The Amsterdam Infant Ventilator and
the Ayre T-Piece in Mechanical
Ventilation

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A pediatric constant-volume time-cycled ventilator (Amsterdam Infant Ventilator, AIV) modified from an Ayre's T-piece to allow for intermittent positive-, positive-negative-, and positive-positive-pressure ventilation was evaluated under laboratory and clinical conditions. The unit performed well under standard simulated conditions of decreased compliance and increased airway resistance. It compared favorably with the pediatric version of the Engrén ventilator. When used by itself as a primary anesthesia system, the T-piece section permitted spontaneous, assisted, or controlled ventilation. It was also successfully mated with four popular ventilators. (Key words: Ventilation: mechanical: pediatric; Equipment: ventilators: pediatric; Anesthesia: pediatric: ventilators.)

The difficulties of mechanical ventilation of neonatal and pediatric patients have been extensively reported. Many techniques have been suggested, yet none is universally accepted. One reason for this is that the small size of these patients presents mechanical problems in addition to the usual physiologic difficulties. Only recently have special pediatric or neonatal ventilators been introduced into commercial production to cope with these problems; prior to this, adult ventilators had to be modified for pediatric use.

Many of the mechanical problems inherent in pediatric ventilators have been overcome during anesthesia by utilizing Ayre's T-piece. The T-piece is reliable and simple to operate. It is admirably suited to meet many requirements of infant ventilation since frequency, flow rate, and pressure are easily adjusted without imposing excessive deadspace or high resistance. As flow direction and, therefore, ventilation, may be controlled by occlusion of the expiratory limb, the utilization of a machine for occlusion in long-term ventilation is a natural development. The present study evaluates a commercial ventilator, the Amsterdam infant ventilator (AIV),† that incorporates in its basic design a modified T-piece. The T-piece was tested by itself and in conjunction with other ventilators for pediatric anesthesia.

Functional Description of Ventilator

The AIV consists of a ventilator body (housing mainly the electronic controls for an expiratory solenoid valve) and a breathing head, interconnected by plastic tubing (fig. 1). Metered gas from an external source is delivered into the rear of the body and provides the volume and work of ventilation. It is channeled by a proportioning valve (control, left front, fig. 1) into the outlets connected to the two inspiratory limbs in the plastic head. When the solenoid valve is closed, this gas inflates the lungs; when the valve is open it exits freely together with the exhaled gas, to room air. Frequency and duration of valve closure are electronically timed. The I/E ratio (inspiration as per cent of the respiratory cycle) can be varied independent of frequency. Minute volume is controlled by adjusting the gas flow and the I/E ratio. The ventilator functions in the control mode only and is a time-cycled, constant-flow generator.

The head is merely a modified Ayre's T-piece (fig. 2 A) machined in a plastic block, and so modified as to allow controllable negative pressure during exhalation. Negative

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pressure in a T-piece can be achieved by directing the inspiratory mixture through a Venturi jet close to the patient port (Fig. 2B). As the negative pressure will vary with total flow, the amount of suction is determined by the patient’s ventilatory requirements. Allowing part of the inspiratory flow to bypass the jet in a controlled manner permits the amount of suction to be regulated, independent of ventilation (Fig. 2C). Compacting this configuration results in a small ventilator head with all gas pathways directed toward one side (Figs. 2D and 3). This small translucent plastic unit (approximately 2.5 × 2.5 × 2.5 cm, weight about 20 g; deadspace about .5 ml) incorporates two inspiratory and one expiratory pathways, a pressure tap and a patient connector. Plastic tubing connects the head to the solenoid valve and to the gas and airway pressure monitoring outlets of the ventilator body (Fig. 3).

The inspiratory gas, having been channelled into two pathways, enters the patient both directly and through a Venturi configuration. During inspiration, the closed solenoid valve blocks the expiratory limb, and gas must go from the Venturi jet, as well as from the direct pathway, into the patient. During exhalation, gas flows from the two inspiratory channels and from the patient, into the Venturi funnel outlet and through the open solenoid valve. This valve is normally open, so that in case of power failure the patient may breathe spontaneously (as he could with the usual T-piece technique).

