A VOLUME CONTROLLED PATIENT-CYCLED RESPIRATOR
FOR ADULTS
With air or anaesthetic gas mixtures
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The arguments in favour of augmenting spontaneous but inadequate respiratory effort in the newborn have been discussed elsewhere (Brit. J. Anaesth. (1957), 29, 553). It was natural, as a corollary, that we should extend our enquiry to adults. The desirability of employing a respirator capable of acting synchronously in step with an adult patient's own breathing (if any) has yet to be assessed. At the same time such a respirator should, as in the case of the newborn, be capable of operating automatically at a suitable and predetermined rate if spontaneous respiration fails or becomes dangerously shallow or infrequent.

The apparatus should work preferentially in step with the patient's breathing, and only when the absence of an adequate inspiratory stimulus exceeds a given period, for example 5 seconds, should the artificial timer operate. As soon as spontaneous breathing is resumed the machine reverts automatically to the patient-triggering system.

Such a machine is here described. It follows the same principles as our respirator for the newborn; however, a more satisfactory control of ventilation was obtained in adults by setting the stroke volume of each breath to a predetermined amount. This advantage is less certain with babies in the presence of atelectasis of varying degrees and where the vital capacity cannot be predicted.

So far clinical trials have been limited to patients undergoing gynaecological operations in whom muscle relaxants have been used and, under these circumstances, the steady rhythm of artificial respiration, maintained by the automatic timer, alters as the effects of the relaxant wear off and the return of spontaneous breathing resumes control of the machine.

GENERAL DESIGN

It was decided to copy, as far as possible, the action of the standard manually operated bag and for this purpose a concertina-like bag was mounted inside a perspex pressure casing (figs. 1 and 2). The bottom of the bag is weighted so that it rests firmly on an adjustable platform when the bag is fully opened. The position of this platform thus sets the stroke volume. Delivery from bag to patient is achieved by filling the perspex casing with compressed air and when the pressure of this is released—or a negative pressure applied—the bag refills itself with gas mixture or air as required. If the patient inhales spontaneously, a change in pressure operates a trigger (fig. 3) causing compressed air to be applied to the bag. If, on the other hand, no breath operates the trigger during a preset period, a delay timer comes into action and causes the respirator to operate in the same way. The compressed air is obtained from a small pump and reservoir. Regulation of the flow of compressed air to the respirator is effected by a needle valve, since the pressure from the pump is kept uniform at about 10 lb. per square inch. The needle valve, therefore, controls the duration of the inspiratory period. As this period can be reduced to under 1 second, if required, the peak flow rate exceeds 50 litres per minute.

Safety Valve.

If the respirator is set to deliver a large stroke volume in a short inspiration time, the pressure required to achieve this might exceed what is clinically desirable. Mushin and Rendell-Baker (1953) refer to pressures of 25 cm H₂O or more as being necessary for efficient ventilation, and suggest an upper limit of 30 cm H₂O. Behnke
Schematic drawing of respirator showing (top left) perspex casing with corrugated bag, adjustable platform, and outlet port with safety valve and pressure gauge. In the interests of clarity the inlet port and manifold have been omitted (see figs. 4A, 4B). $S_1$, $S_2$, $S_3$, are Burgess Microswitches; $V_S$ and $V_R$ solenoid valves; A is a P.O. relay type 3000; B a B.T.H. Electronic Timer type FU21; and C a resettable overload relay (government surplus).

![A volume-controlled patient-cycled respirator for adults.](image-url)
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FIG. 3

Detail of photo-electric inspiration trigger, showing aluminized terylene flap partly raised.

(1941) in experiments on relaxed conscious adults reported that intermittent pressures of 15 mm Hg (20 cm H₂O) were acceptable, but 25 mm Hg (34 cm H₂O) produced a sensation of substernal distress. Saklad (1953), quoting this, adds that the pressure required to overdistend the lungs and thus rupture the alveoli of healthy adults would appear to exceed 30 mm Hg (40 cm H₂O). It would therefore seem that an upper limit of safe pressure might reasonably be fixed anywhere between 25 cm H₂O and 35 cm H₂O, but in the present respirator the weight-operated safety valve has been designed to limit pressures to 25 cm H₂O, although this can readily be increased.

Photo-electric Trigger.

The photo-electric trigger used follows closely the design developed for infant respirators. It consists (fig. 3) of a closed perspex cell with a tube leading off one side and a hole in the base covered with a flap of aluminized terylene. Light from a small bulb is focused by a condenser, and reflected by the aluminized terylene on to a phototransistor (type OCP71). While thus illumined the phototransistor passes enough current to hold open the contacts of A, a Post Office relay (fig. 1). When, however, any air is drawn up through the trigger at the beginning of a spontaneous inspiratory effort the flap is lifted, the light deflected, and these relay contacts close. The speed of this action is limited only by the operating time of the relays and solenoid valve (less than 1/10th second), and there is no perceptible delay between the patient’s effort and the commencement of the resulting inspiration cycle.

Delay Timer and Latching Relay.

