A NEW AND VERSATILE CLOSED CIRCUIT ANAESTHETIC MACHINE WITH AUTOMATIC AND MANUAL VENTILATION

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SUMMARY

A versatile new anaesthetic machine embodying a ventilator with automatic and manual closed circuits, and with provision for semi-open circuits is described.

The ventilator follows the principle of volume and time cycling and generally requires only a low flow of fresh gases (about 2 l./min). It is based on the original Smith-Clarke intermittent positive/negative pressure respirator and is both simple and practical. It is intended later to present a further paper describing clinical experience with this machine.

The machine described in this paper has been used at Gulson Hospital, Coventry, for some fifteen months and has proved reliable and satisfactory in more than 1,000 major operations. It is entirely self-contained, has no protruding parts, and occupies 36 in. by 24 in. (91 cm by 61 cm) floor space.

While the principle of controlled artificial ventilation of the lungs in anaesthesia is established, there is considerable variation in technique—automatic or manual, semi-open or closed. In this design the authors have attempted to bring the practice of these different techniques within the compass of one machine without recourse to inessential complications of circuit or control. Although only the automatic and manual closed circuits are described in detail it may be observed that the ventilator can readily be converted to a semi-open, non-rebreathing circuit with either automatic or manual control.

Much experience with intermittent positive pressure and positive-negative pressure ventilators was gained during the poliomyelitis outbreaks in Scandinavia and in this country in the 'fifties. The majority of the machines evolved then followed the principle of pressure and/or time cycling, possibly because they can be relatively small and easy to manufacture. The authors feel, however, that the principle of volume and time cycling, when applied to artificial ventilation in anaesthesia, has considerable advantages to offer, not the least of these being the ability to maintain delivery of a constant minute volume to the patient with minimal adjustment, since this type of machine will deliver the same stroke volume against varying degrees of resistance.

Among the earlier machines using this principle the Smith-Clarke intermittent positive-negative pressure respirator proved outstanding in long-term reliability and simplicity of control and this machine has been used as the basis for the new ventilator. Many of the original features have been retained, albeit in modified form, and two separate closed circuits, one automatic and the other manual, have, so to speak, been grafted on without interfering with the optional use of subatmospheric (negative) pressure during expiration.

In most cases the flow of fresh gases into the closed circuit need not exceed 2 l./min. By a suitable combination of respiratory frequency and tidal volume adequate ventilation can be maintained with minimal movement of the chest and diaphragm; the consequent economy in the
STAND FOR MOUNTING 
ETHER TRILENE ETC

FLOWMETER

BANK

GASES

INLET

VOLUME INDICATOR

AND CONTROL

MOTOR

MASTER SWITCH

NEGATIVE

PRESSURE CONTROL

RESPIRATION

FREQUENCY CONTROL

MECHANICAL TO

MANUAL CONTROL

O₂ PRESSURE

GAUGES

CO₂, O₃, H₂O

REGULATORS

C₃H₆ STORAGE

CARBON DIOXIDE

ABSORBER

PATIENT INLET

AND OUTLET

RESPIRATION PER

MINUTE INDICATOR

REBREATHTING

BAG INLET

MANOMETER

INDICATING POSITIVE

AND NEGATIVE PRESSURE

STORAGE DRAWER

FOR SPARES

Fig. 1. Front view of ventilator.

CARBON DIOXIDE

STORAGE

REBREATHTING

BAG

NITROUS OXIDE

STORAGE

OXYGEN

STORAGE

MAINS SUPPLY

INLET

STORAGE BAG

STORAGE BAG

Fig. 2. Rear view of ventilator.
consumption of fresh gases can be of more than incidental importance to many hospitals.

GENERAL DESCRIPTION
The machine has been designed primarily to be practical and simple in use; to this end all controls other than flowmeters have been grouped together on a sloping panel at the front (fig. 1) and all extraneous fittings, such as cylinders, bags and soda lime canister (figs. 1 and 2), have been recessed within the overall dimensions of the cabinet so that, without lessening their accessibility, the risk of damage during movement is reduced. Controls are large and easy to identify and manipulate, cylinders are attached by a pin-index system (British Oxygen Company) to a common bar which is rigidly fixed to the main frame. These arrangements allow the flat top of the cabinet to be used as an uninterrupted working surface while, in the base section, there is a spacious drawer for the stowage of tubing, spare parts, etc.

The machine is constructed in two separable sections and all the working parts are contained in the upper section. This, in turn, is divided into two compartments; the lower one houses the heavier components, such as the flameproof motor, variable speed gearbox and reduction gear, and the upper one houses the whole of the patient circuitry. This disposition of the heavier components is designed to give the maximum degree of stability and ease of maintenance.