The jet gas, flowing through the Venturi into the funnel, creates negative pressure at the patient port. The amount of negative pressure is monitored on the airway manometer and can be controlled by varying the proportioning valve, directing larger or smaller flows into the Venturi. The gas to the Venturi can also be shut off, providing a certain amount of positive pressure during exhalation. Thus the head provides for intermittent positive-, positive-positive-, and positive-negative-pressure
FIG. 2. Evolution of Ayre’s T-piece (top schematic) into the AIV head (bottom schematic). I = inspiratory limb; E = expiratory limb; Pt = patient connector. Diagram B shows how suction can be applied to the patient port by utilizing a Venturi configuration in the inspiratory limb. Diagram C shows how a proportioning valve may control this suction by combining the advantages of the two upper configurations. The bottom schematic shows the rearrangement within the AIV head.

ventilation. (For manufacturer’s specifications see Appendix).

Methods

The ventilator was evaluated in the laboratory during the simulation of decreased compliance and increased airway resistance in five anesthetized (pentobarbital Na, 25–35 mg/kg) dogs. The dogs were paralyzed (suxamethonium chloride in intermittent doses) and ventilated via a large-bore (#12 Portex) cuffed endotracheal tube. The gas flow to the ventilator was adjusted to provide nearly normal alveolar CO₂ tensions after frequency was set at 20 and inspiration to 40 per cent of the respiratory cycle (I/E ratio 1:1.5).

Briefly, the sequence of study was: After an equilibration period of at least 30 minutes, decreased compliance was simulated by inflating (to 40 torr) a blood pressure cuff wrapped around the chest. This lasted for 15 minutes, and was followed by a 10-minute "recovery" period. After this, a resistor (2 mm internal diameter) was inserted in the endo-

FIG. 3. Phantom drawing of the AIV head with schematized connections. I = inspiratory paths; E = expiratory limb; M = manometer connection. The inspiratory flow is divided by the proportioning valve: the upper limb connects directly to the patient; the lower limb to the venturi inlet.
tracheal tube connector. This resistor functioned during inspiration; it offered minimal resistance during exhalation. It was left in place for 10 minutes and then removed, after which there was a second 10-minute "recovery" period. At the end of each of these periods, and after 7.5 minutes of chest cuff compression, mean blood pressure (mercury manometer) and esophageal temperature (thermistor probe) were noted and arterial blood samples obtained for blood-gas analysis (Astrup technique; Radiometer equipment).

The following were recorded continuously: gas flow through the tracheal tube connector (V; Fleisch pneumotachograph); airway pressure at the same site (P_{airw}; Hewlett-Packard 267BC transducer); CO₂ concentration at the carina (F_{ECO₂}; Beckman LB-1 CO₂ Analyzer with linearized output); central venous pressure (CVP; Statham P23-BB transducer). The signals of flow and airway pressure were fed continuously to an analog computer (Electronic Associates model TR-48), permitting the calculation, and simultaneous recording (fig. 4), of tidal volume (Vₜ), expired minute volume (Vₑ), total dynamic compliance (C_{dyn}), mean airway pressure (P_{airw}), power (W), and work (W) of ventilation on a multichannel recorder (Sanborn with 350 series preamplifiers). Total dynamic compliance was obtained by dividing the tidal volume by the airway pressure at the end of inspiration, when flow was zero. Work is the integral of the product of flow (V) and airway pressure; power of ventilation is the rate of work performed (V multiplied by P_{airw}). Minute volume was also calculated by multiplying tidal volume by the ventilator frequency. Frequency and I/E ratio were obtained from a record run at 10 mm/sec. Numerical values to be reported were read from this fast record, which was made simultaneously with the blood sampling. The pertinent data were averaged and then analyzed using Student's t test for paired data to determine significance at the 95 per cent confidence level. CVP, power, and work of ventilation are described in typical recordings only; we feel that analog presentation provides greater insight into the parameters than numerical analysis.

Results

Only average data are reported (see table 1 and fig. 4). The mean and standard deviation for each test period are listed in table 1. Blood pressure, temperature, and blood buffer base remained stable throughout an experiment; pH changed according to PaCO₂.

