Setting Positive End-Expiratory Pressure During Jet Ventilation to Replicate the Mean Airway Pressure of Oscillatory Ventilation

Andora L Bass MD, Michael A Gentile RRT FAARC, John P Heinz RRT, Damian M Craig MSc, Donna S Hamel RRT FAARC, and Ira M Cheifetz MD FAARC

BACKGROUND: High-frequency ventilation can be delivered with either oscillatory ventilation (HFOV) or jet ventilation (HFJV). Traditional clinician biases may limit the range of function of these important ventilation modes. We hypothesized that (1) the jet ventilator can be an accurate monitor of mean airway pressure ($\bar{P}_{aw}$) during HFOV, and (2) a mathematical relationship can be used to determine the positive end-expiratory pressure (PEEP) setting required for HFJV to reproduce the $\bar{P}_{aw}$ of HFOV. METHODS: In phase 1 of our experiment, we used a differential pressure pneumotachometer and a jet adapter in-line between an oscillator circuit and a pediatric lung model to measure $\bar{P}_{aw}$, PEEP, and peak inspiratory pressure (PIP). Thirty-six HFOV setting combinations were studied, in random order. We analyzed the correlation between the pneumotachometer and HFJV measurements. In phase 2 we used the jet as the monitoring device during each of the same 36 combinations of HFOV settings, and recorded $\bar{P}_{aw}$, PIP, and ΔP. Then, for each combination of settings, the jet ventilator was placed in-line with a conventional ventilator and was set at the same rate and PIP as was monitored during HFOV. To determine the appropriate PEEP setting, we calculated the $\bar{P}_{aw}$ contributed by the PIP, respiratory rate, and inspiratory time set for HFJV, and subtracted this from the goal $\bar{P}_{aw}$. This value was the PEEP predicted for HFJV to match the HFOV $\bar{P}_{aw}$. RESULTS: The correlation coefficient between the pneumotachometer and HFJV measurements was $r = 0.99$ (mean difference 0.62 ± 0.30 cm H_2O, $p < 0.001$). The predicted and actual PEEP required were highly correlated ($r = 0.99$, $p < 0.001$). The mean difference in these values is not statistically significantly different from zero (mean difference 0.25 ± 1.02 cm H_2O, $p > 0.15$). CONCLUSIONS: HFJV is an accurate monitor during HFOV. These measurements can be used to calculate the predicted PEEP necessary to match $\bar{P}_{aw}$ on the 2 ventilators. Replicating the $\bar{P}_{aw}$ with adequate PEEP on HFJV may help simplify transitioning between ventilators when clinically indicated. *Key words: high-frequency ventilation, jet ventilation, oscillatory ventilation, mechanical ventilation, positive end-expiratory pressure, mean airway pressure, oxygenation, acute lung injury, acute respiratory distress syndrome, neonate, pediatric*. [Respir Care 2007;52(1):50–55. © 2007 Daedalus Enterprises]

At the time of this research, Andora L Bass MD was affiliated with the Department of Pediatric Critical Care Medicine, Duke Children's Hospital, Duke University Medical Center, Durham, North Carolina. She is now affiliated with the Department of Pediatric Critical Care, East Carolina University, Brody School of Medicine, Greenville, North Carolina. Michael A Gentile RRT FAARC, Donna S Hamel RRT FAARC, and Ira M Cheifetz MD FAARC are affiliated with the Department of Pediatric Critical Care Medicine; John P Heinz RRT is affiliated with the Department of Neonatology; and Damian M Craig MSc is affiliated with the Department of Cardiothoracic Surgery, Duke Children's Hospital, Duke University Medical Center, Durham, North Carolina.

Andora L Bass MD presented a version of this report at the 22nd Conference on High-Frequency Ventilation of Infants, Children, and Adults, held April 6–9, 2005, in Snowbird, Utah.

The authors report no conflicts of interest related to the content of this paper.

Correspondence: Andora L Bass MD, Pediatric Critical Care, East Carolina University, Brody School of Medicine, 600 Moye Boulevard, Greenville NC 27834. E-mail: bassa@ecu.edu.

