A NEW PAEDIATRIC VENTILATOR*

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CONTROLLED VENTILATION for adult anaesthesia is generally accepted to be best performed by a ventilator rather than by hand. The reasons for this were summarized by Mushin *et al.*[1] These same reasons apply even more to paediatric anaesthesia. Unfortunately during the last decade very few ventilators especially designed for paediatric anaesthesia have been available. To compensate for this, many adult ventilators had paediatric attachments made for them. These utilized a bag and bottle arrangement,[2,3] leaks,[2,3,4] parallel compliance,[5,6] and other systems[6,7] to enable them to produce small tidal volumes. Apart from the cumbersome size of some of these units the functioning of many of these paediatric adaptors may not be entirely satisfactory for paediatric anaesthesia.[4]

It was decided to build a paediatric ventilator which would be small, cheap and simple, but efficient.

CONSTRUCTION

The basic idea conceived was to create a vacuum powered ventilator. This would operate a valve, which would open and close the expiratory limb of an Ayres T piece circuit,[8] thereby acting as an artificial thumb. (See Figure 1.)

A vacuum powered motor (1), whose shaft rotates back and forth through an arc of 90 degrees is connected to a vacuum source through a graduated valve (2, 3, 27), allowing a variable amount of vacuum through to the motor via a tube (25).

The motor (1) is mounted on a movable plate (14) and is connected by linkages (4, 5, 6) to a piston (7) in such a way that the piston will slide back and forth in a cylinder (8). Radially arranged around the cylinder are 6 holes (9) so that at some period during the travel of the piston, the holes connect the outside to the inside of the cylinder (8) and the rest of the time the holes are covered and sealed by the piston (7).

The whole motor assembly (1, 14) is movable towards and away from this fixed cylinder under control of a screw (10) connected to the inspiratory-expiratory ratio control knob (11). The movement of this assembly is guided by bolts (17) in slots (18). A stop (12) and lock nuts (13) are fitted on the screw (10), so that by turning the screw the maximum amount in either direction, the ratio of the time the holes (9) are occluded by the piston to the time not occluded by the piston can be varied from 1:1 to 1:4. Via a cam needle (15) and a spring (16) this ratio can be read off on a scale (24). The cylinder has at its inlet (28) a 15 mm BS 1 degree female taper.

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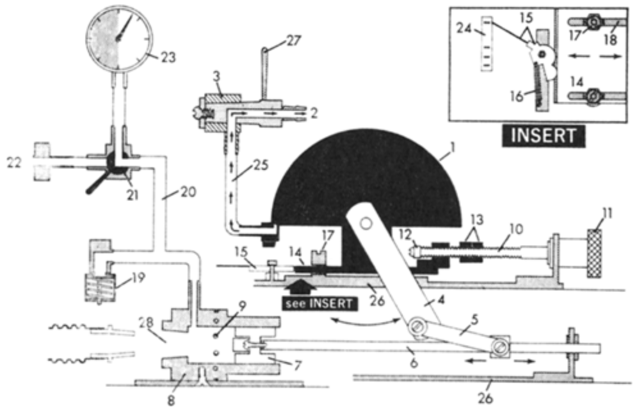

FIGURE 1. A schematic drawing of the ventilator showing:

1. motor
2. vacuum connector
3. vacuum flow regulator
4. linkage
5. linkage
6. linkage
7. piston
8. cylinder
9. hole
10. screw
11. insp./exp. ratio adjustment
12. endstop
13. locknuts
14. plate
15. needle and cam
16. spring
17. nut
18. slot
19. safety valve
20. connecting tubing
21. stopcock (3-way)
22. connector (for external pressure source)
23. pressure gauge
24. scale
25. vacuum tubing
26. base plate
27. vacuum adjusting lever
28. 15 mm female connector

A tube (20) is fitted leading off the side of this cylinder (8) at such a position that it cannot be occluded by the piston (7). This tube leads on the one hand to a pressure release valve (19) set to release at 30 cms H_2O and on the other hand to a 3-way stopcock (21) and thence to a pressure gauge (23) graduated in cms H_2O. By adjusting this stopcock to any of 3 positions it is possible to connect the gauge (23) to the cylinder (8) or to a connector fitted outside the respirator (22) or to switch the gauge completely off.