Controls and indicators (fig. 3).
Reading from left to right of the panel these are:

Higher level: (1) Volume indicator and control, calibrated in stages from 200 ml to 1,600 ml. (2) Tachometer, calibrated in respirations per minute.

Lower level: (3) Motor on-off master switch. (4) Sub-atmospheric (negative) pressure control, 0 to −15 cm. H₂O as indicated on manometer (7). (5) Respiratory frequency control, infinitely variable between 10 and 50 respirations per minute as indicated on tachometer (2). (6) Automatic/manual circuit selection control. (7) Manometer, indicating positive and negative pressure values in whichever circuit is selected.

Gas controls.
The flowmeter bank (fig. 1) is rigidly mounted on the top lefthand side of the cabinet; oxygen, nitrous oxide and cyclopropane flowmeters are fitted and provision is made for the inclusion of a
carbon dioxide flowmeter. Gas identification is by the international colour code. Each oxygen and nitrous oxide cylinder has a separate reducing valve which limits the pressure of gas to the appropriate flowmeter to 12 lb./sq. in. (0.85 kg/cm²). Standard cylinder contents gauges are provided.

Patient connections.
Standard taper female connections are located on the righthand side of the machine; each is clearly identified.

Carbon dioxide absorber.
A common carbon dioxide absorber is used for both circuits, located in the recess in the righthand side of the machine. Provision is made for the optional bypass of the absorber and a spare canister is provided.

WORKING PRINCIPLES

It is not proposed to enter here into any argument as to the relative virtues of automatic, manual or spontaneous ventilation during anaesthesia, for this machine is intended to satisfy all three schools of thought.

Automatic closed circuit (electro-mechanical)
(fig. 4A).
Like its Smith-Clarke progenitor, this machine is fundamentally a flow-generator (Mushin, Rendell-Baker and Thompson, 1959a). Motive power is derived from an A.C. mains, ½ h.p., flameproof motor, driving a 50–1 reduction gearbox through a variable speed control. From the gearbox, drive is transmitted to a combined cam/crankshaft (1) through a chain and sprag clutch. Connecting rods (4, 5) operate the positive (PPB) and negative (NPB) bellows through rocking beams (7, 8) and the stainless steel inspiratory and expiratory poppet type valves (PV 1, PV 2) are operated by the cams (2, 3). These cams are so set that the inspiratory phase occupies one-third of the complete cycle, giving a fixed inspiratory-expiratory ratio of 1:2.
The volume of gases delivered per inspiration is determined by the setting of the variable fulcrum point (6) of the rocking beam (7) which controls the stroke of the positive pressure bellows and a weight-loaded valve (SV) limits the pressure to 40 cm H₂O.
The negative pressure bellows has a fixed stroke, pressure being manually controlled by the valve (NCV) in the bellows bypass and limited by the relief valve (PLV) to ≈ 15 cm H₂O.
Fresh gases enter through the circuit selection control (CSC 1) and circulation is produced by the action of the bellows (PPB, NPB).

During the upstroke of the positive pressure bellows gases are drawn from the bag (SB 1), via the valve (V 1), and from the bag (SB 2), via the valve (V 3). The valve (V 1) closes when the bellows reaches the top of its stroke and it then travels one-third of its downward stroke before the patient inlet valve (PV 1) opens. Thus a certain pressure is built up, and, when the valve (PV 1) opens, the main volume of gases is preceded by a "pulse" wave which overcomes any resistance in the tubing to the patient, the valve (SV) affording protection against the build-up of excessive pressure.
The gases then pass to the patient through the selection control (CSC 2) and the tubing. At the end of the downstroke of the bellows the patient inlet valve (PV 1) closes and the inspiratory phase is completed.

On the closure of the valve (PV 1) the patient outlet valve (PV 2) opens and expired gases flow through the carbon dioxide absorber and back into the machine via the selection control (CSC 3). They then pass on to the reservoir bag (SB 2) via the negative pressure bellows (NPB) and/or the control valve (NCV) in the by-pass. The setting of this control valve determines the amount of subatmospheric pressure applied during the expiratory phase and it is worth noting that, with the valve fully open and no applied negative pressure, the upward movement of the bellows serves to assist the flow of expired gases (Mushin, Rendell-Baker and Thompson, 1959b). When the control valve (NCV) is closed or partially closed the action of the valve (V 2) ensures the presence of negative pressure.