Introduction

High-frequency ventilation has become a standard of care for supporting patients with acute lung injury (ALI) and acute respiratory distress syndrome in adult, pediatric, and neonatal intensive care units.[1–6] During high-frequency ventilation the patient is effectively ventilated and oxygenated without the high peak inspiratory pressure (PIP) and excessive fraction of inspired oxygen (F_{IO_2}) associated with ventilator-induced lung injury.[4,7–10] In the neonatal and pediatric populations, the 2 options for high-frequency ventilation are high-frequency oscillatory ventilation (HFOV) and high-frequency jet ventilation (HFJV). While both modes provide the benefits of low peak airway pressure and tidal volume that is usually less than anatomical dead space, there are distinct mechanistic differences. The choice to ventilate with HFOV or HFJV is often subjective and based on traditional biases and/or clinician preference. Clinicians often cite the intrinsic mechanistic differences in these modes to support their individual preferences.

HFOV allows the clinician to directly set a continuous distending pressure (or mean airway pressure [$\bar{P}_{aw}$]), which controls oxygenation along with F_{IO_2}. In contrast, during HFJV, there is no direct manipulation of $\bar{P}_{aw}$. The positive end-expiratory pressure (PEEP) and PIP are the primary factors that control $\bar{P}_{aw}$. The ability to directly set and maintain high $\bar{P}_{aw}$ during HFOV has created a bias toward HFOV for patients with persistent hypoxemia. Additionally, when $\bar{P}_{aw}$ is indirectly achieved (ie, jet ventilation), there is often a reluctance to set a "high" PEEP to augment oxygenation, thus lending credence to the belief that jet ventilation is not as effective at oxygenation. These intrinsic mechanistic differences between HFOV and HFJV have led to the mode-selection practices commonly seen in high-frequency ventilation.

The mechanistic differences between HFOV and HFJV are also highlighted by the different settings on the machine faces. Frequency, inspiratory time (T_I), and F_{IO_2} are set on both devices. However, during HFOV, amplitude and $\bar{P}_{aw}$ are set; whereas during HFJV, PIP and PEEP (on the conventional ventilator) are set. These differences limit the ability to extrapolate understanding of one device to the other. If the ventilators "spoke the same language," this obstacle could be largely overcome. Additionally, the jet ventilator can be used in the standby mode as an in-line monitoring device, while the oscillator cannot.

Our investigation focused on translating the HFOV setting of $\bar{P}_{aw}$ into the HFJV setting of PEEP. We first hypothesized that the jet ventilator could be used as a monitor during HFOV to provide accurate pressure measurements. Although the jet has been used clinically in some neonatal intensive care units in the standby mode as a monitor during HFOV, it has never been validated for this purpose. We additionally hypothesized that a mathematical relationship could be used to determine the PEEP setting required for HFJV to reproduce the $\bar{P}_{aw}$ of HFOV.

Methods

Phase 1: HFJV as a Monitor

The jet ventilator we studied (Life Pulse, Bunnell, Salt Lake City, Utah) has not previously been validated for use as a monitor during HFOV. Therefore, pressure readings during ventilation with the oscillator (SensorMedics 3100A, Viasys Healthcare, Yorba Linda, California) were monitored by a pressure differential pneumotachometer (NICO monitor, Respironics, Wallingford, Connecticut) and compared to the readings from the jet ventilator. The NICO monitor is a respiratory profile monitor with a flow sensor that can be used as a monitor of gas delivery during HFOV.[11] However, the NICO monitor is not used clinically during high-frequency ventilation because a disconnect between the pneumotachometer and the endotracheal tube (ETT) might not be detected by the ventilator due to the resistance of the pneumotachometer. So, while this device provides appropriate readings for comparison in a bench study with an infant test lung, it should not be used with patients during high-frequency ventilation.

For this phase of the study, the oscillator was connected to an infant test lung (IMT Medical, Oceanside, California) in a closed system that used a 3.5-mm inner-diameter cuffed ETT. The pneumotachometer and the jet ventilator adapter were placed in-line between the HFOV circuit and the test lung. The jet ventilator was maintained in the standby mode (Fig. 1). All devices were calibrated per the manufacturers' instructions.

Thirty-six randomly combined HFOV settings were studied: $\bar{P}_{aw}$ of 15, 20, 25, and 30 cm H_2O; amplitudes of 30, 40, and 50 cm H_2O; and frequencies of 5, 6, and 7 Hz. T_I was maintained constant at 33% of the total respiratory cycle time. With each settings combination, the system was allowed 5 min to reach equilibrium, then the $\bar{P}_{aw}$, PIP, and PEEP readings were recorded.

