A DEVICE FOR MECHANICAL VENTILATION SUITABLE FOR NEWBORN AND INFANTS DURING ANAESTHESIA

BY

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SUMMARY

A simple device for converting the Cyclator, an adult ventilator, to paediatric use with an infant anaesthetic circuit has been described. This improvisation works on the principle of an adjustable leak introduced in the patient's circuit as recommended by Mushin, Mapleson and Lunn (1962).

The need for mechanical ventilation during anaesthesia in the newborn and in infants has been strongly felt recently (Rees, 1958; Smith, 1959; Okemian, 1963). Very few ventilators suitable for paediatric anaesthesia are available (e.g. Bennett and Bird), and all are enormously expensive. The Engström ventilator has been successfully used for paediatric anaesthesia. The Starling pump, designed originally for use in animals, has been found to be of value in paediatric anaesthesia but it does not conform to the requirements for safety in the presence of explosive gases (Monro and Scurr, 1961). Mushin, Mapleson and Lunn (1962) have stressed the scarcity in choice of ventilators for children, particularly for use in anaesthesia. The shortage of a suitable ventilator for use in paediatric anaesthesia inspired the improvisation described in this paper.

PRINCIPLE

The system consists of two separate circuits. One circuit is the driving circuit which consists of a Cyclator,* and the other is the anaesthetic or patient circuit. The latter is a modified Ayre T-piece simulating the Mapleson "D" system (fig. 1). The bag is enclosed in an airtight sweet bottle,** and the Cyclator is connected to it by a separate inlet (fig. 3).

When the Cyclator is switched to "automatic", the Beaver inflating valve assumes the inflating position and air is forced into the bottle to the predetermined pressure. This air cushion squeezes

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*British Oxygen Company, Limited.

**Sweet jar, as seen in confectionery shops. Clear flint 5-lb. size, obtainable from Johnsen and Jorgensen, St. Bride Street, London, E.C.4.

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Present address: Hackney Hospital, London, E.9.

FIG. 1

Shows the difference in the system used and Mapleson "D" system.

(i) In the system used the expiratory valve is at a certain distance away from the patient's mouth, but not near the bag.

(ii) In Mapleson "D" system the expiratory valve is near the bag.
the bag and the pressure in the anaesthetic system starts to rise rapidly, opening the expiratory valve on reaching its opening pressure level. The anaesthetic gases between the expiratory valve and the patient will be forced into the child's lungs, while those between the bag and the valve will escape through the expiratory valve (fig. 2). When the Cyclator reaches its cycling pressure, the Beaver valve opens and air escapes from the ventilating (driving) circuit, causing a rapid fall in the anaesthetic circuit pressure. The expiration, which is completely unobstructed, as the anaesthetic system at the end of the inflation is only partially filled, begins and it is assumed that the fresh gas entering the anaesthetic system near the patient's mouth flushes out part of the expired total volume through the expiratory valve before it shuts on reaching its closing pressure level, that the remainder of the expired air goes back into the bag, and that a reservoir of fresh gas will be built up in the anaesthetic system before next inflation. When the Cyclator compresses the bag again, the reservoir of fresh gas occupying the tube between the patient's mouth and the expiratory valve enters the lungs: the gas mixed with expired breath escapes through the expiratory valve.

**DESCRIPTION**

The anaesthetic circuit is assembled using parts from the infant's carbon dioxide absorption apparatus made by the Medical and Industrial Equipment Co., as follows (fig. 3). The endotracheal tube is connected to a Knight straight endotracheal connection which is coupled to a curved one. The endotracheal connector with gas feed inlet joins the curved connector to a corrugated rubber extension piece. This is joined to a curved facepiece connector with expiratory valve, the gas inlet of which is connected to a manometer. The distal end is joined to a special adaptor carrying...
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a corrugated rubber tube which is fitted to an angle mount and a 500-ml reservoir bag. The distal end of the bag is closed.