METHOD OF FUNCTION

A vacuum source is connected to the vacuum connector (A) on the respirator and the expiratory limb of an Ayres T piece system (B) is connected by a 15 mm male connector (C) to the female connector on the cylinder (D) (Figures 2a, 2b, 2c). In fact any Ayres T piece system will connect onto the ventilator in this way, provided the bag is removed.

The endotracheal tube (F) and the fresh gas flow (E) are connected in the appropriate manner and by adjusting the vacuum tap (A), the speed of cycling can be set. The inspiratory-expiratory ratio is adjusted with the appropriate control (H) until the desired result is obtained on the scale (I).

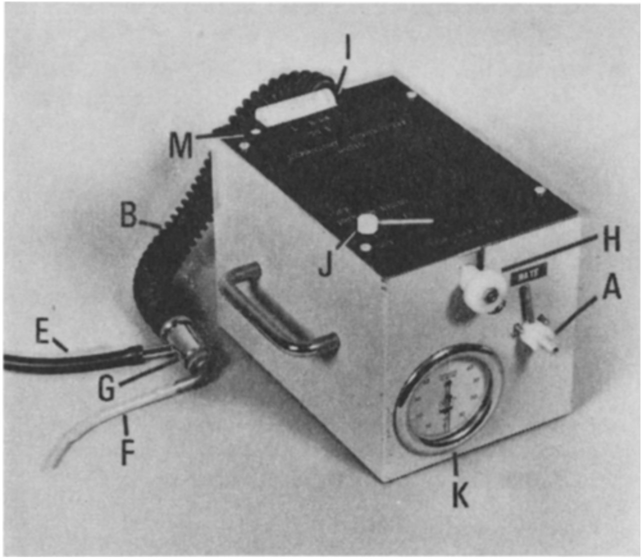

FIGURE 2a. The ventilator seen from two different angles.

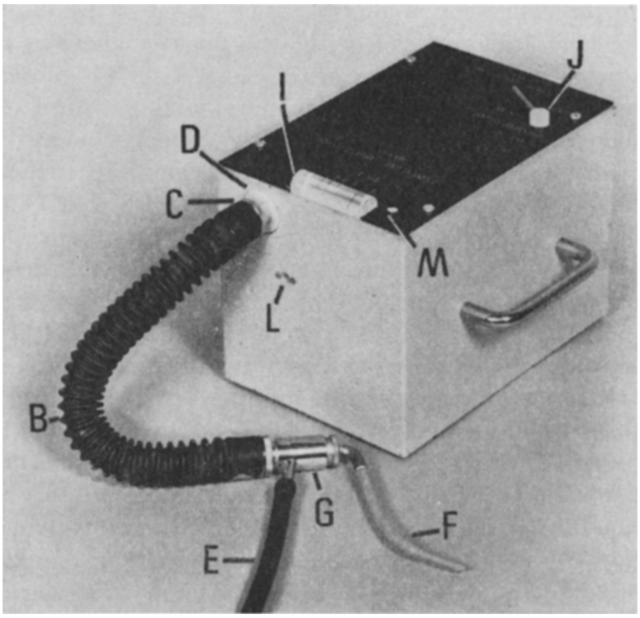

FIGURE 2b.

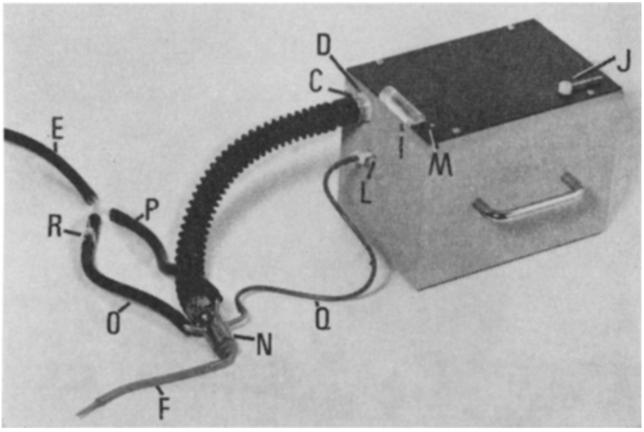

FIGURE 2c. The ventilator with attachments for negative phase.