Phase 2: Predicted PEEP Calculation

Similar to phase 1, the oscillator was attached to the test lung, but the jet ventilator alone was used as the monitoring device. The same 36 randomly combined settings were used. Data from the jet ventilator were recorded as during phase 1. For each combination of settings, the oscillator was then disconnected and HFJV was initiated with a backup conventional mechanical ventilator (Avea, Viasys Healthcare, Palm Springs, California). The HFJV settings of PIP, frequency, and rate were set to match what was occurring during oscillation (ie, to match the previously monitored settings). The T_I was held constant at 0.02 s. The missing variable was the

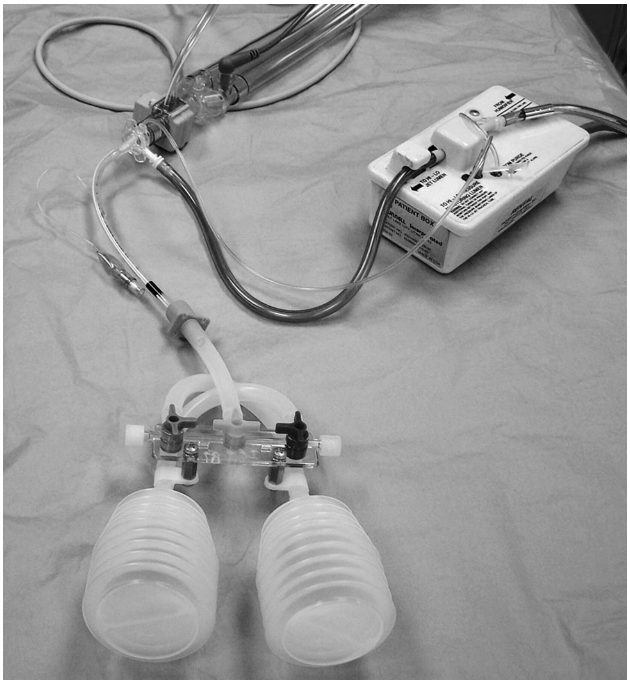

Fig. 1. Phase 1 experimental setup.

PEEP setting on conventional mechanical ventilation. Therefore, the PEEP was sequentially increased until the $\bar{P}_{aw}$ during HFJV matched the set HFOV $\bar{P}_{aw}$. We refer to this PEEP setting as the "required PEEP."

A review of the literature revealed that calculations for $\bar{P}_{aw}$ exist but are lengthy and impractical for use at the bedside.[12–15] Based on our understanding of respiratory mechanics, and noting that these previously validated equations all incorporate T_I, rate, PIP, and PEEP, we developed a simplified equation:

$\bar{P}_{aw} = [(\text{PIP} \times \text{rate} \times T_I)/60\ \text{s}] + \text{PEEP}$

The first part of the equation $[(\text{PIP} \times \text{rate} \times T_I)/60\ \text{s})]$ incorporates the settings we replicated from our oscillator values, so this is termed the "contributed $\bar{P}_{aw}$ from the known settings." If the equation is then rearranged to determine the predicted PEEP, it becomes:

$$\text{Predicted PEEP} = \text{goal } \bar{P}_{aw} - \text{contributed } \bar{P}_{aw}$$

from the known settings, or

$$\text{Predicted PEEP} = \text{goal } \bar{P}_{aw} - (\text{PIP} \times \text{rate} \times T_I)/60\ \text{s}$$

The predicted PEEP was the value our equation predicted would be required to match the HFOV $\bar{P}_{aw}$ setting. We calculated the predicted PEEP for each of our 36 settings combinations.

Statistical Analysis

Correlation was determined with the Pearson product-moment correlation coefficient. Agreement between the NICO monitor and HFJV measurements was tested with a paired *t* test and quantified with linear regression and Bland-Altman plots. The same technique was used to compare the PEEP necessary to match the HFOV $\bar{P}_{aw}$ with the predicted PEEP computed with our equation. All the calculations were performed with statistics software (SAS 9.1, SAS Institute, Cary, North Carolina).

