MODIFIED BEAVER RESPIRATOR: THE APPLICATION OF NEGATIVE PHASE

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That intermittent positive pressure may adversely affect the circulation under certain circumstances, notably when there is hypovolaemia, is widely recognized (Maloney and Handford, 1953; Brecher, 1956) and with many automatic ventilators it is possible to provide a degree of "negative pressure" during the expiratory phase to combat this tendency to circulatory depression.

Many of these machines are complex or expensive, so a simple adaptation of an available ventilator—the Beaver mark I—was made to provide this "negative phase" for use in routine anaesthesia.

The machine used was the production model made by the British Oxygen Company in 1953 and differs somewhat from the prototype originally described by Beaver (1953). It was supplied to many hospitals by the Ministry of Health for treating poliomyelitis cases.

Both the designer (Beaver, 1955) and Burchell (1957) have previously described modifications to produce a negative phase, but it is suggested that the present device is simpler. It can be attached to any closed circuit anaesthetic apparatus provided that, as is customary, the rebreathing bag of the latter is readily detachable.

THE APPARATUS

The apparatus is shown in figure 1. The wide-necked confectionery jar of 5 litres capacity (costing 3s. 6d.) contains a standard rebreathing bag which holds about 2.5 litres. This bag is connected to a length of corrugated tubing and replaces the rebreathing bag on the anaesthetic machine when the ventilator is in use. The existing screw-on lid of the jar is reinforced by a brass plate and is drilled to take two 1-inch diameter brass tubes. (This is the only part of the conversion for which workshop facilities are essential.) One tube is connected to the anaesthetic apparatus above and to the bag below as described. The other opens below into the bottle—outside the bag—and its upper end is connected to the delivery tube from the ventilator. The B.O.C. non-return valve supplied for this tube is not required. This assembly can easily be taken apart for cleaning and sterilizing.

Figure 1

The converted apparatus. The front of the box has been removed to show the position of the subsidiary controls.
Although the electric motor and the gearing of the Beaver ventilator are reasonably silent, the air valves on the cabinet are not, and also the bellows make an appreciable crackling noise when expanded against resistance. To render the machine acceptable for use in the operating theatre, therefore, it has been enclosed in a box lined with sound-absorbent material, and mounted on thick sorbo pads.

A hole has been drilled in the floor of the box underneath the existing hole in the machine cabinet to allow air to enter, and vents have been left at the top corners.

There has been no trouble with overheating, and the standard of silence compares very favourably with that of many other ventilators in common use.

THE WORKING OF THE MACHINE

During inspiration air from the electrically driven bellows on the machine enters the bottle and compresses the bag containing the anaesthetic gases, thus inflating the patient’s lungs. Surplus air from the bellows blows off from the valve on the machine in the usual way.

In the expiratory phase, the bellows of the machine fills, partly from the air inlet valve on the ventilator, but chiefly from the bottle, thus tending to produce a negative pressure inside the bag and anaesthetic circuit.

Whether or not this negative pressure is produced depends mainly on the amount of gas in the anaesthetic circuit. This is controlled by the flow of fresh gases and by the usual expiratory valve in the closed circuit.

Using the customary closed circuit with a leak, and a gas flow of about 3 litres per minute, this valve can usually be adjusted within a few seconds. Often the setting used for the previous manual compression of the bag is satisfactory.

An essential aid to this adjustment is a pressure gauge. An air speed indicator registering up to 160 knots is very satisfactory for this purpose. This is connected by sphygmomanometer tubing to the side arm of an Ayre’s T-piece in the catheter mount. The existing gauge on the machine is ignored.

**Fig. 2**

The ventilator connected to a standard anaesthetic machine, showing the pressure gauge and modified catheter mount.

*Warning.* Although the cyclopropane cylinder is shown in this photograph, this apparatus is **NOT** suitable for use with explosive anaesthetics.
THE MACHINE IN USE

After the induction of anaesthesia, the endotracheal tube is attached to the special catheter mount connected to the pressure gauge, and note is taken of the respiratory movements and of the "feel of the bag" in the normal way. These are then correlated with the pressure shown on the gauge. In a straightforward case this would be, say, +2 to +15 cm water. The rebreathing bag is then disconnected and replaced by the corrugated tube attached to the bag in the bottle (fig. 2) and the pump is switched on. The expiratory valve on the anaesthetic circuit is then adjusted to produce a negative pressure of about -2 to -4 cm water, and in the case just quoted the inspiratory pressure would probably be between 10 and 15 cm water. A typical pressure tracing is shown in figure 3.

