoid leaks.

Pressure Relief Valves: If the anaesthetic machine is fitted with a pressure relief valve it will usually be located on the back bar distal to the vaporisers. The valves are designed to protect the machine

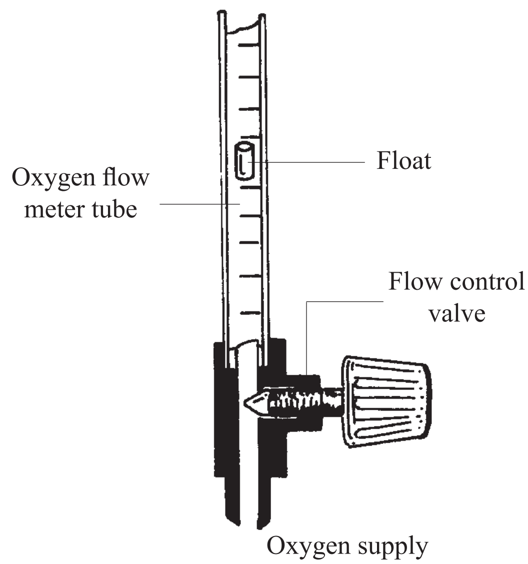

Fig. 2. Oxygen rotameter

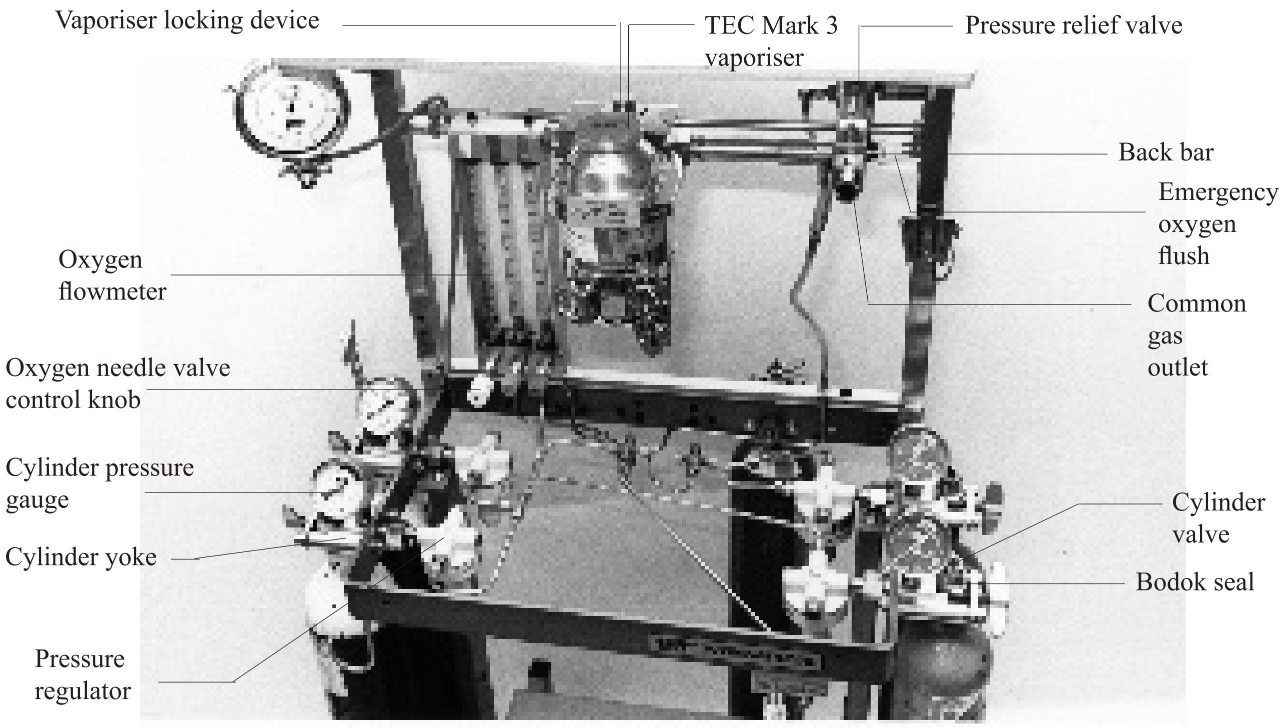

Fig.3. BOC Boyle International Continuous Anaesthetic Machine

and vaporisers against high pressures. They do not offer any protection to the patient. By occluding the common gas outlet with a thumb the pressure rises within the machine and will open a pressure relief valve, commonly at about 35kPa. Never try this in a machine without checking to see if a valve has been fitted.