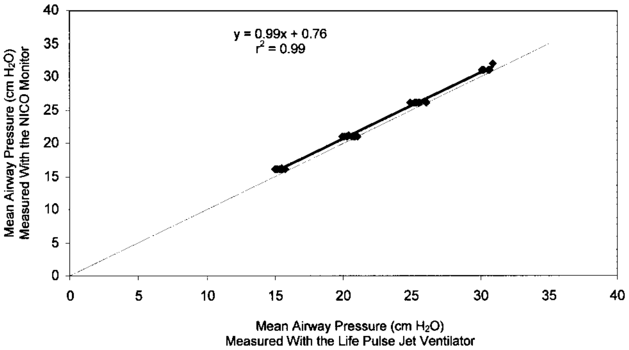

Fig. 2. Comparison of mean airway pressure measurements from the NICO cardiopulmonary monitor and the Life Pulse jet ventilator.

Results

Phase 1: HFJV as a Monitor

Our primary goal in phase 1 was to compare the NICO monitor and HFJV $\bar{P}_{aw}$ readings. The correlation coefficient between these values was $r = 0.99$ ($p < 0.001$) with a mean difference of 0.62 ± 0.30 cm H_2O. Because of the consistency of this bias, the mean difference is statistically significantly different from zero ($p < 0.001$), but the magnitude is small, ranging from 4% at a $\bar{P}_{aw}$ of 15 cm H_2O to 2% at a $\bar{P}_{aw}$ of 30 cm H_2O. The bias has no correlation to the $\bar{P}_{aw}$ setting ($r = 0.09$, $p = 0.59$). The equation relating the NICO monitor and HFJV $\bar{P}_{aw}$ readings was:

$\text{NICO } \bar{P}_{aw} = (\text{HFJV } \bar{P}_{aw} \times 0.99) + 0.76$

The largest difference between the 2 measurements was 1.1 cm H_2O. Therefore, the jet ventilator provides a very accurate measure of airway pressure during HFOV (Figs. 2 and 3).

We made 2 other interesting observations during phase 1. First, the PEEP recorded at the ETT by both devices during HFOV was surprisingly high (Table 1); PEEP reached a maximum of 23 cm H_2O. Second, when the HFOV amplitude was set 3 times greater than the $\bar{P}_{aw}$, the resultant PEEP was zero. In our settings this occurred when the $\bar{P}_{aw}$ was 15 cm H_2O and the amplitude was 50 cm H_2O (Table 2).

Phase 2: Predicted PEEP Calculation

When the PEEP required to match the HFOV $\bar{P}_{aw}$ in each of the 36 settings was compared to the predicted

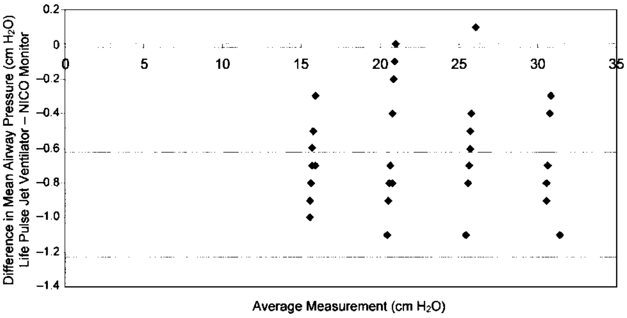

Fig. 3. Bland-Altman plot of mean airway pressure differences between the measurements from the jet ventilator and the cardiopulmonary monitor.

Table 1. Examples of PEEP Generated During 3 HFOV Setting Combinations

	$\bar{P}_{aw}$ (cm H_2O)	Amplitude (cm H_2O)	Frequency (Hz)	Monitored PEEP (cm H_2O)
Example 1	15	30	5	7.5
Example 2	25	40	7	15
Example 3	30	30	7	23

PEEP = positive end-expiratory pressure
HFOV = high-frequency oscillatory ventilation
$\bar{P}_{aw}$ = mean airway pressure

Table 2. HFOV Settings in Which Generated PEEP Was Zero

Amplitude (cm H_2O)	Frequency (Hz)	$\bar{P}_{aw}$ (cm H_2O)	Monitored PEEP (cm H_2O)
50	5	15	0
50	6	15	0
50	7	15	0

HFOV = high-frequency oscillatory ventilation
PEEP = positive end-expiratory pressure
$\bar{P}_{aw}$ = mean airway pressure

PEEP from the mathematical equation, the correlation coefficient was $r = 0.99$ ($p < 0.001$), with a mean difference not statistically significantly different from zero (mean difference 0.25 ± 1.02 cm H_2O, $p > 0.15$). The predicted PEEP was related to the actual PEEP by the equation:

$$\text{Actual PEEP} = (\text{predicted PEEP} \times 1.12) - 2.38$$

The greatest difference was 2.0 cm H_2O (Fig. 4).

