Clinical and laboratory observations

Decreased gas flow through pneumothoraces in neonates receiving high-frequency jet versus conventional ventilation

Felipe Gonzalez, M.D., Thomas Harris, M.D., Philip Black, M.D., and Peter Richardson, Ph.D.

From the Departments of Pediatrics, University of Utah School of Medicine, Salt Lake City, Temple University School of Medicine, Philadelphia, and Baylor College of Medicine, Houston

The incidence of pulmonary air leaks in infants receiving conventional mechanical ventilation for severe respiratory failure associated with severe pulmonary diseases is in the range of 25% to 41%.[1] Treatment of air leaks consists primarily of reducing ventilator pressure and volumes,[2] but this most often necessitates the use of increased inspired oxygen concentrations. For infants already receiving 100% oxygen, alternative methods of ventilation must be explored. We hypothesized that high-frequency jet ventilation would result in similar arterial blood gas values at lower mean airway pressures and thereby reduce the rate of leakage through catheters placed to relieve persistent pneumothoraces. This hypothesis was tested in a series of six infants with continuously bubbling chest tubes.

METHODS

The six infants all had severe pulmonary diseases and were given HFJV as part of a separate study investigating the efficacy of HFJV in infants whose condition failed to stabilize with conventional modes of assisted ventilation. The infants all had persistent air leak through pneumonothoraces continuously evacuated via chest tubes; all were receiving ventilation with high $\overline{Paw}$ and 100% oxygen using pressure-limited time-cycled ventilators (Bourns BP200, Bear Medical Systems, Inc., Riverside, Calif.). HFJV was administered using a Bunnell Life Pulse Jet Ventilator (Bunnell Inc., Salt Lake City). Tracheal airway pressures were monitored through a triple-lumen Hi-Lo jet endotracheal tube (National Catheter Co., Mallinckrodt Inc.—NCC Division, Glens Falls, N.Y.), using the BLSI monitor having a frequency response, including endotracheal tube, flat to within ±5% in amplitude and ±5% in phase to frequencies above those used for the patients.

HFJV	High-frequency jet ventilation
$\overline{Paw}$	Mean airway pressure
$A\text{-}aDo_2$	Alveolar to arterial oxygen difference
Pao_2	Arterial oxygen pressure
$Paco_2$	Arterial carbon dioxide pressure

The rate of flow through the chest tubes was measured by collecting the escaping gas in a low-resistance small-volume spirometer (Collins IL, Warren E. Collins Inc., Braintree, Mass.). Each measurement was repeated three times, and the results averaged. Differences in repeated

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Reprint requests: Felipe Gonzalez, M.D., Department of Pediatrics, University Medical Center, 50 N. Medical Dr., Salt Lake City, UT 84132.

Table. Ventilator settings and arterial blood gas results in six infants

	Conventional ventilation	High-frequency ventilation
Inspired oxygen (%)	100	100
Ventilator rate (breaths/min)	60 ± 6	420 ± 44*
Peak inspiratory pressure (cm H_2O)	41 ± 3	28 ± 3*
Positive end-expiratory pressure (cm H_2O)	3.9 ± 0.6	3.7 ± 0.6
Mean airway pressure (cm H_2O)	15.0 ± 1.4	9.7 ± 0.7*
PaO_2 (mm Hg)	49 ± 5	44 ± 3
PaCO_2 (mm Hg)	43 ± 71	34 ± 6*
A-aDO_2 (mm Hg)	485 ± 15	503 ± 12

Values represent mean ± SE.
*$P < 0.05$.

measurements never varied by more than 5%. On completion of air leak flow rate determinations, HFJV was started, and the infants were allowed to stabilize for at least 1 hour, but never longer than 2 hours. The rate of leakage was then determined on HFJV. Heart rate, arterial blood pressure, and transcutaneous PO_2 and PCO_2 were continuously monitored, and were unaffected by the flow rate measurements.

Arterial blood gas determinations were made prior to the flow rate measurements. As an estimate of severity of disease, the alveolar-arterial oxygen differences were calculated. Paired t tests were used for statistical inferences; differences yielding $P < 0.05$ were considered significant.

The study protocol was approved by the Institutional Review Board, and informed written consent was obtained from each infant's parents before entry into the study.

RESULTS

Ventilator settings at the time of pulmonary air leak rate determinations are listed in the Table. The average $\overline{Paw}$ during HFJV was 30% less than during conventional ventilation. Decreases in $\overline{Paw}$ were achieved primarily by decreases in peak inspiratory pressure.

