APPARATUS FOR DENTAL ANAESTHESIA

BY

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The peculiar isolation of dental anaesthesia from the specialty as a whole, which has developed over the past hundred years, is exemplified by the fact that one particular type of apparatus has, at least until recently, always been used in this field.

DISTINCTIVE FEATURES OF DENTAL ANAESTHETIC APPARATUS

Ideally, this type of apparatus* should be able to:

1. Deliver a mixture of nitrous oxide and oxygen, the composition of which can be varied by adjustment of a single calibrated control. For any setting of this control, the composition of the mixture should remain constant under all circumstances.

2. Deliver this mixture, depending on the setting of a second control,
   a) over a range of pressures (flows);
   b) at a flow which will follow the patient's inspiratory effort—in other words, it would operate as an intermittent flow, i.e. a demand flow apparatus.

Of these, the most difficult to achieve is constancy of any set gas mixture over the whole pressure (flow) range. Many instances have been reported of inaccuracy much greater than that illustrated in figure 1 (Goldman, 1958; Hunter and Fraser, 1959; Bourne, 1960; Smith, 1961; Parbrook, 1964; Nainby-Luxmoore, 1967). In this particular example it can be seen that, while the calibration was accurate at high flows, considerable discrepancy existed between the indicated and the actual composition of the gas mixture at low flows. However, modern dental anaesthetic apparatus, if properly maintained, is usually well able to meet this requirement (fig. 2).

* The precise criteria for the performance of the “on-demand” type of apparatus is the subject of current consideration by the British Standards Institution.

REASONS FOR THE DEVELOPMENT OF THESE DISTINCTIVE FEATURES

The need for the above features reflects (a) certain limitations of early anaesthetic apparatus, and (b) some of the requirements of dental anaesthetic techniques as they were, and sometimes still are, practised.

(a) Limitations of early apparatus.

i) The use of twin narrow-bore tubes (fig. 3) to deliver gas to a nasal mask was once universal. The resistance of such tubing was usually too high to allow the patient to inspire freely from a reservoir bag. It was therefore necessary for the gas mixture to be supplied at a positive pressure sufficient to force the required flow through these tubes to the patient. (The use of single wide-bore tubing, as shown on page 159, eliminates this problem of resistance.) A coincidental effect of using high flows was to surround the patient’s head with a cloud of anaesthetic gases! This
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Relationship between the setting of the mixture control of (a) the A.E. "Gas-Oxygen Machine", (b) the British Oxygen "Walton Five Apparatus", and the mixture delivered.

\[ X = \text{low flow; } O = \text{high flow.} \]

(b) Requirements of early dental anaesthetic techniques.

(i) Until its dangers were fully appreciated some hypoxia, often severe, was usual during dental anaesthesia. For example, a common technique was to begin the induction of anaesthesia with a certain number of breaths of pure nitrous oxide, followed by a certain number of breaths of 5 per cent oxygen, and so on until, if the surgical procedure lasted for a sufficient time, 20 per cent oxygen was occasionally reached! This sort of use demanded a mixture control which could be altered instantaneously and accurately, and in which (fig. 4) the part of the scale devoted to 0–20 per cent oxygen was disproportionately large.

(ii) It was even more convenient if the anaesthetist could make such adjustments without letting go of the patient's head. Many an anaesthetist moved the mixture control of the "Walton II"...
apparatus (fig. 5) with his elbow, although it may not have been specifically designed for the purpose! The pressure in this apparatus was controlled by a foot-pedal.

Now that dental anaesthesia and surgery have moved out of the “smash and grab” era, these considerations no longer apply with such force, and all dental machines in current production have both controls sited for manual operation, although a foot-pedal for pressure control is available on the A.E. “Gas-Oxygen Machine”.