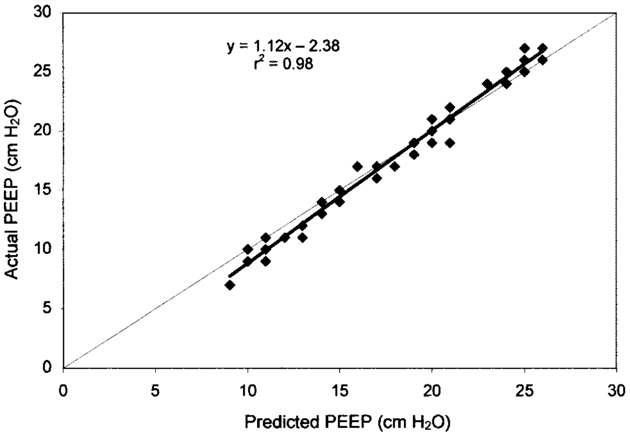

Fig. 4. Predicted versus actual positive end-expiratory pressure (PEEP).

Discussion

High-frequency ventilation strategies have benefited many patients with ALI and acute respiratory distress syndrome.[1,4,16] HFOV improves oxygenation,[2,3,17] but there may be times when changing to HFJV would be beneficial. For instance, infants with severe airway obstruction (eg, bronchospasm) and concurrent ALI (eg, bronchiolitis/pneumonitis) may have unacceptable "gas trapping" during HFOV and would thus benefit from the continuous, passive exhalation of HFJV while maintaining higher $\bar{P}_{aw}$. Additionally, neonates with ALI who develop air leak syndromes on HFOV might benefit from the high-velocity jet pulses that can bypass these areas but still deliver adequate gas to the more distal airways.[18,19] Although the need to transition between HFJV and HFOV should be minimal, a greater understanding of maintaining comparable $\bar{P}_{aw}$ would allow for a more optimal transition and preservation of lung recruitment[20] when such a need exists.

The jet device, placed in-line in the standby mode, provides an accurate reading of airway pressure during oscillation. Once the rate, F_{IO_2}, and PIP are set for HFJV to match the HFOV settings, the remaining variable is the PEEP setting on the conventional ventilator. One method to determine a PEEP setting would be to use the monitored PEEP value displayed by the jet when it is used as a monitor during HFOV. However, this value cannot be used alone, because it measures all PEEP in the system, including intrinsic PEEP, so setting the PEEP on the conventional ventilator during HFJV to match the reading during oscillation might cause overdistention and worsen air trapping. The predicted PEEP calculation can be used to determine an accurate PEEP setting that will match the $\bar{P}_{aw}$ to what was occurring during HFOV.

Our data demonstrate that the predicted PEEP equation can serve to match $\bar{P}_{aw}$ settings when transitioning between HFOV and HFJV. More importantly, it can also be used when transitioning from conventional mechanical ventilation directly to HFJV, to achieve a goal $\bar{P}_{aw}$. In a patient on conventional mechanical ventilation who would benefit from HFJV, clinicians can use the same principles that guide them when initiating HFOV. During HFOV, the goal $\bar{P}_{aw}$ is usually set at 4–6 cm H_2O above the measured

$\bar{P}_{aw}$ during conventional mechanical ventilation.[2] This same strategy when applied to HFJV allows for calculation of the PEEP necessary to meet the goal $\bar{P}_{aw}$.