This bag is enclosed in a wide-mouthed sweet bottle, the lid of which is specially modified to carry two angle pieces. A central angle piece joins the reservoir bag and corrugated rubber tubing of the patient circuit. The peripheral angle piece is connected to the ventilating circuit. The lid is tightened to make the bottle airtight by flanged screws to two side rods fitted to a wooden base on which the bottle stands. As can be seen, the anaesthetic circuit is not in direct communication with the ventilating system.

**Manometer and pressures.**

If the anaesthetic circuit manometer indicates a pressure below 1 cm H₂O during the expiratory pause, the expiratory valve should be turned clockwise to minimize the leak to ensure that the bag fills to the correct extent for the next respiration.

It has been observed that the inflation pressures in the anaesthetic circuit accurately equal the pressures determined on the Cyclator manometer and follow immediately without delay.

**Expiratory valve and tubing connecting the patient.**

The expiratory valve should be partially open. It should be a certain distance away from the patient so that the tube between the child's mouth and the expiratory valve can contain a reservoir of fresh anaesthetic mixture for inflation into the lungs. It is felt that the capacity of the reservoir tubing should at least equal the tidal volume of the patient. If the valve is too near the child's mouth, a large volume of fresh gas will escape through the valve; part of this will enter the lungs during inflation but, during the late phase of inflation, a mixture containing much expired gas and a small volume of the incoming anaesthetic gases will be introduced. There is in these circumstances a small danger of rebreathing even though the flow used is high.

If the work of Waters and Mapleson (1961) is applicable to this system, then, using the recommended high flows and a reservoir tube of appropriate length, there should be no rebreathing. It was not possible to measure blood carbon dioxide tension to verify this assumption. Gross clinical signs of carbon dioxide retention such as rise in systolic pressure, tachycardia, sweating or excessive oozing of blood have not been evident in practice.

The recommended length of the reservoir tube for children up to the age of 12 months is 30 cm and for those between 12 and 24 months it is 45 cm. The diameter of the tube is 2 cm. Table I shows that the capacities of such tubes almost equal the maximum tidal volume for those age groups.

**Reservoir bag.**

This should fill to about three-quarters of its capacity during the expiratory pause, if it does not, the expiratory valve should be turned clockwise to allow the bag to fill to this extent. If the bag collapses after a period of satisfactory ventilation, the gas flows should immediately be checked.

**Tidal volume.**

This is easily increased or decreased by adjusting the ventilating system cycling pressure, and the expiratory valve as inferred by the clinical observations, such as the movement of the diaphragm and chest.

The tidal volumes were measured by connecting a Wright respirometer,* to a 5-month infant, illustrated that the V̇ for children aged 12 and 24 months at the ventilation rate of 20 and 16/min almost equals the capacities of the recommended lengths of the reservoir tubing.

**TABLE I**

<table>
<thead>
<tr>
<th>Child's age (month)</th>
<th>Weight of child quoted from Holt and McIntosh, 1953 (kg)</th>
<th>Tidal volume (ml)</th>
<th>Rate/min</th>
<th>Length (cm) of tubing 2 cm diam.</th>
<th>Capacity of reservoir tube (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>10.8</td>
<td>85</td>
<td>20</td>
<td>30</td>
<td>94.3</td>
</tr>
<tr>
<td>24</td>
<td>13.2</td>
<td>130</td>
<td>16</td>
<td>45</td>
<td>141.43</td>
</tr>
</tbody>
</table>

*Wright's respirometer was used to get approximate readings. It is recognized that according to Nunn and Ezi-Ashi (1962) this instrument under-reads at low flow rates.
weighing 6 kg. The ventilation rate applied was 20/min, and at this rate the ventilation requirement of this patient should be satisfied by a tidal volume of 50 ml. This was achieved at a cycling pressure approximately 16 cm H₂O (the Radford nomogram was used for deriving the minute volume). If it is assumed that 50 ml was introduced in 0.5 sec, then the inspiratory flow will be 6 l./min. The pressure volume curve plotted from the data recorded in this subject suggests that there is little gain in tidal volume when an inflation pressure over 25 cm H₂O is exceeded (fig. 4).