THE DENTAL ANAESTHETIC MACHINE TODAY

The retention of the two controls described may well be largely a matter of tradition. They undoubtedly constitute a convenience for the dental operator-anaesthetist, who is thereby enabled to lean across the patient and make any necessary adjustments with a minimum disturbance to the progress of his surgical procedure! Whether the steady reduction in the number of anaesthetics given by operator-anaesthetists (Ministry of Health, 1967) will lead to a reappraisal of the need for such considerable engineering effort is a matter for speculation. The increasing realization that a standard continuous flow anaesthetic apparatus can be perfectly satisfactory for dental work, has led some manufacturers to produce simplified versions of such apparatus which are well suited for use in dental anaesthesia (figs. 6 and 7).

Another recent development which simplifies dental anaesthetic apparatus is the introduction of premixed gases by Latham and Parbrook (1966). They have already described one such apparatus (Latham and Parbrook, 1967).
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INTERMITTENT FLOW DENTAL ANAESTHETIC APPARATUS

The machines which are currently available in this country are the A.E. “Gas-Oxygen Machine” (fig. 8; see also page 158), the British Oxygen “Walton Five Apparatus” (fig. 9; see also page 158), and the McKesson “Anesthesor Special” (figs. 10 and 11) and “Simplor Special” (fig. 12). Each of these machines is described in detail below, but certain features are common to all of them.

Features common to all intermittent flow machines.

In each the composition of the gas mixture is determined by the setting of a single control tap, rotation of which proportionately varies the sizes of the orifices through which each gas flows. Since the flow of a particular gas through a given orifice (Macintosh, Mushin and Epstein, 1963) depends, inter alia, on the pressure difference across the orifice, such an arrangement will only be reliable if the pressures of the two gases are equal before they reach the mixture control. To this end, each machine incorporates linked second-stage pres-
sure reduction mechanisms for the two gases. The flow of a gas through a fixed orifice also varies with density of the gas. For this reason equality of orifice areas does not necessarily result in equality of flow for any two gases. However, this factor need not directly concern the anaesthetist, since it is eliminated by the manufacturers when the apparatus is calibrated. Clearly, the combined area of the orifices must be sufficient to allow peak flows. Moreover, the larger the orifices, the less likely is the calibration to be upset to a significant degree by the accumulation of dirt and grease or by wear of the moving parts. Finally, the apparatus can be set in such a way that there is no flow until the patient makes an inspiratory effort.

The A.E. "Gas-Oxygen Machine" (fig. 8; Hunter and Fraser, 1959).

Oxygen and nitrous oxide, supplied from cylinders or pipelines, flow through the inlets of the apparatus to regulators which reduce the pressure to approximately 60 lb./sq.in. The supply and reduced pressures of each gas are shown on separate gauges. The gases flow from the regulators to separate chambers (16, 17) of the second-stage pressure regulators. A spring (15), linking the diaphragms of these chambers, ensures that the pressures of the two gases are balanced at 70 cm H₂O. From the second-stage regulators the gases flow to the rotatable barrel (7) of the mixing tap, and through separate orifices in this barrel and a common orifice in its outer sleeve (10), into the mixing chamber (6). This outer sleeve is attached to a rubber diaphragm (9) which covers one end of the mixing chamber (6). When the pressure of the gas mixture in the chamber (6) increases, this diaphragm (9) moves outwards against the force exerted by the fixed spring (8) and takes with it the outer sleeve (10). Movement of the outer sleeve (10) progressively reduces the area of the orifices in the rotatable barrel unit until, when the pressure in the mixing chamber (6) reaches 40 cm H₂O, the orifices are completely shut and the flow of gases is cut off. In this apparatus, therefore, unlike other demand flow machines, the pressure set by the second-stage regulators cannot be adjusted. Instead, the pressure (flow) control is a separate device (1, 2, 3, 4, 5) in which the diaphragm (3) is set to hold the valve (5) closed when the pressure in the chamber (4) is atmospheric. This device is in its resting position when the pressure (flow) control (1) is at its lowest setting, in which the spring (2) is not exerting any force on the diaphragm (3). When the patient makes an inspiratory effort the negative pressure produced in the chamber (4) causes the diaphragm (3) to move inwards and the valve (5) is opened. The gas mixture now flows from the mixing chamber (6), through the chamber (4), and past the one-way valve (14), to the patient. Movement of the one-way valve (14) can be observed through a transparent dome on the top of the machine.