Our data demonstrate several important concepts related to high-frequency ventilation. The PEEP values (measured at the ETT) during some of the HFOV settings are higher than many clinicians would feel comfortable setting on any other type of ventilator. But since the peak airway pressure is limited during both types of high-frequency ventilation, these higher PEEP values should not be feared and could provide better oxygenation during HFJV.[15,20–22]

Additionally, we found that HFOV generated a PEEP of zero when the amplitude was set at a number 3 times that of the $\bar{P}_{aw}$. During these periods the ventilator may be "robbing" the alveoli of PEEP. Our study is the first to document this phenomenon, which has previously only been theorized. However, it is unlikely that this effect is clinically important, since the time at end-expiration during high-frequency ventilation is extremely short.

Neonatal and pediatric patients can present with a complicated combination of pulmonary pathologies, which makes it difficult to choose the most appropriate high-frequency ventilation mode. Although most pediatric patients with ALI can be managed with HFOV, the medical literature and our clinical experience support the use of HFJV in patients with ALI who require tight control of carbon dioxide elimination and "high" $\bar{P}_{aw}$ for adequate oxygenation.[23,24] This strategy is useful in managing patients with pneumonia and severe bronchospasm (eg, respiratory syncytial virus, bronchiolitis/pneumonitis) and patients with substantial pulmonary hypertension and ALI with no untoward pulmonary or cardiovascular effects from the higher PEEP settings.

Study Limitations

It is important to note the limitations of our study. The most obvious is that we used a pediatric test lung model, and it is unknown if these same findings would be seen in patients with dynamic, heterogeneous lung injury. Second, comparing the $\bar{P}_{aw}$ readings at the ETT is important, but these pressures are not necessarily transmitted to the alveoli. Comparing the effects of PEEP more distally would provide additional information, although this would be technically difficult. Repeating our study with an in vivo, injured lung model would facilitate this comparison by allowing us to analyze gas exchange and hemodynamics. It should be noted that the NICO monitor has not been validated for use during high-frequency ventilation, although its predecessor (the CO_2SMO+ monitor), which has very similar software algorithms for pressure and flow determination, has been validated for small tidal volume delivery.[25] Finally, we used the PIP measured by the HFJV device during HFOV as our PIP setting. Since the amplitude is both a positive and negative force around the $\bar{P}_{aw}$ on HFOV, equating these numbers may have led to unequal settings for carbon dioxide elimination and thus might have impacted the HFJV $\bar{P}_{aw}$ as well.

Conclusions

The Life Pulse jet device can accurately measure airway pressure during HFOV. Our predicted PEEP equation allows calculation of the optimal PEEP when transitioning to HFJV from conventional mechanical ventilation or HFOV. Our results should help clinicians feel more comfortable using higher PEEP during HFJV with patients who require improved oxygenation.

REFERENCES

1. Gerstmann DR, Minton SD, Stoddard RA, Meredith KS, Monaco F, Bertrand JM, et al. The Provo multicenter early high-frequency oscillatory ventilation trial: improved pulmonary and clinical outcome in respiratory distress syndrome. Pediatrics 1996;98(6 Pt 1):1044–1057.
2. Arnold JH, Anas NG, Luckett P, Cheifetz IM, Reyes G, Newth CJ, et al. High-frequency oscillatory ventilation in pediatric respiratory failure: a multicenter experience. Crit Care Med 2000;28(12):3913–3919.
3. Derdak S, Mehta S, Stewart TE, Smith T, Rogers M, Buchman TG, et al, and the Multicenter Oscillatory Ventilation for Acute Respiratory Distress Syndrome Trial (MOAT) Study Investigators. High-frequency oscillatory ventilation for acute respiratory distress syndrome in adults: a randomized, controlled trial. Am J Respir Crit Care Med 2002;166(6):801–808.
4. van Kaam AH, Haitsma JJ, De Jaegere A, van Aalderen WM, Kok JH, Lachmann B. Open lung ventilation improves gas exchange and attenuates secondary lung injury in a piglet model of meconium aspiration. Crit Care Med 2004;32(2):443–449.
5. Cotten M, Clark RH. The science of neonatal high-frequency ventilation. Respir Care Clin N Am 2001;7(4):611–631.
6. Henderson-Smart DJ, Bhuta T, Cools F, Offringa M. Elective high frequency oscillatory ventilation versus conventional ventilation for acute pulmonary dysfunction in preterm infants. Cochrane Database Syst Rev 2005.
7. Parker JC, Hernandez LA, Peevy KJ. Mechanisms of ventilator-induced lung injury. Crit Care Med 1993;21(1):131–143.
8. Dreyfuss D, Saumon G. Ventilator-induced lung injury: lessons from experimental studies. Am J Respir Crit Care Med 1998;157(1):294–323.
9. Arnold JH, Truog RD, Thompson JE, Fackler JC. High-frequency oscillatory ventilation in pediatric respiratory failure. Crit Care Med 1993;21(2):272–278.
10. Farias LL, Faffe DS, Xisto DG, Santana MC, Lassance R, Prota LF, et al. Positive end-expiratory pressure prevents lung mechanical stress caused by recruitment/derecruitment. J Appl Physiol 2005;98(1):53–61.
11. Hamel DS, Katz AL, Craig DM, Davies JD, Cheifetz IM. Carbon dioxide elimination and gas displacement vary with piston position during high-frequency oscillatory ventilation. Respir Care 2005;50(3):361–366.
12. Field D, Milner AD, Hopkin IE. Calculation of mean airway pressure during neonatal intermittent positive pressure ventilation and high frequency positive pressure ventilation. Pediatar Pulmonol 1985;1(3):141–144.