The inspiratory flows (0.30 l/sec), I/E ratio, and ventilator frequency, once set, did not change; therefore they are not reported in detail.

During the first control period (Control A) mean Vₑ was 5.227 l/min (fig. 4, panel A); Vₜ/kg was 15.1 ml. The mean peak airway pressure was 9.9 cm H₂O during inspiration and minus 2.2 cm H₂O during exhalation, though the ventilator was set to give zero pressure at the end of exhalation. The mean airway pressure equaled 2.9 cm H₂O and the mean dynamic compliance 21.3 ml/cm H₂O. Mean P_{AECO₂}, P_{ACO₂}, and P_{AO₂} were 37.8 torr, 41.1 torr, and 79.8 torr, respectively.

Compliance decreased significantly during chest compression (fig. 4, panel B). Inspiratory and expiratory peak pressures increased significantly, while mean airway pressure remained essentially unchanged. W and W increased according to the changes in P_{airw}. Vₑ and Vₜ remained unchanged. P_{AECO₂} and P_{ACO₂} decreased, while P_{AO₂} rose. There were no differences between the measurements obtained 7.5 minutes and 15 minutes after chest compression.

Values found 10 minutes after release of chest compression (Control B) were not significantly different from those during Control A except for the decrease in mean dynamic compliance (21.3 to 20.6 ml/cm H₂O).

After insertion of the inspiratory resistor (fig. 4, panel D), Vₑ, Vₜ, and P_{AO₂} decreased while P_{AECO₂} and P_{ACO₂} increased. Only the change in Vₑ was significant (5.165 to 5.140 l/min). For this phase, airway pressures were recorded not only at the usual site (Pᵢ), but also in the tracheal tube on the carinal side of the resistor (P₀) (table 1, values in parentheses). Airway pressure (P₀) increased greatly when measured above the resistor; when measured below the resistor (P₀) (fig. 4, panel C), inspiratory P_{airw} increased only slightly, but expiratory P_{airw} decreased significantly. This resulted in a moderate but significant increase in mean airway pressure. When compliance was computed using the P₁ value it was significantly lowered; when P₁ was used, no significant change was noted. The ability of the ventilator to overcome increased resistance is demon-
FIG. 4. Records of a typical experiment. Each panel is excerpted from a different phase: Panel A, first control; Panel B, chest compression; Panel C, after insertion of the inspiratory resistor, using an airway pressure tap between the resistor and the carina (Pc); Panel D, as in Panel C, but using the usual pressure tap between resistor and ventilator (P). The channels from top to bottom are: central venous pressure (CVP); tidal and minute volumes (VT, VE); flow (V); airway pressure (Paw); mean airway pressure and total dynamic compliance (Paw, Cdyn); power and work of ventilation (W/W); and CO2 concentration close to the carina (FeCO2). The straight part of the CO2 record is an average of the FeCO2 curve and is not used in this study. The calibration marks start at zero and have the following values in all panels: CVP 15 cm H2O; VT 400 ml; VE 8 l/min; V 0.9 l/sec; Faw 20 cm H2O; Paw 10 cm H2O; Cdyn 35 ml/cm H2O; W 3.75 l·cm H2O/sec; W 1.5 l·cm H2O; FCO2 2 per cent. The exception to this is in panel D, second channel from the bottom, where calibration for work and power is twice the usual (W = 3 l·cm H2O and W = 7.5 l·cm H2O/sec). The time marks at the bottom are one second apart (paper speed is 10 mm/sec). On the continuous compliance curve, values are read at the knee of the curve, which occurs when the flow reaches zero at the end of inspiration.

strated in the tracings of power and work in panel D of figure 4, where increased preamplifier attenuation was needed to prevent them from going off-scale.

Ten minutes after removal of the inspiratory resistor (Control C), all measurements returned to close to the values 20 minutes before (Control B).

The values of the physiologic parameters—Cdyn, Paco2, and Paco2—during Control C were also compared with the values of Control A in order to assess the stability of the preparation throughout the study. While Paco2 and Paco2 were not significantly changed, decreases in compliance (−1.3 ml/cm H2O) and Paco2 (−2.2 torr) attained statistical significance.