A spill valve (SPV 2), set to open at a pressure of 3 cm H₂O, is located at the mouth of the reservoir bag (SB 2) to prevent the build-up of excessive pressure within it, although this condition can hardly arise unless the inflow of fresh gases is unnecessarily high. From the bag (SB 2) carbon-dioxide-free expired gases can be drawn through the non-return valve (V 3) to mix with
Schematic diagram of ventilator.

**Fig. 4A**: Automatic operation.

**Fig. 4B**: Manual and/or spontaneous closed circuit operation.
A NEW AND VERSATILE CLOSED CIRCUIT ANAESTHETIC MACHINE

the incoming fresh supply and complete the closed circuit. The valve (V 3) is weighted to lift at 5 cm H₂O pressure and prevents any fresh gases entering the expiratory side.

Additional safety factors.

Apart from the normal action of the pressure relief valves other safety factors are included in this design. The reservoir bag (SB 2) prevents the building up of any unwanted negative pressure between the patient and the bellows (NPB) during expiration if the bellows capacity exceeds the patient's tidal volume. In this event, except when maximum negative pressure is being applied with the valve (NCV) closed, the bellows draws gases from the bag (SB 2) via the bypass. If, for any reason, the bag is empty and the negative pressure reaches its permitted maximum of −15 cm H₂O the valve (PLV) opens and allows air to be drawn into the circuit.

This same valve (PLV) will also open and allow air into the circuit if there is any failure in the supply of fresh gases, since the positive pressure bellows cannot draw from either of the bags (SB 1, SB 2) because in those circumstances they are empty.

Automatic semi-open circuit (air-oxygen).

By disconnecting the bag (SB 2) and increasing the flow of fresh gases the ventilator is readily converted to a semi-open circuit without rebreathing, at the same time maintaining the inspiratory and expiratory pressure characteristics of the closed circuit (fig. 5). When used in this manner it may be necessary to introduce a humidifier between the machine and the patient.

Manual and/or spontaneous closed circuit (fig. 4B).

The change-over from automatic to manual operation is effected by the circuit selection control (CSC 1, 2, 3) which consists of three 2-way stopcocks linked together. The control (CSC 1) directs the flow of fresh gases while the controls (CSC 2, 3) occlude the valves (PV 1, 2) and so isolate the automatic circuit. A microswitch is also linked to these controls and this cuts out the flameproof motor when manual operation is selected.

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BOOK REVIEW


In the preface to this monograph, which is number 450 of the American Lecture series, the author states that the work is intended to be an introductory syllabus, rather than a reference book on the subject of structure-activity relations. In the light of this statement and the amount of information contained in the monograph, it is interesting to speculate on the amazing knowledge of organic chemistry which our American counterparts must be required to know.

Most British anaesthetists would find the reading of this book rather tedious, particularly as many of the drugs are known by alternative names in this country, and much of the chemical terminology is unfamiliar. The author deserves commendation for some of the new descriptive words which he uses. As an example, there is a chapter entitled "Anaesthetics", meaning "anaesthesia-conferring" groups. This chapter also refers to "hybridization of anaesthetics", but makes no mention of azetropic mixtures.

In many ways this is a most disappointing book: it lists the formulae of practically every drug with narcotic properties and summarizes very inadequately the pharmacology of those in clinical use. The gaseous and volatile agents are covered in four chapters (5-8), which occupy only twenty-six pages of the book. Apart from the formulae of about seventy drugs, these chapters are of little value to the inquisitive reader as the data on the relationship between their chemistry and clinical action are very incomplete. It is surprising to find no information on the stability of the vinyl ethers, the reaction between trichloroethylene and soda lime or the synthesis of any of these drugs. The ingenious terminology of the author again shows itself by reference to Raventós's studies of "polyhalo" compounds. The barbiturates are covered in seven pages. They list six principles for the alteration of structure-activity relationship of which two are directly contradictory (Nos. 1 and 4, page 83), and the importance of N-methylation is not even mentioned. Details of pH and other chemical properties of these drugs are also absent. The chapter on other sedatives and hypnotics is even briefer (five pages) and only one paragraph is allocated to hydroxydione, although mephenesin-like compounds are given two pages.

Mistakes in the text are not numerous: SCTZ is referred to as SZTZ, but other apparent errors may be due to a differing terminology, e.g. "reflexes are quite restive" (page 99), "fusel oil" (page 66). Although over 500 references are quoted, only about 10 per cent of these are from this country.

The volume is produced in the excellent form to which we are accustomed from the American Lecture series. It unfortunately falls far short of the reviewers' expectations, and while it may be a useful addition to reference libraries, it cannot be recommended as a "must" for postgraduates or others who require a detailed knowledge of either the chemistry or pharmacology of anaesthetic compounds.

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