A Simple and Versatile Mechanical Ventilator for Infants

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To provide adequate mechanical respiration for newborns and infants following operations for congenital heart disease, a simple and versatile mechanical ventilator was developed in 1959. Since then, it has been used in the treatment of more than 250 infants with a variety of cardiac and non-cardiac diseases, both before and after operation. The ventilator is based on the anesthetic system originally described by Ayre for use with a T-tube.[1] Metered oxygen flows into the respiratory limb of a Y-tube. The second limb is connected to an endotracheal or tracheostomy tube, and closure of the third limb results in inflation of the lungs. Both Inkster and Pearson[2] and Reynolds[3] described ventilators for infants based on this principle and accomplished interruption of the expiratory limb by an electronically-controlled device. Others[4,5] attached a conventional respirator to the expiratory limb of a T-tube to accomplish the same thing. In the ventilator described here, interruption is achieved mechanically by a rotating slotted cylinder. Since most of the characteristics and merits of such a system for mechanical ventilation have been described in detail by others,[2-5] this description will be limited primarily to the mechanism for interrupting gas flow out of the expiratory limb of the Y-tube.

The interrupter (fig. 1) consists of a revolving cylinder (*A*) rotated by a small conventional electric motor (*B*) governed by a rheostat (*C*) for variable speeds of 10–120 rotations per minute. An off-on switch is incorporated in the rheostat. From the revolving cylinder a tapered section in the form of a regular trapezoid has been removed, leaving recessed slotted supports. The dimensions of the trapezoid section removed were selected

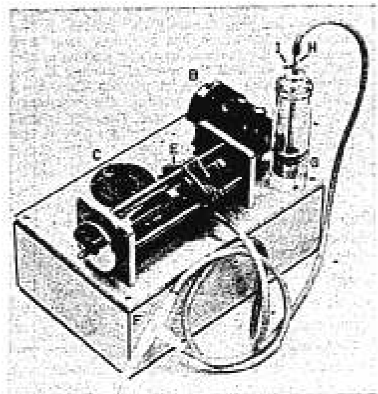

FIG. 1. The mechanism for interrupting gas flow from the expiratory limb of a Y-tube when used to respire infants. See text for detailed description. The tubing shown is thin-walled rubber tubing. To prevent kinking, thick-walled plastic tubing or rubber pressure tubing should be used. The length of this tubing is not critical. However, the T-piece (*F*) should be placed at the infant's face. A lead counterweight (extreme left) is attached to a disc on the axle of the rotating cylinder to compensate for the weight lost by removal of a trapezoid section of the cylinder.

so that at one end the circumference of the cylinder is ⅓ intact and ⅔ open and at the other end ⅔ intact and ⅓ open. The expiratory limb of the Y-tube is attached to a metal tube (*D*) which projects completely through that side of the bridge (*E*). The internal surface of the bridge is flush with the portion of the rotating cylinder which has not been cut away. When flush, the system is airtight at the pressures used, and inflation of the lungs results. When the cutaway portion of the cylinder is opposite the internal orifice of metal tube (*D*), gas flows freely to the interior of the cylinder and lung deflation occurs. The bridge rides on three metal rods, permitting

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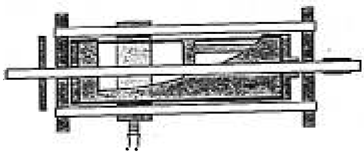

FIG. 2. Diagram showing the portion of the rotating cylinder which has been cut away and recessed. At the bottom the uncut portion of the cylinder is flush with the internal opening of the metal tube which attaches to the expiratory limb of the Y-tube. In this position the expiratory limb is occluded and inflation of the lung is produced. At the top is a recessed portion of the cylinder surface. When this portion of the cylinder is opposite the metal tube, gas flows freely and expiration is permitted.

it to slide to either end of the cylinder and thereby to vary the inspiratory-expiratory ratio from 1:2 to 2:1. The bridge is of sufficient width to keep the internal opening of the metal tube (*D*) from being occluded by the completely intact areas of the cylinder at either end. Thus, as the cylinder rotates, the expiratory limb is alternately closed and opened and causes inflation and deflation of the lungs. The diagram (fig. 2) shows more clearly the flush and cut-away portion of the cylinder. A T-piece (*F*) is attached to the expiratory limb of the Y-tube at the infant's face, and the side tube is extended to a mercury seal (*G*) to provide a release valve for excessive pressure in the expiratory limb. The metal tube (*H*) has been marked with a centimeter scale from below upward which can be read through the plastic container. The depth of the tube (*H*) in the mercury can be adjusted by screw (*I*) to provide any maximum inspiratory pressure desired. Thus, in the event of electrical failure with cylinder in a closed position or other obstruction of the expiratory limb, the excessive pressure is dissipated by gas bubbling through the mercury seal. The entire device can be as remote as desired from the patient by extending the tubing from the T-piece. This tubing should be thick-walled to prevent kinking. Any desired system which provides effective humidification or nebulization can be used on the oxygen inflow limb. The apparatus is mounted on a 12″ × 18″ box and weighs approximately 12 pounds.

