Mechanical Ventilation of Newborn Infants:

IV. Technique of Controlled Intermittent Positive-pressure Ventilation

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This paper describes in detail the techniques used for prolonged, controlled, intermittent positive-pressure ventilation (IPPV/I) of 204 newborn infants with severe respiratory failure. (Key words: Mechanical ventilation; IPPV/I; Controlled ventilation; Nasotracheal intubation; Pulmonary physiotherapy.)

Prolonged mechanical ventilation of the newborn infant was first described by Donald and Lord in 1953. Since that time, mechanical ventilation of the neonate has been used widely, and the survival of newborn infants treated in this manner reviewed. 2, 5 There is no evidence that the type of mechanical ventilation used to support the breathing of newborn infants with respiratory failure affects their survival. 2 However, changes in the pattern of intermittent positive-pressure ventilation (IPPV/I) predictably influence oxygenation and ventilation of infants with respiratory distress syndrome (RDS). 4-6 Few authors have outlined in detail their techniques for the management of newborn infants during mechanical ventilation. 7

Since 1964, we have mechanically ventilated 204 newborn infants with respiratory failure who had failed to respond to conventional treatment. The scoring system used for the selection of these infants for IPPV/I has been described. 8 Because the specific pattern of ventilation is known to influence the response of the newborn infant to IPPV/I, and might, thus, influence survival, this paper describes in detail the techniques used during IPPV/I of these 204 infants.

Management of Infants during Intubation and Intermittent Positive-pressure Ventilation

Nasotracheal Intubation

Nasotracheal intubation was accomplished by or under the direct tutelage of an experienced anesthetist or pediatrician. Maximal oxygenation prior to intubation was achieved by manual hyperventilation with 100 per cent oxygen for three to five minutes. Initially, Davol, but subsequently Foregger (FOR-CLEAR), plastic endotracheal tube with internal diameters (i.d.) between 3.5 and 4.0 mm, 9 to 11 cm long, were used. 9 Only rarely was it necessary to insert a tube of smaller diameter (2.5-3.0 mm i.d.). Lightweight plastic connectors of large ID (Bennett 4S, 4L, 5S) were used to connect the endotracheal tubes to the ventilator circles (fig. 1). The connectors were firmly inserted into the endotracheal tubes prior to intubation.

Before insertion, sterile lubrication of the endotracheal tubes was accomplished with a film of steroid ointment. 9 Each tube was cooled in ice with a stylet in place to produce a semicircular curve. The stylet was removed before intubation. A laryngoscope with a Miller 0 or 1 blade was used. Slight flexion of the neck or external pressure on the larynx

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often facilitated visualization of the glottic orifice, and hyperextension of the neck or the use of McGill forceps was not required. Attempted intubation was not allowed to exceed 45 seconds without an intervening period of manual ventilation with oxygen and was discontinued if bradycardia (<100 bpm) ensued. The largest endotracheal tube possible was inserted to minimize damage to the mucosa by excessive motion and the risk of increased airway resistance due to blockage of the tube with secretions. Large air leaks around the endotracheal tube and consequent dilatation of the stomach with air were thus avoided. Immediately following intubation, the position of the nasotracheal tube was verified by observation of the color of the skin and movement of the abdomen and thorax, and by auscultation of the chest during manual ventilation. When it was confirmed that the trachea had been intubated, the tube was fixed in place and IPPV/I begun. Anteroposterior and lateral roentgenograms of the chest were obtained after fixation to document the exact relationships of the tip of the tube to the carina and mainstem bronchi. The length of the tube was recorded so that subsequent tubes could be cut to the same length prior to intubation.

**Fixation of Nasotracheal Tubes**

The endotracheal tube was fixed by tying a single loop of umbilical tape around the neck of the connector (fig. 1). A single length of nonirritating, non-elastic adhesive tape was then passed behind the head of the infant and the ends of the tape were passed through the umbilical tape loops on either side of the tube. The adhesive tape was then folded back and stuck to itself. When the position of the tube had been verified clinically and it had been located roentgenographically, it was marked at its point of entry into the external naris. A rubber band was attached at the patient-ventilator interface and secured to the dome of the incubator (fig. 1). Adjustment of the direction and tension of this band maintained tube position and prevented movement of the endotracheal tube. No additional supporting apparatus was required.

Following initiation of mechanical ventilation, respiratory tract secretions often increased abruptly. For this reason, endotracheal tubes were changed routinely 24 hours after initiation of IPPV/I and thereafter every 48 to 72 hours. Tubes were removed and replaced immediately when there were signs of airway obstruction which could not be relieved completely by suction or alteration of tube position. When tubes were removed they were inspected and sent for bacteriologic examination.