A. Connection for vacuum and rate control.
B. Expiratory limb of T piece
C. 15 mm BS male connector
D. 15 mm BS female connector
E. Tubing for fresh gas flow
F. Endotracheal tube with connector attached
G. T piece
H. Insp./exp. ratio control
I. Insp./exp. ratio scale
J. 3-way stopcock
K. Pressure gauge
L. External pressure gauge connector
M. Top of safety valve
N. Special T piece
O. Fresh gas flow ("easy way")
P. Fresh gas flow to injector
Q. Connection to pressure gauge
R. Variable resistance

The holes in the cylinder will alternately be closed off by the piston causing inflation of the lungs (Figure 3a) or will be opened, allowing the gas in the circuit to escape to air. Exhalation can therefore occur (Figure 3b). Since the fresh gas flow is known (from the rotameters) and the inspiratory-expiratory ratio is also known (from the scale) the minute volume can easily be calculated (e.g. fresh gas flow 6 l/min, insp./exp. ratio 1:2. One third of the cycle is occupied by inspiration. Therefore the minute volume is $6/3 = 2$ l/min). The tidal volume can be calculated by dividing this number by the rate per minute (which has to be counted). The actual amount may be less than this depending on the compliance of the tubing and the fit of the endotracheal tube.

At no time can the pressure in the system exceed 30 cms H_2O (the blow off pressure of the safety valve) unless the safety valve is manually held shut.

A negative phase on expiration can be produced by this machine with the use of a special T piece. This method was first suggested by Eger,[9] and later improved on by Keuskamp.[10] The negative pressure is produced by injecting part of the fresh gas flow down a venturi tube built into the T piece. This creates a negative pressure proximal to the injector (see Figure 3c). In this system the resistance to fresh gas flow through the injector is much higher than the alternative route so gas will preferentially not flow through the injector. As more resistance to the fresh gas flow occurs by occluding the "easy way" then more and more gas flows through the injector. More negative phase is therefore produced.

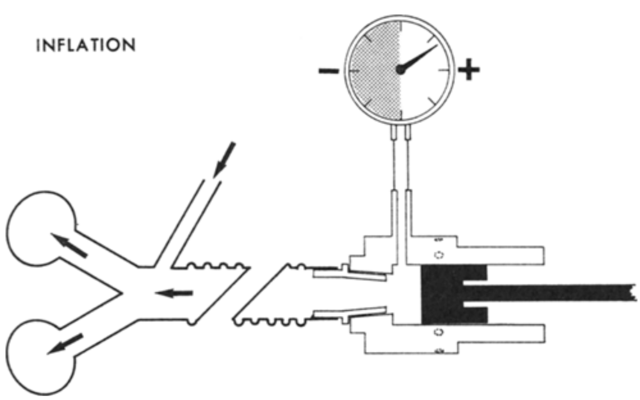

FIGURE 3a.

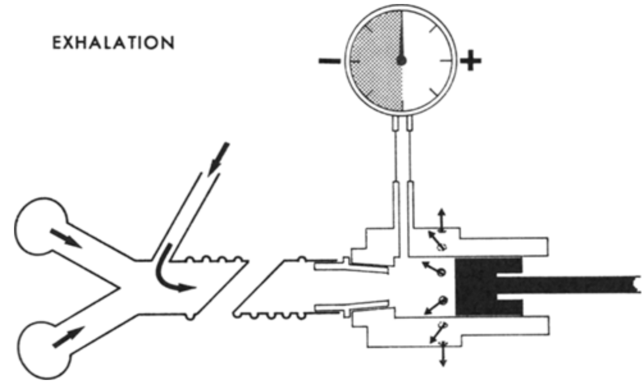

FIGURE 3b.