Discussion

The mechanical requirements for a pediatric ventilator stand in contrast to those for an adult ventilator: significantly lower flow rates and shorter inspiratory times are needed to mimic normal respiration. Unfortunately, there is no agreement about ventilator controls for optimal gas exchange in the abnormal lung. But deviation from a normal pattern has been suggested; optimizing the inspiratory flow rate and widely different frequencies have
TABLE 1. Ventilatory Data, Amsterdam Infant Ventilator*

<table>
<thead>
<tr>
<th></th>
<th>Control A</th>
<th>7.5 Min after Chest Compression</th>
<th>15 Min after Chest Compression</th>
<th>Control B (Recovery)</th>
<th>10 Min after Inspiratory Resistol</th>
<th>Control C (Recovery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>30 Min</td>
<td>37.5 Min</td>
<td>45 Min</td>
<td>55 Min</td>
<td>65 Min</td>
<td>75 Min</td>
</tr>
<tr>
<td>VT/kg (ml)</td>
<td>15.1 ± 1.4</td>
<td>15.2 ± 1.6</td>
<td>15.1 ± 1.4</td>
<td>14.9 ± 1.0</td>
<td>14.4 ± 1.1</td>
<td>14.7 ± 1.0</td>
</tr>
<tr>
<td>V̇E (liters)</td>
<td>5.227 ± 0.939</td>
<td>5.267 ± 0.937</td>
<td>5.227 ± 0.939</td>
<td>5.165 ± 0.951</td>
<td>5.040 ± 0.989B</td>
<td>5.118 ± 0.984B</td>
</tr>
<tr>
<td>Peak inspiratory pressure (P_{air}) (cm H₂O)</td>
<td>9.9 ± 1.0</td>
<td>12.2 ± 1.4A</td>
<td>12.2 ± 1.7A</td>
<td>9.9 ± 1.0</td>
<td>17.6 ± 1.5B (11.0 ± 1.6)</td>
<td>10.1 ± 1.5</td>
</tr>
<tr>
<td>End-expiratory pressure P_{air} (cm H₂O)</td>
<td>-2.2 ± 1.1</td>
<td>-3.0 ± 1.5A</td>
<td>-2.8 ± 1.4A</td>
<td>-2.6 ± 1.3</td>
<td>-3.1 ± 1.5B (-1.6 ± 1.2B)</td>
<td>-2.2 ± 1.5</td>
</tr>
<tr>
<td>F_{air} (cm H₂O)</td>
<td>5.9 ± 0.9</td>
<td>3.1 ± 0.9</td>
<td>3.1 ± 0.9</td>
<td>2.7 ± 0.9</td>
<td>5.0 ± 1.1B (3.2 ± 1.0B)</td>
<td>2.7 ± 0.9</td>
</tr>
<tr>
<td>Cdyn (ml/cm H₂O)</td>
<td>27.3 ± 6.8</td>
<td>17.7 ± 6.4A</td>
<td>17.7 ± 6.4A</td>
<td>20.6 ± 6.8A</td>
<td>11.3 ± 3.8B (19.5 ± 6.2A)</td>
<td>20.0 ± 6.5A</td>
</tr>
<tr>
<td>P_{Aco₂} (torr)</td>
<td>37.8 ± 2.4</td>
<td>36.0 ± 2.8A</td>
<td>35.8 ± 3.0A</td>
<td>37.7 ± 2.5</td>
<td>38.8 ± 3.1</td>
<td>37.5 ± 2.9</td>
</tr>
<tr>
<td>P_{aco₂} (torr)</td>
<td>41.1 ± 3.5</td>
<td>38.1 ± 3.9A</td>
<td>39.2 ± 3.5A</td>
<td>40.7 ± 3.0</td>
<td>42.4 ± 3.4</td>
<td>38.9 ± 3.5A</td>
</tr>
<tr>
<td>P_{aco₂} (torr)</td>
<td>79.8 ± 10.1</td>
<td>81.5 ± 13.5A</td>
<td>81.4 ± 13.6A</td>
<td>79.6 ± 12.7</td>
<td>77.6 ± 10.3</td>
<td>78.7 ± 13.2</td>
</tr>
</tbody>
</table>

* All values are the means for five dogs ± 1 standard deviation.
1 The data in parentheses are pressure measurements (P₂) between the resistor and lower airway.
A Significantly different from control A at least at the 95 per cent confidence limits.
B Significantly different from control B at least at the 95 per cent confidence limits.

been advocated. Because this ventilator was evaluated as part of an ongoing study, it was set at a frequency of 20, and tidal volume adjusted so that end-tidal P_{aco₂} was about 40 torr. Its adaptability to simulated clinical conditions of decreased compliance and increased airway resistance is demonstrated by the results of the laboratory tests.