**VENTILATORS**

Intermittent positive-pressure ventilation was used in all 204 infants. A Bird Mark VIII ventilator was used for the first seven infants, and a Bennett FR-2 respiratory incorporating a low-deadspace infant circle (“Q-circle”) was used for the other 197 infants. Six infants were ventilated for short periods during the course of mechanical ventilation with a modified small-animal respiration pump.§

**PATTERN OF VENTILATION**

Controlled ventilation was used for all infants. Routine curarization was abandoned early as unnecessary and potentially hazardous. Control of ventilation was accomplished by adjusting respiratory rate and airway pressure until the infant did not attempt to breathe. During this procedure arterial blood gases and pH were determined and individual or concomitant variations of rate and pressure made until a PaO₂ between 60 and 100 mm Hg, a PaCO₂ between 25 and 35 mm Hg and a pH between 7.40 and 7.50 were attained.4,5

All Bennett respirator controls except “rate,” “pressure,” and “inspiratory nebulizer” were maintained in the “off” position throughout the course of IPPV/I. The inspiratory nebulizer was used to administer isoproterenol prior to pulmonary physiotherapy and occasionally to help maintain a 1:1 inspiratory/expiratory ratio. The air-dilution control of the respirator was maintained in the “out” position (“100 oxygen”) at all times. Arterial pH, P0₂, and Pco₂ were measured at least every four hours, and often as frequently as every half hour until the condition of the infant stabilized. Thereafter, no change in pattern of ventilation was attempted in the first 12 hours of ventilation unless the condition of the infant deteriorated. The overall status of each infant dur-

ing IPPV/I was reviewed at least every eight hours.

$F_iO_2$

An 80–100 per cent inspired oxygen concentration was used during initial control of the infant’s ventilation. Thereafter, the oxygen concentration was decreased in small increments (2–5 per cent) until a $P_aO_2$ between 60 and 100 mm Hg was obtained in the absence of metabolic acidosis. Every effort was made to reduce $F_iO_2$ to less than 70 per cent as rapidly as possible. After every change in $F_iO_2$, $P_aO_2$, $P_aCO_2$, and $pH_2$ were measured.

When more than 70 per cent oxygen was needed, the ventilator was powered with oxygen (40–45 psi) and air was added proximal to the humidifier and bacterial filter at a rate sufficient to produce the desired oxygen concentration. If an oxygen concentration less than 70 per cent was needed, the ventilator was powered by air and oxygen was used as the diluent gas. This technique for the mixing of gases avoided overloading the Bennett respirator valve system and consequent ventilator malfunction. Even with careful adjustment, inspired oxygen concentration under these circumstances may vary from 10 to 15 per cent. A preventilator gas-mixing valve became available in 1969. This device has obviated the need for mixing gases in the ventilator system and allows delivery of a stable, preselected oxygen concentration. $F_iO_2$ was monitored intermittently from the inspired limb of the Q-circle, using a paramagnetic oxygen analyzer.

Prevention of Bacterial Contamination

All equipment used for mechanical ventilation was washed in Cidex and sterilized in ethylene oxide prior to use. No bacterial contamination of inhalation therapy equipment was found prior to use in the nursery. Preliminary studies had indicated that bacterial contamination sometimes could be detected in the humidifiers and moist respirator tubings after 12 hours of continuous use. For this reason, the warming nebulizer and all ventilator tubing distal to it were replaced with sterile components during routine maintenance checks every eight hours.

PULMONARY PHYSIOTHERAPY

During and following mechanical ventilation, pulmonary physiotherapy was done by the nursing staff every two to four hours to facilitate mobilization and clearing of pulmonary secretions. When wheezing was heard on auscultation, 1 ml of 1:4,000 isoproterenol was administered through the inspiratory nebulizer of the ventilator ten minutes prior to therapy as often as every four hours. Each routine of pulmonary physiotherapy consisted of vibration and percussion of the chest, sterile suctioning of the airways, and change in body position.

Vibration was accomplished by intermittently tensing the muscles of the arm, forearm, and hand with the tips of one or two extended
fingers on the chest wall of the infant. Vibration was applied in the expiratory phase of breathing for five to ten breaths.

Percussion was performed by cupping the fingers and tapping the chest wall firmly for two to three minutes. No attempt was made to time percussion to the phase of breathing.

Suction to remove secretions from the airways after percussion was accomplished by passing a sterile, disposable catheter 1 cm longer than the endotracheal tube into the bronchi. (Following suctioning, the lungs were manually reinflated before the endotracheal tube was reconnected to the ventilator.) To pass the catheter into the right mainstem bronchus, the infant’s head was rotated 90 degrees to the left, and to pass the catheter into the left mainstem bronchus the head was rotated 90 degrees to the right. (The suction catheters did not occlude the airway.)

Positions during Pulmonary Physiotherapy

With the patient supine, the anterosuperior portions of the chest were vibrated andpercussed for 30 seconds. This 30-second routine was repeated in both supine, oblique (lateral) positions. The vibrations and percussion routine was then repeated with the infant semi recumbent. Thus, six positions were used for physiotherapy. Neither percussion nor vibration in the head-down position was attempted.