![Pressure Volume Curve](image)

Fig. 4 Shows the relationship between the pressure at mouth and tidal volume plotted from the following data:

<table>
<thead>
<tr>
<th>Pressure applied (cm H₂O)</th>
<th>VT average (ml)</th>
<th>10 readings</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>15</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>20</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>25</td>
<td>80</td>
<td>80</td>
</tr>
</tbody>
</table>

There is a proportional rise in the tidal volume until about 25 cm H₂O pressure is reached. The curve flattens at this pressure level.

Wave form.

The pressure wave form was recorded by connecting an improvised pen-writer to the anaesthetic circuit near the patient's mouth. An expandable corrugated tubing was used as its principal component. Variations in its length were assumed to be proportional to the pressure changes and a writing pen attached to it made a reproducible graph of the pressure wave on a moving kymograph.

The wave forms show four pressure curves. First, there is a rapidly rising pressure curve; the second is a rapidly falling pressure curve, followed by the third, sustained curve; and lastly, a straight tracing. Rapidly rising curve begins when the Cyclator starts to inflate and the Beaver valve takes up the inflating position. The bag is squeezed and there is rapidly rising pressure in the anaesthetic circuit. The expiratory valve opens immediately at the chosen pressure and leak-off starts. The peak of the rising pressure curve indicates the completion of inflation when the lungs are fully expanded. It is followed by rapidly falling pressure curve; its onset might coincide with opening of the Beaver valve to let the air out of the driving circuit when the Cyclator changes to expiratory phase at its cycling pressure. The pressure in the anaesthetic circuit rapidly falls and the expiration begins. The expiratory valve allows part of the tidal volume to leak off before it shuts at its closing pressure. Then follows a sustained pressure of about 3 cm H₂O lasting for 1 second. It might, possibly, be due to an artefact. Perhaps the inertia of the improvised recorder stops the pen-writer reaching the atmospheric level during that apparent period, eventually showing a straight tracing. Briefly, the first curve indicates the inspiratory phase and the next three curves indicate the expiratory phase (fig. 5).

Spontaneous respiration and patient triggering.

If the patient makes a feeble spontaneous effort during inspiration the anaesthetic circuit manometer shows an anticlockwise swing and negative pressure, and also the bag shrinks. This gives a good clinical indication that a further dose of muscle relaxant is required. If the spontaneous effort is to be assessed, the ventilating drive should be turned off. The Cyclator triggering mechanism functions quite satisfactorily when slow rate of ventilation is used. With the patient's small inspiratory effort there is a reduction in the bag size and fall in pressure inside the bottle. This is transmitted to the Cyclator and immediately assisted respiration takes place. Thus this device satisfies another requirement set by Mushin, Mapleson and Lunn (1962) for the conversion of an adult ventilator to paediatric use.

Approximate gas flow rates.

The approximate gas flow rates used are slightly simplified, but follow the pattern advised by Ayre (1956), using smooth tubing of 1 cm diameter and with spontaneous ventilation. These high flows are
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FlO. 5 Shows the wave forms recorded by connecting an improvised pen-writer (see text) to the anaesthetic system near the patient's mouth: "a" is a tracing taken when 15 cm H₂O (ventilation) pressure was applied; "b" is a tracing recorded with 10 cm H₂O ventilation pressure. Ventilation rate used: 16 cycles/min, each respiratory cycle taking 3.75 sec to complete.

I Inspiratory phase corresponds with the beginning of rising pressure curve till its peak = 0.55 sec.
E Expiratory phase is as from the rapidly falling pressure curve till the beginning of the next inflation = 3.2 sec.
I/E ratio is 0.55/3.2, i.e. approximately 1/6.

TABLE II
Shows that the flows of fresh gases used with the mechanical ventilation follow the pattern advised by Ayre with spontaneous ventilation using T-piece.