The special merit of this ventilator is that it allows independent control of four parameters of respiration; respiratory rate, inspiratory-expiratory ratio, inspiratory flow rate, and peak inspiratory pressure. An increase in respiratory rate by the rheostat without altering the other controls will shorten duration of inspiration and decrease the theoretical tidal volume at any given oxygen flow rate. Since some leak occurs about the uncuffed endotracheal tube used in infants, actual tidal volume depends on the size of this leak and the resistance of the lung–thorax to inflation. An increase in inspiratory–expiratory ratio without altering the other controls will increase theoretical tidal volume. In practice, respiratory rate is set at approximately 40/minute, the inspiratory–expiratory ratio at between 1:2 and 1:1, the safety valve at 1.5–2.0 cm. Hg (19–27 cm. water) and the flow rate of oxygen is adjusted (4–3 l./min.) to provide visual expansion of the chest with each inspiration. Subsequent adjustments are based on clinical observations and blood gas analyses. In the presence of severe pulmonary hypertension or pulmonary edema, duration of inspiration and peak inspiratory pressure are increased. In the presence of systemic hypotension or decreased pulmonary blood flood flow (tetralogy of Fallot), these are both decreased.

The performance of the ventilator can be estimated from the data in table 1 which were obtained during use of a 50-ml. rubber bag as an artificial lung. Duration of inspiration

TABLE 1. Measured Duration of Inspiration at Three Rates of Cylinder Rotation and Three Inspiratory—Expiratory Ratios of a Mechanical Ventilator

Cycling Rate per Minute	Inspiratory–Expiratory Ratio	Duration of Inspiration Seconds
20	2:1	1.7–1.9
	1:1	1.0–1.3
	1:2	0.8–1.0
75	2:1	0.48–0.50
	1:1	0.38–0.45
	1:2	0.24–0.33
120	2:1	0.22–0.30
	1:1	0.16–0.21
	1:2	0.10–0.12

was measured from pressure curves within the bag recorded at a paper speed of 50 mm. /second. These data approximate well the theoretical values which can be calculated and can provide an estimate of tidal volume at any selected oxygen flow rate. The flow pressure curves obtained with this system have been described.[2,3] At an oxygen inflow rate of 4 l./min. and with a deliberate leak in the artificial lung, pressures from 11 to 28 cm. water were recorded within the bag. With a Y adapter attached to the endotracheal tube, end-expiratory intratracheal pressures measured in five infants ranged from 0 to 3 cm. water at oxygen flow rates up to 12 l./min. If the Y adapter is inverted and the oxygen inflow introduced in the direction of the expiratory limb through a 13- or 15-gauge needle, a negative intratracheal pressure can be developed. This is a modification of the system suggested for a T-piece by Eger and Hamilton[6] and has produced an end-expiratory tracheal pressure of −4 to −5 cm. water, measured in three infants at oxygen flow rates of 6–8 l./min.

The major limitation of this ventilator is that it does not assist respiration and can be applied only to apneic infants. Since respiratory rates up to 120/min. are available, it has not been difficult to gain control of respiration by hyperventilation and without drugs in all except the most severely tachypneic infants. In these a small dose of succinylcholine has been used to obtain respiratory control. We have been able to provide effective respiration for critically ill infants with this ventilator when commercially available respirators were ineffective. The major complication associated with its use is crusting and obstruction of the endotracheal tube due to inadequate humidification of the inspired oxygen, particularly in patients with blood pulmonary edema. With proper humidification, crusting does not occur. The simplest device which provides effective humidification is the Bird Mainstream Micronebulizer, introduced into the oxygen inflow line near the infant's face. Distilled water is then injected at regular intervals into the nebulizer through the rubber stopper.

Appendix

Construction details of this apparatus include the following: The cylinder was made of brass tubing 2" in diameter with a wall thickness of ⅛" and was 7¼" long. The ends were sealed with brass plate. The cutaway trapezoid portion of the cylinder was 6¼" in length and the brass supporting pieces which remained were 1/16" thick. The slide was 1¼" wide and rode on solid aluminum rods supported at each end by aluminum plates of 3⅜" × 3½" × 4". The motor used to drive the cylinder was a Model V 10-R Bodine which requires 115 v. a.c. or d.c.

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