The negative pressure can easily be abolished, if required, by closing the valve or increasing the fresh gas flow.

The possible fallacies of deducing the respiratory exchange solely from pressure changes must be borne in mind and the patient's chest must be observed to see that it moves adequately.

This method of assessing ventilation does not differ materially from that used in manual compression of a rebreathing bag, and it takes only a moment to revert to the latter method of inflation when this is felt desirable.

A Wright ventilation meter was employed on many early cases, but its routine use was discontinued as ventilation was always considered to be more than adequate except in the rare case where a very high inflation pressure—over 25 cm water—was required to inflate the chest.

For cases of this kind, the necessary high inspiratory pressure may be produced by using adhesive tape to occlude partially the "blow-off" valve (A in fig. 1) on the ventilator cabinet.

The corresponding air inlet valve may be similarly occluded to increase the negative pressure during expiration, but this has very seldom been necessary, and indeed is not devoid of risk (Lynch, Levy and Kent, 1959).

For small patients it is possible to reduce somewhat the effective ventilation produced by the machine by opening the tap (B in fig. 1) and bleeding off air through the side arm. (The original purpose of this fitting was to admit oxygen to enrich the air supplied by the ventilator.)

It should be emphasized that these three adjustments are only seldom required; indeed the need to silence the machine has rendered them relatively inaccessible. Normally the expiratory valve on the anaesthetic circuit is the only control that needs attention.

ADVANTAGES OF THE MODIFIED MACHINE

No originality is claimed for this conversion: the "bag in bottle" principle is employed in many ventilators (Mushin, Rendell-Baker and Thompson, 1959).

It is described partly because it has proved most successful in routine anaesthesia, and partly in the belief that there are many Mark I Beaver ventilators which are not fully utilized. This machine is devoid of the controls for adjusting the rate, the stroke volume and the inspiratory-expiratory ratio, which, together with other refinements are provided in the Mark II design.

The absence of such controls has not proved a disadvantage in practice; indeed the reverse is the case, and the rapidity and ease with which this apparatus may be adjusted has proved one of its...
greatest assets. This simplicity of adjustment is obtained only at the expense of causing an appreciable degree of overventilation in the majority of patients. This is not considered undesirable, for deliberate overventilation is a recommended, and widely used, adjunct to anaesthesia (Geddes and Gray, 1959). It would appear to cause clinically insignificant changes in the acid base balance over the period of an average surgical operation (Papadopoulos and Keats, 1959). Using this machine coupled to a standard anaesthetic apparatus with proximal unidirectional valves, and the usual fairly distensible corrugated tubing, no ill effects have been observed in some hundreds of cases including a few having operations of 9 hours duration.

Indeed, one has perhaps had the impression that normal respiration is more easily re-established after prolonged ventilation with a machine with "negative phase", than after ventilation by manual compression of the bag.

No audible wheezing during expiration, as reported by Lynch, Levy and Kent (1959), has been observed. These authors used a considerably greater negative pressure (−5 to −10 cm water) than the −3 cm water most commonly employed in the present series.

The Beaver Mark I ventilator is supplied with a fixed respiratory rate of either 14 or 18 per minute. Both types have been used and have given satisfactory and completely reliable service over the past two years. However, the machine with the faster respiratory rate has been preferred, as with it the gas flow is more rapid and overventilation more certainly achieved.

The smoothness of expiration seen with this machine is a pleasing minor feature, and compares favourably with the noticeable "jerk" produced by some other ventilators in common use.

The types of case where a negative phase has been most appreciated have been:

1. Abdominal surgery where major haemorrhage was encountered.
2. In head and neck surgery, where the collapsed veins provide excellent operating conditions.
3. Cases with "fixed chest" or obesity requiring high inflation pressures.
4. Certain cases where hypotension was deliberately induced, usually with halothane.
5. Poor risk cases.

The knowledge that the ventilator does not materially impair the circulation is very reassuring, and enables a fuller attention to be given to the assessment of the circulation and to the control of blood transfusions.

SUMMARY

A simple and inexpensive modification of the Beaver Mark I ventilator is described. It produces a "negative" (subatmospheric) pressure during expiration when used in conjunction with a standard closed circuit anaesthetic machine.

The merits of this combination are briefly outlined and its successful use in clinical anaesthesia is reported.

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REFERENCES