The mean weight of the dogs studied (16.3 kg) approximated infant weights. The preparation remained stable, as indicated by the unchanging blood pressure, central venous pressure, and blood buffer base. Only total compliance deteriorated (21.3 to 20.0 ml/cm H₂O); this consequence of monotonous mechanical ventilation was reversed by manual administrations of several deep breaths. During chest cuff compression, tidal and minute volumes remained unchanged in the fact of a 16 per cent decrease in mean compliance. The ventilator functioned as a nearly-ideal constant-flow generator; therefore, flow remained constant and airway pressure rose according to the change in compliance. The gas source (i.e., anesthesia machine outlet) provided more than enough power for ventilation. In fact, alveolar ventilation increased, reflected by the significant decrease in P_{aco₂}. This is explained by the fact that the control volume was ventilating a smaller lung. Even though mean peak airway pressure increased 23 per cent, mean airway pressure (P_{air}) increased only 6 per cent. The suction action of the Venturi (powered by a constant gas flow) produced a larger negative pressure when it was connected to the smaller lung. This increased negative pressure was not harmful; on the contrary, P_{aco₂} increased during chest compression.

The insertion of an inspiratory resistor in the upper airway (endotracheal tube) produced small reductions in tidal and minute volumes. This was a result of the rise in peak inspiratory pressure in the deadspace of the connecting tubings. The blood gases reflect a small, but statistically insignificant, hypventilation. On the tracheal side of the resistor the peak inspiratory pressure rose only from 9.9 to 11 cm H₂O (11 per cent), while on the ventilator side of the resistor the airway pressure rose 77 per cent. The changes in end-expiratory pressure (19 per cent increase on the ventilator side; 38
Table 2. Ventilatory Data, Engström Ventilator*

<table>
<thead>
<tr>
<th>Duration</th>
<th>Control A</th>
<th>15 Min after Chest Compression</th>
<th>Control B (Recovery)</th>
<th>10 Min after Inspiratory Resistol</th>
<th>Control C (Recovery)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 Min</td>
<td>45 Min</td>
<td>55 Min</td>
<td>65 Min</td>
<td>75 Min</td>
</tr>
<tr>
<td>VE (liters)</td>
<td>4.860 ± 0.470</td>
<td>4.690 ± 0.450</td>
<td>4.800 ± 0.460</td>
<td>4.540 ± 0.340</td>
<td>4.770 ± 0.440</td>
</tr>
<tr>
<td>Peak inspiratory pressure (Paw) (cm H2O)</td>
<td>9.6 ± 0.6</td>
<td>11.9 ± 0.6</td>
<td>10.4 ± 1.2</td>
<td>25.6 ± 3.1</td>
<td>10.0 ± 0.3</td>
</tr>
<tr>
<td>End-inspiratory pressure (Paw) (cm H2O)</td>
<td>7.7 ± 1.6</td>
<td>9.6 ± 1.0</td>
<td>8.3 ± 1.3</td>
<td>8.4 ± 1.3</td>
<td>8.4 ± 1.3</td>
</tr>
<tr>
<td>Cdyn (ml/cm H2O)</td>
<td>31.6 ± 3.7</td>
<td>24.7 ± 1.7</td>
<td>29.6 ± 3.9</td>
<td>27.2 ± 4</td>
<td>28.7 ± 3.9</td>
</tr>
<tr>
<td>Paco2 (torr)</td>
<td>-42.3 ± 1.8</td>
<td>41.5 ± 2.5</td>
<td>-42.4 ± 1.8</td>
<td>-45.9 ± 2.5</td>
<td>43.1 ± 3.1</td>
</tr>
</tbody>
</table>

* All values are the means for five dogs ±1 standard deviation.
† The data in parentheses are derived from pressure measurements between the resistor and lower airway (P2).

per cent decrease in negativity on the dog's side) indicate that the resistor was not inspiratory only. Mean airway pressure rose proportionately. The change in total compliance reflects the methodology; if one divides the volume delivered by the peak airway pressure, changes in resistance will affect compliance calculations. This is true for any measurement of dynamic compliance. Therefore, when compliance was measured in the usual way (using P2) it decreased 45 per cent. However, when pressures distal to the resistor (P2) were used, no significant change occurred.