Maintenance of Airway

The endotracheal tube and airways were suctioned hourly, using sterile catheters 1 cm longer than the nasotracheal tube. The temperature of the inspired gases was maintained between 30 and 35°C and the humidity more than 60 per cent to prevent secretions from drying within the tube. When secretions were viscid, 0.5 ml of 0.9 per cent sterile sodium chloride solution was instilled into the trachea prior to suctioning. The position of the tracheal tube at the nas is checked hourly and following all procedures during which the infant was moved.

Discontinuance of Mechanical Ventilation

Weaning of infants from mechanical ventilation was accomplished in two phases. The first phase consisted of gradual reduction of \( F_{102} \) while maintaining \( P_{aO2} \) greater than 60 mm Hg. Reduction in \( F_{102} \) was followed by alternation of the pattern of ventilation. First respiratory rate and then airway pressure were decreased, and \( P_{aCO2} \) was allowed to increase until the margin of control of ventilation was minimal but maintained. Each change in \( F_{102} \), or in any condition of ventilation, was followed by immediate determination of \( P_{aO2} \), \( P_{aCO2} \), and \( pH \). When the pressure required to maintain oxygenation was less than 35 cm Hg and \( F_{102} \) less than 50 per cent, the second phase of weaning could be attempted.

In the second phase of weaning the infant was separated from IPPV/I. Following percussion, vibration and suctioning, the infant was observed for one to three minutes while spontaneously breathing an oxygen concentration 20 per cent higher than that required during mechanical ventilation. \( P_{aCO2} \), \( P_{aO2} \), and \( pH \) were measured at the end of this period to assess the efficiency of spontaneous breathing. If marked acidosis, hypoxemia or carbon dioxide retention did not occur, the duration of spontaneous breathing was then prolonged from one to three minutes per hour to five to ten minutes per hour, and thence to five minutes every half hour. If five minutes every half hour were tolerated, the periods of spontaneous breathing were prolonged until arterial blood gas tension and \( pH \) were stable for eight hours.

Tracheal extubation was attempted when an infant could tolerate spontaneous breathing for eight hours or more. In very small infants (less than 1,100 g), extubation to prevent carbon dioxide retention was often necessary before weaning could be accomplished. An infant was considered weaned from IPPV/I when spontaneous breathing was maintained for 24 hours without nasotracheal intubation or mechanical support. One to 17 days were required for weaning. A T tube was found not to be useful in the weaning of newborn infants from IPPV/I.

Inadvertent excessive hypercapnia, hypoxemia or metabolic acidosis during the weaning process was considered an indication for the cessation of attempted weaning. When this occurred during the first phase of weaning, increased alveolar ventilation and oxygenation
were achieved by increasing FiO₂ and peak airway pressure. During the second phase of weaning, reinitiation of IPPV/L was necessary. Sodium bicarbonate was given if there was associated metabolic acidosis, and 24 hours or more were then allowed to elapse before weaning was attempted again. Inadvertent complications during weaning from prolonged mechanical ventilation ultimately proved fatal to some infants.

**Nutrition**

During the first 48 to 72 hours of IPPV/L, hydration was maintained by intravenous infusion of 5–10 per cent dextrose in water (65–100 ml/kg/24 hours). When mechanical ventilation was required for more than 72 hours, a gastroscope was established and small feedings with 5 per cent dextrose and water begun. If tolerated, feedings were then increased in calorie content and volume until the nutritional requirements of the infant could be met. Most infants were fed intermittently by gravity drainage, but very small infants sometimes required slow, continuous infusions of formula. After weaning, gastrostomy feedings were discontinued and the gastrostomy tube removed when the infant tolerated oral feedings. Regurgitation and aspiration of gastric contents resulting from overfeeding or malposition of the gastrostomy tube was an unusual but serious complication during mechanical ventilation.

**Conclusions**

This technique for the management of newborn infants during intermittent positive-pressure ventilation has been effective in maintaining prolonged controlled ventilation in our nursery. The techniques used to alter arterial blood gases predictably during IPPV/L of neonates with RDS have been described. When a Bennett PR-2 respirator is used in the manner described in these reports, its performance should resemble closely the performance of the East-Radcliffe respirator used as described by Tunstall and co-workers and that of the Bird Mark VIII respirator used as described by Heese and co-workers.

We can draw no conclusions regarding the superiority of any one ventilator over another for mechanical ventilation of the neonate. It is clear, however, that the pattern of ventilation selected may modify the infant's response to IPPV/L. Whether such a predictable alteration of the response of the infant to the initiation of IPPV/L ultimately affects his survival is not known. There is no information to suggest that the specific ventilator used is more important than the technique and experience of the personnel necessary to maintain a newborn infant on prolonged mechanical ventilation.

**References**

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