As the pressure falls in the mixing chamber (6), the diaphragm (9) is forced inwards by its spring (8), taking with it the outer sleeve (10) which opens the orifices in the rotatable barrel and allows the flow of gases from the second-stage pressure regulators to start again. The exposed area of the orifices, and hence the flow of gases delivered, depends on the amount of inward movement of the outer sleeve. This in turn is determined by the extent to which the pressure in the mixing chamber (6) is reduced below 40 cm H₂O by the patient's demand. When the demand is low the area of the orifices is small, and when the demand is large the area of the orifices is large. This mechanism is intended to ensure accurate mixing by maintaining a more or less constant pressure...
difference across the orifices irrespective of the flow through them.

The pressure (flow) control (1) can be set to deliver the mixture at any pressure up to 25 cm H$_2$O. When set in this way there is a continuous flow of mixed gases until the pressure in the chamber (4) increases sufficiently to move the diaphragm (3) outwards, against the force now exerted by the spring (2), and thereby close the valve (5).

The composition of the gas mixture is set by rotating the barrel (7) with the “per cent oxygen in nitrous oxide” control (11). This proportionately decreases the area of the orifice through which one gas flows as it increases the area of the orifice through which the other gas flows.

If the oxygen supply should fail, the cut-off valve (12) shuts off the flow of nitrous oxide, while an inlet valve (13) allows the patient to inspire air. An emergency oxygen supply is delivered to the outlet by pressing a button (18).

This apparatus is available in two forms; in one the “pressure” control is a foot-operated lever; in the other it is a hand-operated knob.

**The British Oxygen “Walton Five Apparatus”** (fig. 9).

Nitrous oxide and oxygen, supplied from cylinders or pipelines, flow through the inlets of the apparatus and pass through regulators which reduce the pressure of each to 7–11 lb./sq.in. Oxygen flows to three positions, the nitrous oxide cut-off valve (18), the “emergency oxygen” control (11), and the inlet of the second-stage pressure regulator (12, 13, 15, 16). The pressure of the oxygen forces over the diaphragm of the valve (17), opening the pathway for nitrous oxide to flow to the inlet of its second-stage regulator (3, 5, 6, 7).

When the pressure (flow) control (1) is set to “0 mm mercury” no force is exerted by the spring (2) on the stem of the valve (7). This valve (7) is therefore held closed and there is no flow. When the patient makes an inspiratory effort, a negative pressure is produced in the mixing tap (8) and hence in the chamber (5) of the nitrous oxide second-stage pressure regulator. The diaphragm (3) is moved over to the right, opening the valve (7) against the force of its spring, and allowing nitrous oxide to flow through the chamber (6) to the mixing tap (8). The pressure now existing in the chamber (6) is transmitted through the tube (14) to the chamber (16) of the oxygen second-stage regulator, the diaphragm (13) is moved over, and the oxygen inlet valve (15) is opened.

The interconnection, through the tube (14), of the chamber (6) of the nitrous oxide second-stage regulator and the chamber (16) of the oxygen second-stage regulator ensures that the pressures of the two gases as they leave the second-stage regulators are equal. As soon as inspiration ceases the pressure in the mixing tap (8) and in the chamber (5) rises to atmospheric, the diaphragm (3) moves over to the left, and the nitrous oxide inlet valve (7) closes. Pressure in the chambers (6, 16) now falls to atmospheric, and the oxygen inlet valve (15) is closed. Flow ceases until another inspiratory effort is made by the patient.