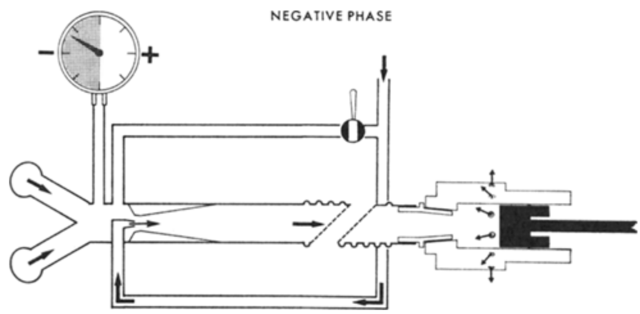

FIGURE 3c.

FIGURE 3. A schematic representation of:
(a) inflation
(b) exhalation
(c) negative phase.

(a) the exit holes from the cylinder are sealed by the piston. The fresh gas flow is therefore directed into the lungs.

(b) the exit holes in the cylinder are now open. Both the air from the lungs and the fresh gas flow are seen to exit this way.

(c) the exit holes in the cylinder are now open. Both the air from the lungs and the fresh gas flow are seen to exit this way. The fresh gas flow, however, is being injected down a venturi tube. The negative pressure created by this is seen to help suck the gas out of the lungs.

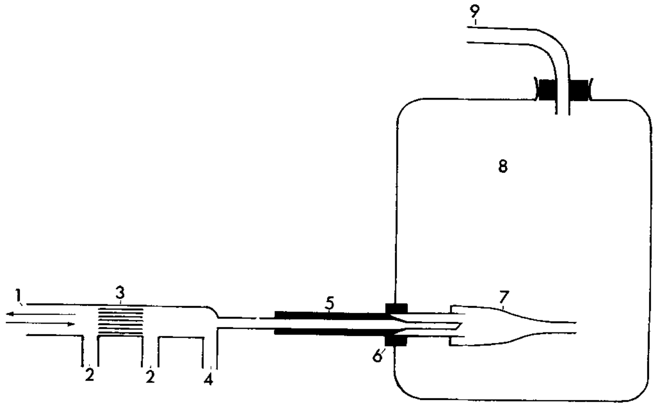

FIGURE 4. Test apparatus used to obtain results seen in Figure 5 a and b.

1. Connection to ventilator
2. Connections to flow recorder
3. Fleisch Pneumotachograph
4. Endotracheal tube pressure tapping
5. Endotracheal tube
6. Model trachea
7. Model lower airway resistance
8. Model compliance
9. Alveolar pressure tapping

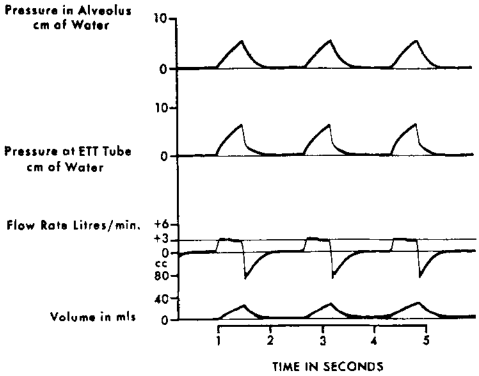

FIGURE 5a. Positive pressure ventilation.

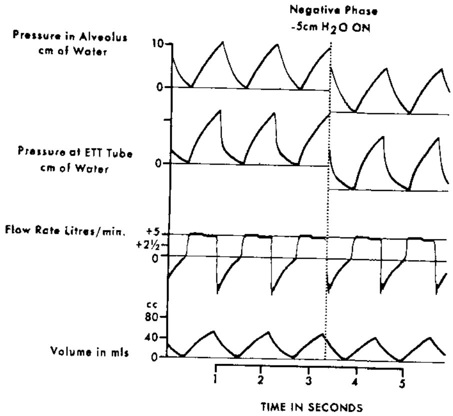

FIGURE 5b. Positive and positive negative ven tilation.

FIGURE 5. Pressure flow and volumes obtained whilst testing the ventilator on a test lung (see Figure 4).