PaO_2 and calculated A-aDO_2 values were not significantly different before and after HFJV, even though $\overline{Paw}$ was lower during HFJV than during conventional ventilation. PaCO_2 values were significantly lower during HFJV.

Mean flow rate decreased from 227 ± 96 mL/min (mean ± SE) during conventional ventilation to 104 ± 59 mL/min during HFJV (Figure). Three infants had a large air leak and three a small leak during conventional ventilation, but the percentage of decrease in flow obtained during HFJV, in relation to the initial leak, was comparable for each individual patient.

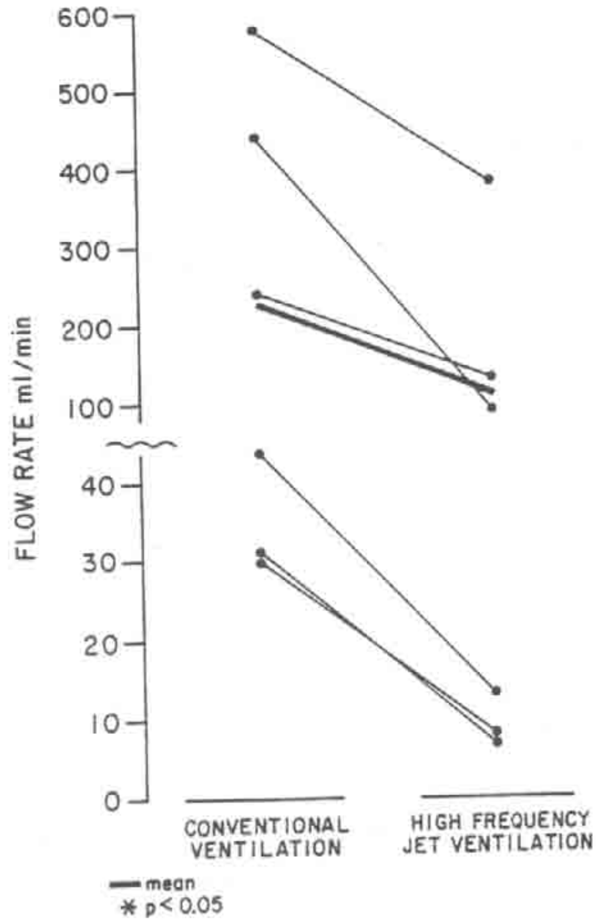

Figure. Flow rates through chest tubes in infants with pneumothoraces.

DISCUSSION

The replacement of conventional mechanical ventilation with HFJV resulted in decreases in $\overline{Paw}$, PaCO_2, and rate of pulmonary air leakage. Similar changes in $\overline{Paw}$ and PaCO_2 have been observed by other investigators.[3,4] HFJV has been used to reduce leakage from bronchopulmonary fistulas in adult patients,[5-8] but to our knowledge has not been reported previously as a means of reducing the rate of leakage in infants with active pneumothoraces.

Determining the mechanism of decreased pulmonary air leakage with HFJV was not considered in the design of this study. However, we speculate that alterations in the distribution of ventilation[9] resulting from the short inspiratory times used during HFJV may have contributed to the observed decreases in leakage flow. Air leaks in premature infants occur most commonly at the alveolar bases or ducts,[2] and then dissect along airways and large vessels to reach the mediastinum and rupture into the pleural space.[10] In the process, some of the airways are compressed by the gas that has dissected along or around them, reducing their radius and increasing their flow resistance. If very high rates and short inspiratory times occur in this situation, as in HFJV, turbulence and high resistance to flow become factors, resulting in preferential ventilation of areas with the least resistance, away from damaged areas producing the leak.

The extremely short inspiratory times used in HFJV (as low as 0.02 sec, or 20 msec) also represent a shorter duration of positive pressure applied to points of rupture. The size of the leak increases during the positive pressure phase of inspiration, and because flow varies with the square of the cross-sectional area of a hole, a small increase in the hole caused by even minimal increases in peak and mean airway pressure are likely to cause relatively large increases in leak.[8,9] Furthermore, inasmuch as $\overline{Paw}$ determined in the trachea of these patients was less during HFJV, we can assume that mean alveolar pressure was also less. This results in a decreased pressure differential between leakly alveoli and pleural space, reducing the pressure head driving gas through the pneumothorax.

We conclude that this study has demonstrated HFJV to be an effective alternative to conventional ventilation for decreasing the rate of air leakage through pneumothoraces in infants with severe pulmonary disease. We believe a randomized controlled study to compare this new method with the old in cases of persistent airleak, such as bronchopleural fistulas and pulmonary interstitial emphysema developing early in acutely ill neonates requiring assisted ventilation, is now indicated.

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