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>Used with mechanical ventilation</th>
<th>Spontaneous respiration as suggested by Ayre, 1956</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn</td>
<td>3</td>
<td>3-4</td>
</tr>
<tr>
<td>0-3</td>
<td>4</td>
<td>3-4</td>
</tr>
<tr>
<td>3-6</td>
<td>5</td>
<td>4-5</td>
</tr>
<tr>
<td>6-12</td>
<td>6</td>
<td>5-6</td>
</tr>
<tr>
<td>12-24</td>
<td>7</td>
<td>6-7</td>
</tr>
</tbody>
</table>

Rate of respiration.

The faster rate of ventilation and smaller tidal volumes were preferred for the premature and newborn babies, in order to avoid excessive expansion of the lungs (Engström, Herzog and Norlander, 1962; Okemian, 1963). However, the overall ventilation rates suggested are much lower than those observed in spontaneous respiration in subjects of the same age (table III). The rates of ventilation recommended maintained pulse volume and blood pressure at the normal levels for the subjects.

TABLE III
Comparison between the suggested cycles for controlled ventilation and rates of spontaneous respiration for neonates and children aged between 0—12 and 12—24 months.

<table>
<thead>
<tr>
<th>Age</th>
<th>Rate of respiration (b.p.m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Controlled</td>
</tr>
<tr>
<td>Premature (1.7 kg)</td>
<td>30</td>
</tr>
<tr>
<td>Newborn (3.5 kg)</td>
<td>25</td>
</tr>
<tr>
<td>0—12 months</td>
<td>20</td>
</tr>
<tr>
<td>12—24 months</td>
<td>16</td>
</tr>
</tbody>
</table>

CLINICAL REPORT

Experience has been gained by using this device for controlled ventilation in twelve babies with body weights of 2.16 to 11.86 kg, aged between 1 day and 2 years, in whom the durations of the operations varied between 3/4 and 4 hours (table IV). The efficiency of ventilation was judged clinically from the movement of abdomen or chest, air entry, colour of blood, pulse rate, blood pressure, and
TABLE IV
Brief details of twelve babies in whom the device for mechanical ventilation was used.

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Age</th>
<th>Weight (kg)</th>
<th>Operation performed</th>
<th>Duration of operation and controlled ventilation (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common bile duct atresia</td>
<td>2 months</td>
<td>3.24</td>
<td>Choledocho-duodenal anastomosis</td>
<td>95</td>
</tr>
<tr>
<td>Duodenal atresia and imperforate anus</td>
<td>3 days</td>
<td>3.12</td>
<td>Gastro-jejunostomy and opening of anus</td>
<td>120</td>
</tr>
<tr>
<td>Large post-cervical mass</td>
<td>2 years</td>
<td>11.86</td>
<td>Excision of fibrolipoma</td>
<td>90</td>
</tr>
<tr>
<td>Hydrocephalus</td>
<td>1½ years</td>
<td>9.6</td>
<td>Ventriculo-peritoneal shunt</td>
<td>75</td>
</tr>
<tr>
<td>High imperforate anus</td>
<td>1 day</td>
<td>2.64</td>
<td>Sigmoid-colostomy and Spitz-Holter valve shunt</td>
<td>45</td>
</tr>
<tr>
<td>Hydrocephalus</td>
<td>4 months</td>
<td>6.72</td>
<td>Ventriculo-jugular Spitz-Holter valve shunt</td>
<td>100</td>
</tr>
<tr>
<td>Oesophageal atresia</td>
<td>4 days</td>
<td>2.16</td>
<td>R. thoracotomy oesophageal anastomosis; closure of fistula</td>
<td>35</td>
</tr>
<tr>
<td>Hydrocephalus</td>
<td>10 months</td>
<td>10.32</td>
<td>Ventriculo-jugular Spitz-Holter valve shunt</td>
<td>105</td>
</tr>
<tr>
<td>Hydrocephalus</td>
<td>5 months</td>
<td>6.0</td>
<td>Ventriculo-peritoneal shunt</td>
<td>75</td>
</tr>
<tr>
<td>Hydrocephalus</td>
<td>3 months</td>
<td>4.32</td>
<td>Ventriculo-peritoneal shunt</td>
<td>60</td>
</tr>
<tr>
<td>Huge cervical teratoma</td>
<td>15 days</td>
<td>3.36</td>
<td>Excision</td>
<td>120</td>
</tr>
<tr>
<td>Cranio synostosis</td>
<td>7 months</td>
<td>5.76</td>
<td>Transverse linear craniectomy</td>
<td>240</td>
</tr>
</tbody>
</table>