13. Jacob J, Gluck L, DiSessa T, Edwards D, Kulovich M, Kurlinski J, et al. The contribution of PDA in the neonate with severe RDS. J Pediatr 1980;96(1):79–87.
14. Dillard RG. Mean airway pressure calculation (letter). J Pediatr 1980; 97(3):506–507.
15. Glenski JA, Marsh HM, Hall RT. Calculation of mean airway pressure during mechanical ventilation in neonates. Crit Care Med 1984; 12(8):642–644.
16. Clark RH, Yoder BA, Sell MS. Prospective, randomized comparison of high-frequency oscillation and conventional ventilation in candidates for extracorporeal membrane oxygenation. J Pediatr 1994; 124(3):447–454.
17. Arnold JH, Hanson JH, Toro-Figuero LO, Gutierrez J, Berens RJ, Anglin DL. Prospective, randomized comparison of high-frequency oscillatory ventilation and conventional mechanical ventilation in pediatric respiratory failure. Crit Care Med 1994;22(10):1530–1539.
18. Keszler M, Donn SM, Bucciarelli RL, Alverson DC, Hart M, Lunyong V, et al. Multicenter controlled trial comparing high-frequency jet ventilation and conventional mechanical ventilation in newborn infants with pulmonary interstitial emphysema. J Pediatr 1992;119(1 Pt 1):85–93.
19. Campbell D, Steinmann M, Porayko L. Nitric oxide and high frequency jet ventilation in a patient with bilateral bronchopleural fistulae and ARDS. Can J Anaesth 2000;47(1):53–57.
20. Barbas CS, de Matos GF, Pincelli MP, da Rosa Borges E, Antunes T, de Barros JM, et al. Mechanical ventilation in acute respiratory failure: recruitment and high positive end-expiratory pressure are necessary. Curr Opin Crit Care 2005;11(1):18–28.
21. Keszler M, Modanlou HD, Brudno DS, Clark FI, Cohen RS, Ryan RM, et al. Multicenter controlled clinical trial of high-frequency jet ventilation in preterm infants with uncomplicated respiratory distress syndrome. Pediatrics 1997;100(4):593–599.
22. Spitzer AR, Butler S, Fox WW. Ventilatory response to combined high frequency jet ventilation and conventional mechanical ventilation for the rescue treatment of severe neonatal lung disease. Pediatr Pulmonol 1989;7(4):244–250.
23. Engle WA, Yoder MC, Andreoli SP, Darragh RK, Langefeld CD, Hui SL. Controlled prospective randomized comparison of high-frequency jet ventilation and conventional ventilation in neonates with respiratory failure and persistent pulmonary hypertension. J Perinatol 1997;17(1):3–9.
24. Boros SJ, Mammel MC, Coleman JM, Horcher P, Gordon MJ, Bing DR. Comparison of high-frequency oscillatory ventilation and high-frequency jet ventilation in cats with normal lungs. Pediatr Pulmonol 1989;7(1):35–41.
25. Castle RA, Dunne CJ, Mok Q, Wade AM, Stocks J. Accuracy of displayed values of tidal volume in the pediatric intensive care unit. Crit Care Med 2002;30(11):2566–2574.