When this system is used (see Figure 2c), the pressure distal to the injector is recorded on the pressure gauge. To do this the 3-way stopcock is adjusted to connect the gauge to the external connector as explained earlier (see Figure 1), and from here a tube leads to the appropriate part of the T piece. The fresh gas flow is fed into the T piece through two tubes, with a variable resistance fitted onto the tube which is not connected to the injector.

The Ventilator in Use

To test the performance of the ventilator it was connected to a test lung through a 14-gauge French endotracheal tube. A Fleisch Pneumotachograph was connected between the ventilator and the endotracheal tube, and pressure transducers were connected just proximal to the tube and to the inside of the test lung (see Figure 4). Having first calibrated the instruments, the test lung was ventilated whilst flow volume and pressure readings were recorded on an Electronics for Medicine Multichannel Recorder. The compliance of this system was 6 cc/cm H_2O and the resistance to flow was 25 cm H_2O/l/sec (recordings obtained are seen in Figure 5).

The ventilator was given a clinical trial. Over a four-month period it was used to ventilate a variety of patients for operations ranging from cystoscopies to ventriculojugular shunts, with ages ranging from a few days to four years (see Figure 6). In all cases the ventilator functioned perfectly, as confirmed by blood gas studies. Very little vacuum is needed to keep a rate of 30 cycles per minute so we experienced no undue change of speed or slowing (see Figure 7).

Functional Analysis

Inspiration: Flow generator. Pressure limited.
Change from inspiration to expiration: Time cycled.
Expiration: Constant pressure generator, or constant negative pressure generator.
Change from expiration to inspiration: Time cycled.
Ventilation rates: 0 to 80 cycles per minute (using up to 300 mm Hg vacuum)
Inspiratory-expiratory ratio 1:1 to 1:4.
Resistance to expiration: 2 mms H_2O at 20 l/pm.
Displacement of gas by piston: 2 cc.

Mechanical Specifications

The overall size of the unit is 19 cm long, 13 cm wide, 13 cm high. The motor is a Trico Type HSB600 IR Windscreen Wiper motor. The cylinder, piston, and all bearings are made of a polyacetal nylon, the linkages and other moving parts are brass, nickel plated. Other parts are either anodized aluminum or painted steel to protect against corrosion.

Discussion

The aim when this ventilator was designed was to make it simple and cheap, yet efficient. It is small!

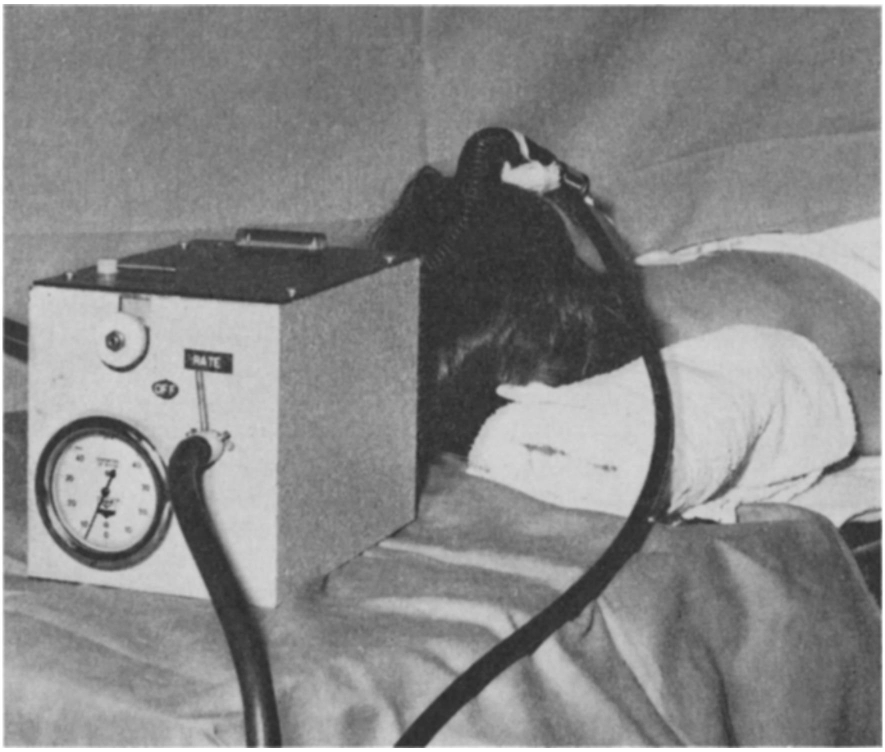

FIGURE 6. The ventilator seen in use on a three-year-old girl.