Emergency Oxygen Flow: An additional high flow rate emergency oxygen supply (35 litres/min) bypasses the flow meters and vaporisers joining the common gas pathway near the common gas outlet. This emergency oxygen supply is operated by a spring loaded button. If this flow is accidentally left on there is a risk of diluting the other anaesthetic gases resulting in light anaesthesia or even awareness. Some modern machine are designed so that the flow cannot be left on.

Oxygen Failure Alarms: The risk of supplying an hypoxic gas mixture to the patient must never be forgotten. Oxygen failure warning devices are now fitted to all anaesthetic machines. Most are powered only by the oxygen pressure and do not depend on mains electricity or battery power. They are activated by a fall in oxygen pressure and emit a loud whistle that may only be reset by the return of the correct oxygen pressure. Until that time all the gases are vented to the atmosphere and away from the patient by a safety valve.

Non-return valves prevent empty cylinders from being refilled by other cylinders if they are left turned on. These are also fitted on the back bar and prevent gases from being pumped backwards through the vaporisers. This may occur during the ventilation cycle of a minute volume divider ventilator such as the Manley ventilator when the flow of gases from the common gas outlet may be briefly reversed. Without a non-return valve these gases can be pumped backwards through the vaporisers thus increasing the concentration of volatile agent being delivered.

Checking the Anaesthetic Machine

The anaesthetist is responsible not only for the peri-operative care of the patient but also for ensuring that all the equipment being used functions without fault. A guide to checking a Boyles anaesthetic machine which uses cylinders as the source of compressed gases is shown in Table 1. This should be performed before each theatre list.

If the machine is attached to pipelines then do the above test attaching and detaching pipelines as well as checking the cylinders.

Table 1. Checking a Boyles anaesthetic machine which uses cylinders as the source of compressed gases.

If an oxygen analyser is available, use it. It is the only way to verify the contents of an oxygen cylinder.

1. Check that cylinders are securely attached and turned off.

2. Open all flow meter control valves and check there is no flow.

3. Turn on oxygen cylinder and check its contents on pressure gauge. Set the rotameter to read 4 litres minute. If a second oxygen cylinder is present, turn off the first and check the contents of second. Check there is no flow at the nitrous oxide rotameter.

4. Turn on the nitrous oxide cylinder and check the contents on the pressure gauge. Set the rotameter to 4 litres/minute and check the oxygen rotameter setting has not changed. If a second nitrous oxide cylinder is present turn it on to check its contents then turn it off again.

5. Turn off the oxygen cylinder and empty system via oxygen flush. The oxygen warning device should sound (if fitted), and should vent all gases from the machine. There should be no flow at the common gas outlet.

6. Turn on the oxygen cylinder again.

7. Check that the vaporisers are properly fitted to the back bar, with no leaks. They should contain an adequate amount of volatile anaesthetic agent and the controls operate throughout their full range without sticking.

8. If the anaesthetic machine is fitted with a pressure relief valve it should be tested by occluding the common gas outlet with a thumb whilst gas is flowing. The pressure relief valve should open with an audible release of gas. Do not do this test if a PRV is not fitted as it may damage the vaporisers.

9. Check your breathing circuit to ensure that it has been assembled correctly, close the valve, fill with gas and squeeze the resevoir bag to ensure there are no leaks. Open the valves following this check and ensure circuit empties.

10. Check the function of other equipment such as suction apparatus and laryngoscopes and ensure that all the drugs, endotracheal tubes, facemasks and airways you may require are present.