Under these test conditions this comparatively simple ventilator met the requirements for constant-volume ventilators, that is, it had the ability to adapt automatically to changing conditions of compliance and resistance while continuing to deliver predetermined volumes. In this test situation the AIV compared well with a group of ventilators previously evaluated.11

When adjusted to deliver small tidal volumes, the deadspace and internal compliance of a ventilator could lead to large losses of delivered tidal volume because of high pressures needed to overcome the inspiratory resistor.12,13 A comparison with a well-accepted constant-volume ventilator modified for pediatric use is therefore of value. The Engström Model 200 ventilator with pediatric tubing and a full humidifier was tested for this purpose in five dogs (mean weight 16.3 kg), according to the laboratory methods described. The Engström ventilator was set to a frequency of 20/min and a working (system) pressure of 100 cm H2O (the 1:E ratio is fixed at 1:2). The ventilating gas volume was controlled by the dosing valve. The data in table 2 were selected for comparison.

During chest compression, VE decreased significantly; however, as previously reported for the adult Engström ventilator,19 Paco2 also decreased. (This is a reflection of the increase in alveolar ventilation.) During the resistance test, VE decreased still further and Paco2 rose, reflecting the larger internal compliance of the Engström ventilator. While the changes in peak pressures during chest compression were comparable, during the resistor test the higher peak flow rates (Engström mean 52 l/min; AIV mean 18 l/min) necessitated much larger peak airway pressures in order to continue delivering the predetermined volume.

With the Engström ventilator, the sinusoidal flow with an end-inspiratory pause results in an early peak pressure followed by an end-inspiratory pressure plateau. In spite of different peak pressures, these characteristics and the decreased 1:E ratio resulted in mean airway pressures comparable to those recorded with the AIV. As equilibrium between lung and machine was achieved during the in-
spiratory period of no-flow, pressures (P₁ and P₂), and therefore compliances, recorded from the two sides of the resistor were almost identical.

During the conditions of this study (constant ventilation of a paralyzed subject) neither ventilator, despite their equally good performances and different flow patterns, prevented the slow and continuous decrease in compliance. A transient increase in tidal volume (five manually assisted deep breaths) increased compliance consistently.

The excellent performance of the AIV in the laboratory prompted us to use it clinically. Over a five-year period the AIV was employed successfully to provide ventilation for a variety of surgical procedures. For example, during one six-month period it was used for all thoracic and open-heart procedures done in children less than five years old.

As the body of the ventilator may be considered an "electronic thumb" occluding a T-piece, the AIV head was also used separately for administering anesthesia. In this circumstance, gas flow from the anesthesia machine is delivered to the head via a proportioning device fashioned from a Y-piece and venotube clamps. An aneroid manometer connected to the monitoring outlet of the head permitted the adjustment of flow to create suction as needed. In this manner, the inherent resistance of small endotracheal tubes could be selectively overcome without applying negative pressure directly to the lungs. This system was used during spontaneous, assisted, and controlled ventilation. Whenever mechanical ventilation was desired, it was operated manually either by thumb occlusion of the expiratory tube or by squeezing a bag in the Rees modification. The impressions of the clinical utility of these systems (ventilator or T-piece alone) were always favorable. In some cases, blood-gas monitoring confirmed the clinical impression of the adequacy of ventilation.