When a continuous flow of gas is required, the pressure (flow) control (1) is turned to a positive pressure setting. The spring (2) now exerts a force on the stem of the valve (7) which moves the
Nitrous oxide now flows to the mixing tap, and a positive pressure exists in the chamber (6). This pressure is transmitted through the connecting tube (14) to the chamber (16) of the oxygen second-stage regulator, where it forces over the diaphragm (13), allowing oxygen to flow to the mixing tap at a balanced pressure. Flow continues until the pressure in the mixing tap reaches that set on the pressure control, at which point the pressure in the chamber (5) is sufficient to force the diaphragm (3) outwards against the force exerted by the spring (2), and the nitrous oxide inlet valve is closed. The forces exerted on either side of the diaphragm (13) are now equal and the oxygen inlet valve (15) is therefore closed. At the maximum setting of the control (1) the pressure is about 20 mm Hg.

The ratio of oxygen to nitrous oxide in the mixture delivered to the patient depends on the setting of the calibrated mixing tap (10). Rotation of this tap proportionately increases the area of the orifice through which one gas flows and decreases the area of the orifice through which the other gas flows. This tap is calibrated in “oxygen percentage” (fig. 4). The maximum flow varies between 120 and 200 l./min, depending on the setting of the mixture control.

The safety cut-off valve (17) in the nitrous oxide supply line is held open by the pressure of the oxygen. If at any time the oxygen supply should fail, the valve (17) at once closes. If this should happen, the patient can inspire air through the inlet valve (4) which opens at a negative pressure between -7 and -9 cm H₂O. Air flowing through this valve causes a whistle to sound. A safety valve (9) opens at a pressure slightly above the maximum which can be set on the pressure control (1). An emergency oxygen button (11) allows a flow of at least 35 l./min of oxygen to the mixing tap (8), irrespective of the setting of this tap. Additional safety valves (19, 20) are fitted in the supply lines connecting the first-stage and second-stage regulators.

The McKesson “Anesthesor Special” (figs. 10 and 11).

Nitrous oxide and oxygen, from cylinders or pipelines, are supplied through the inlets of the apparatus to regulators which reduce the pressure to the “operating range” of approximately 60 lb./sq.in shown on the gauges (1, 13—fig. 11). The gases flow through the valves (2, 9) into the circular bags (14, 15) which are contained in rigid housings. Expansion of the bags forces the plates (4, 11) outwards, moving the pivoted levers (3, 10) and closing the valves (2, 9). The levers (3, 10) are connected through the pivot (8), and therefore the pressures in the two bags are balanced. The pivots of this mechanism are arranged in such a way that as the plates move outwards the casing around the spring (7) is drawn downwards, and the spring (7) is compressed.
The force exerted by this spring, therefore, determines the pressure which must be attained in the bags in order to cut off the gas flow.

When the pressure (flow) control is set to "0" the bags (14, 15) fill and close the valves (2, 9) before the spring (7) is compressed. The pressure in the bags is then atmospheric. When the patient makes an inspiratory effort, a negative pressure is produced in the mixing tap (5), the higher pressure (atmospheric) in the bags opens the one-way valve in the mixing tap (5), and the gas mixture flows to the patient. As the bags empty, the plates (4, 11) move inwards, opening the valves (2, 9) and allowing gas to flow again into each bag. When continuous flow is desired the pressure (flow) control (6), which is calibrated up to 40 mm Hg, is adjusted. This compresses the spring (7) and gas flows into each bag until the pressure in the bags has risen sufficiently to force the plates (4, 11) out against the force of the spring (7) and close the valves (2, 9). There is, therefore, a continuous flow from the bags until the pressure in the mixing tap (5) is the same as the pressure in the bags.

The mixture delivered to the patient depends on the setting of the tap (5), rotation of which proportionately increases the area of the orifice through which one gas flows as it decreases the area of the orifice through which the other gas flows. This control is calibrated in "oxygen per cent". An emergency oxygen button (12) is provided.