A standard industrial timer controls relay B so that its contacts close at any preset interval up to 5 seconds after switch S2 has been operated by the bag coming to rest on the platform at the end of expiration. The latching relay (C) is stable in either of two positions, following a momentary pulse in either coil. It is used to switch the solenoid valves Vs and Vr and, as a matter of convenience, its coils have been labelled “Squeeze” and “Release” (fig. 1) to indicate their functions in relation to the rubber bag. During the inspiratory phase the bottom of the bag rises off the platform and in doing so opens switch S1, thereby rendering the trigger inoperative until the cycle is completed.

OPERATING CYCLE

The weighted bottom of the bag rests on an adjustable platform, (fig. 1). While in this position it closes switches S1 and S2, simultaneously connecting the photo-electric trigger and initiating the delay timer. If now either relay A or B closes, due to the action of the trigger or the timer, whichever is the sooner, the latching relay swings to “Squeeze”, and compressed air is admitted to the perspex casing via the solenoid valve Vs. This squeezes the bag and continues to do so until all the air or gas it contained has been conveyed to the patient (or released via the safety valve). By now the base of the bag presses against the top of the perspex casing, and a third contact (S3) in thus closed. This swings the latching relay C to the release position, and the solenoid valve Vs is shut, cutting off the compressed air, while at the same time Vr is opened, allowing the air in the perspex casing to escape. The weighted base of the bag now falls until it again rests on the platform, so recharging the bag (fig. 4) and at the same time...
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preparing for the next cycle by closing S1 and S2.

CLOSED CIRCUIT OPERATION

The apparatus can be arranged to operate in either a "total loss" or a closed circuit system. It was originally tested on the latter and this application will therefore be described first.

Considering the cycle from the point where compressed air starts to squeeze the bag, the gas passes out to the patient through one-way valve V1 (fig. 4A), the pressure being indicated by a pressure gauge. (This is limited to a maximum of 25 cm H₂O by the weight-operated safety valve.)

When the bag is released it is filled by expired air from the patient, after this has passed through a soda lime canister (S.L.). Lost gas, and CO₂ absorbed by the soda lime is replaced by fresh gas or air at atmospheric pressure drawn in through valve V3. The flap of V3 is designed so that a pressure gradient of 5 cm H₂O is required to open it; thus a negative pressure of 5 cm is maintained throughout expiration. A further purpose in raising the operating threshold of V3 is to prevent a gradual build-up of gas pressure within the respirator bag due to the possible leakage of gas accumulating inadvertently under pressure within the reservoir.

The primary use of a closed circuit system is with anaesthetic gases, and it was found desirable to use the respirator in the same manner as a manually operated bag—namely to leave the valve on the Y-piece partly open, and to

Fig. 4

(a) Connection of respirator to patient for closed circuit operation showing fresh gas inlet on the right, and corrugated tubing to facepiece on the left.

(b) Connection of respirator to patient for total loss operation, showing fresh gas inlet on the right, and corrugated tubing to facepiece and expiratory valve V4 on the left.
work with rather larger stroke volumes than are required by the patient—thus ensuring a continual replenishment of the gas mixture, and preventing a progressive alteration in the proportion of the component gases, as a result, for example, of oxygen uptake.

"TOTAL LOSS" OPERATION

Partly because of the difficulty of estimating the precise nitrous oxide/oxygen mixture in a closed circuit, and partly in view of reports of a lower incidence of postoperative hangover among patients where a total loss technique was employed, it was decided to modify the apparatus to use this method as an alternative. Apart from its advantages with trichloroethylene, such a system is, in any case, clearly preferable to a closed circuit when atmospheric air alone is being used.

The main alteration concerns the return tube from the patient to the bag. In the closed circuit (fig. 4A) pressure from the bag held the non-return valve (V2) closed during the inspiratory phase, ensuring that all the gas reached the patient; while, during expiration, the same valve permitted expired air to pass from the patient back to the bag. This valve was therefore replaced by another (V4), with a corresponding function (fig. 4B). This valve consists of a thin rubber membrane lightly applied over the return tube from the patient. The membrane is connected with the perspex pressure casing. During the inspiratory phase, compressed air is admitted to the perspex casing, squeezing the bag and, simultaneously, pressing the membrane firmly against the end of the return tube, thus preventing loss of gas. At the end of inspiration, the compressed air is shut off, the membrane relaxes, and the patient is free to exhale to atmosphere.

As there is now no return path from the patient to the bag, it is no longer possible to obtain the negative phase from the falling bag, and it would instead be necessary to derive this from the low pressure side of the pump—in some respects a less elegant solution. On the other hand, the absence of an intermittent negative pressure in the return tube makes it possible to connect the trigger directly to the return tube from the patient with a substantial increase in sensitivity.

SUMMARY

A respirator is described which, it is believed, represents a new approach to the problem of ensuring optimal ventilation of certain difficult cases. This is achieved by a dual timer-trigger system, coupled with a variable rate of delivery, which may be increased to over 50 litres/minute. Two forms of the respirator are considered, one for use in a closed circuit, the other for "total loss" operation: each has been used successfully throughout surgical operations in which relaxants were used, the return of normal breathing coinciding with a smooth change-over from automatic to patient-triggered operation. The apparatus has not as yet been sealed against explosive gases.

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REFERENCES