from the presence or absence of sweating. Also, wherever feasible, tidal volumes were assessed by means of a Wright respirometer.

ANAESTHETIC TECHNIQUE
Atropine only was given in premedication. In all except the neonates anaesthesia was induced by means of halothane. Suxamethonium with hyaluronidase was given by intramuscular injection to all except neonates prior to endotracheal intubation. Mechanical ventilation of the lungs was then commenced, using the anaesthetic circuit described. In neonates intubation was carried out before induction of anaesthesia. Control of ventilation was achieved by injecting further doses of suxamethonium or non-depolarizing drugs. Anaesthesia was maintained using 0.5 to 1 per cent halothane in a 50 per cent nitrous oxide and oxygen mixture provided at appropriate gas flows. The use of muscle relaxants in control of ventilation helped to maintain light anaesthesia. All patients awoke on the operating table immediately the anaesthetic was discontinued on completion of the operation.

RESULTS
All the patients had uneventful postoperative recoveries except one, a premature baby with oesophageal atresia, who died of breakdown of the anastomosis on the fifth day. None of the patients showed any signs of hypoxia, carbon dioxide accumulation or circulatory collapse during anaesthesia and did not have any postoperative pulmonary complications, excepting the fatal case already described who developed a pleural effusion as a result of the surgical complication on the fourth day of the operation.

CONCLUSION
The use of mechanical ventilation permits the anaesthetist to watch the condition of these small patients more carefully; he can supervise the intravenous drip, check the pulse, blood pressure, temperature and replacement of blood loss. The lungs are inflated at regular intervals; expiration is unimpaired and free; the inspiratory gas flow is near recommended figures. There is no explosion risk, thus allowing the use of inflammable agents if these are indicated. Further, it is a device which modifies the Cyclator (an adult ventilator) for use in paediatric anaesthesia. The cost of bottle, adaptor and anaesthetic circuit manometer would be only a few pounds.

ADDENDUM
Since completion of this paper this device has been used with very satisfactory results in four more infants.
ACKNOWLEDGMENTS

I am indebted to Dr. Odeku, neurosurgeon, U.C.H., Ibadan, for his patience and co-operation; Prof. Ralph Hendrickse (paediatrics) for his encouragement; Mr. Eves, instrument curator, who made this device possible by creating various parts such as adaptors, the bottle, lid, etc., to the specifications; Mr. Speed for the illustrations; Mrs. S. B. Jackson for her secretarial help; all my anaesthetic colleagues for their valuable advice and suggestions. I am especially grateful to Professor Mushin for his criticism and guidance.

REFERENCES


UN DISPOSITIF DE VENTILATION MÉCANIQUE
POUR SERVIR PENDANT L’ANESTHÉSIE DE NOUVEAUX-NÈS ET D’ENFANTS EN TRES BAS ÂGE

SOMMAIRE

Description d’un dispositif permettant de convertir le "Cyclator" (ventilateur pour adultes) aux emplois en pédiatrie, en y fixant un circuit d’anesthésie pour petits enfants. Ce dispositif improvisé marche d’après le principe de la “fuite” réglable, on l’introduit dans la circulation, comme déjà recommandé par Mushin, Mapleson et Lunn en 1962.

EINE VORRICHTUNG FÜR DIE MECHANISCHE
BEATMUNG ANWENDBAR BEI NEUGEBORENNEN UND KLEINKINDERN WÄHREN
DER ANÄSTHESIE

ZUSAMMENFASSUNG