There are several previous reports describing the adaptation of a T-piece for mechanical ventilation. Essentially two paths have been followed: 1) use of an adult ventilator for occlusion (fig. 5A, B, C); 2) use of a valve which is electrically 14-16 or pneumatically 5 timed (fig. 5D, E, F). With the latter group, which is closely analogous to thumb occlusion, an adult ventilator can also control the timing of a pneumatic valve. In the first group, corrugated tubing 17-19 a controlled leak 20 or a breathing bag in parallel 14,21,22 has been utilized to interface an available ventilator with the T-piece. In essence, these provide a compliance to permit matching ventilator characteristics with the infant's input impedance, in much the same fashion as the breathing bag in the Jackson Rees modification.

We have successfully applied four different ventilators in the configurations depicted in fig. 5A and D. The main consideration in adjusting the ventilator was the need to provide an appropriate inspiratory time; this was easily accomplished with the aid of a corrugated tube or a valve. For example, a corrugated anesthesia tube connected a Bird Mark VII ventilator to the expiratory limb of the AIV head. With the inspiratory flow set to a low value, the cycling pressure was adjusted until adequate inspiratory time was achieved. Flows from the anesthesia machine were set according to the demands of the T-piece technique. 24-26 During anesthesia, we usually determine the adequacy of ventilation by observing chest-wall movement. However, a Wright respirometer placed between the expiratory port and the corrugated tube may be used to measure the total gas flow. This value should agree with the flow from the anesthetic machine and can be used, together with the I:E ratio, to calculate minute volume. If the measured total flow exceeded the input to the T-piece, rebreathing occurred. Another way to quantitate rebreathing is to reverse the Wright respirometer, measuring the flow into the expiratory limb during inspiration. We prefer knowing whether a large amount of rebreathing is occurring, even though it has been shown that there will be less rebreathing when a ventilator is combined with a T-piece than with the usual manual system in the Rees configuration.

The ease with which the head was adapted to adult ventilators whenever long-term ventilation was needed was surprising and gratifying. The pressure-flow characteristics of the AIV were retained when a ventilator was used to shut a valve in the expiratory limb of the AIV head. However, when a corrugated anesthesia tube was used without a valve, the flow pattern was slightly altered (rounding out of the square wave). Neither of these
FIG. 5. T-piece configurations and attachments reported for mechanical ventilation. The orientation of the T-piece is the same in each circuit and labeled in circuit A: I = inspiratory limb; E = expiratory limb; P = patient connector. Some T-piece configurations in D and E may also provide negative pressure during exhalation. The attachments in circuits A–C allow for artificial ventilation when using adult ventilator (V) with a T-piece. A pneumatic valve (circuit D) may also be used to attach the ventilator to the T-piece. In circuits E and F, an electric timer and an electric motor are used to operate an occlusive valve in the expiratory limb. For details and references, see text.

carousal altered the operation of the pressure-limiting mechanism intrinsic to the ventilator operating the AIV head.

The AIV has proved to be a reliable and effective constant-volume pediatric ventilator in the laboratory, operating room, and recovery room. Its successful use in long-term ventilation has also been reported. The AIV head, which determines most of this ventilator’s functional characteristics, provides all of its advantages and is simple and inexpensive. It is an improved T-piece which helps to overcome the resistance of small endotracheal and connecting tubes while providing all the advantages of the T-piece technique. It may be used for anesthesia by itself, or with other ventilators to provide adequate ventilation in any mode desired. This versatility warrants more extensive clinical application.

References


APPENDIX

Information Provided by the Manufacturer

1. Recommended application—neonatal, pediatric
2. Minute volume—zero to 6 l/min
3. Frequency—20 to 55/min
4. Tidal volume—zero to 300 ml
5. Inspiratory phase time—0.25 to 1.50 sec
6. Expiratory phase time—0.50 to 2.25 sec
7. Inspiratory-expiratory phase time ratio—1:1 to 1:3
8. System pressure control—minus 10 to +60 cm H2O
9. Peak inspiratory pressure—zero to 100 cm H2O
10. Internal compliance—0.15 ml/cm H2O
11. Expiratory resistance—0.3 cm H2O at 0.1 l/sec
12. Humidifier—optional heated vaporizer type
13. Power source—110 V, 60 Hz
14. Power consumption—10 watts
15. Dimensions—11.5 x 26 x 17 cm
16. Weight—3 Kg
17. Method of sterilization—ethylene oxide

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