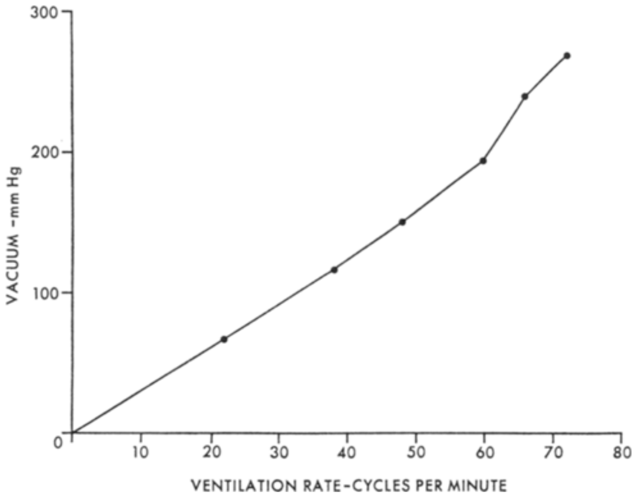

FIGURE 7. Maximum cycling rate of the ventilator with changes in the amount of vacuum.

This ventilator is simple both in construction and in the principles on which it works. Inflation pressure, inspiratory/expiratory ratio, and fresh gas flow can be seen at a glance. The minute volume and tidal volume can be calculated swiftly.

As regards cost, the parts to build this machine cost approximately $40.00, the rest was easily made. The T piece circuit is readily available in most hospitals, as is a source of vacuum.

The efficiency of the T piece technique as a ventilation method for paediatrics is well established, particularly when it is used with an artificial "thumb."

Flow generators with time cycling have distinct advantages in paediatrics provided the fresh gas flow rates can be lowered as low as 1.9 litres per minute, which is easily done here. This figure is regarded by Mushin *et al.*[1] as minimal flow necessary.

An inspiratory/expiratory ratio of 1:2 is agreed to be desirable in most clinical practice.[9] Variation of inspiratory/expiratory ratios from 1:1 to 1:4 is available in this ventilator to allow enough variation to be able to manage any respiratory problem which may occur.

The negative phase is more important in paediatric than in adult anaesthesia. It is considered by some[10,11] that it should be used routinely in premature babies and neonates to aid expiration through small bore endotracheal tubes during the short period available for expiration. This is particularly important when rapid respiratory rates are used. It has, of course, a better recognized place in neurosurgical anaesthesia.

The ventilator could be used for long-term ventilation in the post-anaesthetic room or the intensive care unit, in which case humidification of the gases would be required. This is simply done either by using a condenser humidifier between the T piece and the patient or a humidifier connected to the fresh gas flow.

There are only three ventilators exclusively designed for paediatric anaesthesia available at the present time.[1] Of these, two utilize the system of an artificial thumb on a T piece circuit, but both are powered by electricity in the form of batteries or mains. This ventilator has been designed to eliminate the need for electricity and all the hazards that go with it.

Summary

A ventilator has been designed specifically for use in paediatric anaesthesia. It is small, simple, cheap and efficient.

From this machine positive and positive-negative pressure ventilation is available. It has proved to function well both in the laboratory and in clinical use. It has the advantage that it is vacuum powered so that it can be used with impunity with explosive anaesthetics and in hyperbaric chambers.

Résumé

Nous avons mis à point un ventilateur pour usage spécifique en anesthésie pédiatrique. Cet appareil est petit, simple, peu dispendieux et efficace.

Cette machine peut procurer une ventilation à pression positive ou à pression

positive-négative. Elle s'est avérée capable de travailler aussi bien en laboratoire qu'en clinique. Elle possède l'avantage de fonctionner par le vide de sorte qu'il est possible de l'employer impunément avec les agents anesthésiques explosifs et dans les chambres hyperbares.

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