The development of new volatile agents, which have justifiably found a place in dental anaesthesia, has led to the design of vaporizers suitable for use with the high peak flows delivered by dental anaesthetic apparatus. Provided that excessive pressures, leading to continuous high flows in excess of the patient's demand, are not used, wastage of liquid anaesthetic does not occur, but
clearly, misuse in such a way will consume large quantities of these volatile agents, some of which are relatively expensive. Three such vaporizers are shown in figs. 13, 14 and 15. They are primarily intended for use over short periods of time only. No provision is made for temperature compensation, and there is usually a rapid decline in the concentration delivered after only a short period of use. Accurate calibration is not deemed necessary, and the controls are marked in arbitrary units. Figures for the vapor concentrations delivered under various circumstances are supplied by the manufacturers.

If a vaporizer is to be used more or less continuously throughout a full session of dental anaesthetics it is convenient to make use of a vaporizer which (a) is accurately calibrated, and (b) incorporates a temperature-compensation mechanism. The A.E. "Fluothane Vaporizer" (fig. 16) is such an apparatus. The temperature compensation is complete over the range 18 to 35°C, and the manufacturers state that even outside these limits the deviation is very slight. The resistance to breathing is of the order of 1 cm H₂O at a gas flow of 30 l./min, and therefore there is virtually no alteration of the performance of the main apparatus. A valve is incorporated which eliminates any possibility of rebreathing through the vaporizer. For halothane there are two ranges available, 0 to 3.0 per cent, and 0 to 5.0 per cent. Alternative models can be supplied calibrated for 0 to 1.0 per cent methoxyflurane (Penthane), 0 to 1.5 per cent trichloroëthylène (trichloroethane), or 0 to 4 per cent chloroform.

THE CARDIFF APPARATUS

In the period immediately prior to the introduction of halothane and methohexitone on a large scale into dental anaesthetic practice, the use of a non-explosive mixture containing cyclopropane
FIG. 15
The McKesson Halothane Vaporizer Mark II.

FIG. 16
The A.E. "Fluothane Vaporizer".

FIG. 17
The Cardiff apparatus for the supply of a non-explosive mixture of cyclopropane, oxygen and nitrogen.

FIG. 18
Diagram of the Cardiff apparatus for the supply of a non-explosive mixture of cyclopropane, oxygen and nitrogen.
was found to give good results. It is still particularly useful for the induction of anaesthesia or as a single-dose anaesthetic in small children and other patients who are unwilling to have an injection.

The Cardiff apparatus (figs. 17 and 18) (Hillard, 1962) was designed as a simple and economical means of filling a reservoir bag with a non-explosive mixture of 40 per cent cyclopropane, 30 per cent oxygen, and 30 per cent nitrogen. No gas flows from any cylinder until the reservoir bag mount is pushed into the spring-loaded outlet of the apparatus. Pneumatic safety valves then ensure that neither cyclopropane nor oxygen can flow unless nitrogen can flow, and neither cyclopropane nor nitrogen can flow unless oxygen can flow. So that the mixture can be seen to be accurate, Rotameters are included, the settings of which are fixed at the correct flows.

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REFERENCES

POSTGRADUATE COURSE IN ANAESTHESIA

The Glasgow Postgraduate Medical Board has organized a full-time course of postgraduate lectures entitled “Current Concepts in Anaesthesia”, which will be held in Glasgow from Monday, May 20, to Saturday, May 25, 1968.

The course has been designed for senior anaesthetists wishing to keep abreast of important advances in anaesthesia and related fields, including intensive care, patient monitoring, acid-base measurement, and metabolic care. The course would also be of value to those sitting the Final part of the F.F.A.R.C.S.

The provisional programme and application forms can be obtained from the Director of Postgraduate Medical Education, The University, Glasgow, W.2