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Comparison of two inspiratory: expiratory ratios during high frequency oscillation

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Abstract The aim of this study was to compare gas exchange and volume delivery during high frequency oscillation at two frequently used inspiratory:expiratory (I:E) ratios: 1:2 and 1:1, other oscillatory settings being kept constant. A group of 13 infants with respiratory distress syndrome, median gestational age 28 weeks (range 23–36) and postnatal age 1 day (range 1–8) were studied. At the I:E ratio of 1:1 compared to 1:2 the median $paCO_2$ was lower, $P < 0.05$ (30 mmHg, range 22–47 vs 34 mmHg, range 27–46) and the volume delivered higher, $P < 0.01$ (2.6 ml/kg, range 1.2–5.6 vs 2.0 ml/kg, range 1.0–3.9). There was no significant difference in oxygenation levels at the two I:E ratios. In a related in vitro study, changing the I:E ratio from 1:2 to 1:1 increased the mean airway pressure by a median of 8.6% (range 2.9–28.1%).

Conclusion Routinely maintained longer expiratory than inspiratory times during high frequency oscillation should be discouraged.

Key words High frequency oscillation · Respiratory distress syndrome

Abbreviations *HFJV* high frequency jet ventilation · *HFO* high frequency oscillation *I:E* ratio inspiratory:expiratory ratio · *MAP* mean airway pressure

Introduction

High frequency oscillation (HFO) is now frequently used to support infants with severe respiratory distress [7]. During HFO, small tidal volumes are delivered at fast frequencies and, although both inspiration and expiration are active [10], there has been concern that gas trapping might occur [12]. As a consequence, certain oscillators allow manipulation of the proportion of the oscillatory cycle time spent in inspiration and hence the inspiratory:expiratory (I:E) ratio [13]; gas trapping being theoretically less likely at an I:E ratio of 1:2 than 1:1. A physiological study [1], however, demonstrated that that hypothesis was incorrect, with no significant gas trapping occurring at either of those I:E ratios. In addition, as the inspiratory proportion of the cycle was prolonged the tidal volume increased, which might result in more effective CO_2 elimination. The aim of this study was, therefore, to assess whether blood gas exchange was improved at an I:E ratio of 1:1 compared to 1:2 and whether any such effect was explained by increased volume delivery. In addition, in a related in vitro study we determined the effect on mean airway pressure (MAP) of prolonging the inspiratory proportion of the cycle during HFO.

Patients and methods

Patients

A total of 13 infants with a median gestation age of 28 weeks (range 23–36), birth weight of 1064 g (range 480–2120) and postnatal age 1 day

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(range 1–8) were studied. At the time of study, their median MAP was 14 cmH_2O (range 9.7–19.9), oscillatory amplitude 25 cmH_2O (range 17–57) and fraction of inspired oxygen concentration 0.35 (range 0.22–1.00). Volume delivery measurements during HFO have been approved by the King's College Hospital Ethics Committee. Parents were encouraged to sit by their infant during the measurements.

Methods

In vivo study

Infants with respiratory distress in whom HFO was used as rescue therapy were studied. A SensorMedics 3100A oscillatory was employed, which has a variable I:E ratio. A high volume strategy was used, that is the MAP was increased until oxygenation was optimized, allowing a decrease in the inspired oxygen concentration. A frequency of 10 Hz, was used as at that frequency, compared to 15 Hz there is a higher volume delivery [6] and better CO_2 elimination [5]. The two I:E ratios (1:1 and 1:2) were each examined for 30 min in random order. All other oscillatory settings, in particular the MAP, were kept constant. A blood gas was sampled at the end of each 30 min period from an indwelling arterial line sited for clinical purposes. The infant was subsequently supported at the I:E ratio associated with superior blood gas exchange.

To assess delivered volume, a pneumotachograph (Mercury F10L, GM Instruments, Kilwinning, Scotland) was inserted between the infant's endotracheal tube and ventilator circuit. The pneumotachograph was attached to a Validyne pressure transducer (± 2 cm H_2O, Northridge Calif., USA). The flow signal was electronically integrated to give volume (Gould integrator 13-4615-70, Cleveland Ohio, USA). The flow and volume signals were recorded simultaneously on a Gould polygraph (2800S). Recordings were made only when the infant was apnoeic. A calibration curve [6] had been previously devised. This was a bell-shaped curve with maximum augmentation of the ratio of the measured to the delivered volume at 12 Hz and subsequent damping. The volume waveform of the SensorMedics is not truly sinusoidal [13], thus, particularly when the I:E ratio is 1:2, the frequency content of the two phases of ventilation differed, the uncorrected inspiratory volume being less than the expiratory volume due to damping at higher frequencies. To compensate for this, the average value of the inspiratory and expiratory volumes was determined, which was then converted to the actual volume delivered using the calibration curve. We had previously validated using the mean of the inspiratory and expiratory volume trace when inspiration only took 30% of the cycle time [9]. The delivered volume did not differ significantly between different levels of humidity (0–80%) or inspired oxygen concentrations (21–100%). For the studies on the infants, the mean volume delivered in 100 cycles during the last 5 min of each 30 min study period was calculated using the calibration curve and related to body weight.

In vitro study

The oscillator was then attached to the dummy lung and the effect of changing the I:E ratio from 1:2 to 1:1 on MAP was measured at each of the oscillatory settings of the individuals examined in the in vivo study.

Statistical analysis

Differences between the two I:E ratios were assessed for statistical significance using the paired Wilcoxon test.

Results

In vivo study

Overall, CO_2 elimination was significantly better at an I:E ratio of 1:1 ($P < 0.05$), (Fig. 1). In five patients, the $paCO_2$ level remained the same or increased as the I:E ratio was changed from 1:2 to 1:1 (median change 1.1 mmHg, range 0–4). In the remaining eight patients, $paCO_2$ decreased by a median of 9.3 mmHg (range 3–13.4). The two groups did not differ significantly with regard to their gestational age or birth weight, but the infants in whom CO_2 elimination improved at an I:E ratio of 1:1 tended to be receiving a higher MAP (median 17.2 cmH_2O, range 11.5–19.9) than the other infants (median 12.1 cmH_2O, range 9.7–16) $P < 0.06$. There was no statistically significant difference in the oxygenation level at the two I:E ratios (Table 1). It was only possible to measure the delivered volume in 8 of the 13 infants at both I:E ratios; this was higher at the I:E ratio of 1:1 in all infants studied ($P < 0.01$) (Table 1).

In vitro study

Increasing the I:E ratio resulted in a significant elevation in MAP, a median change of 8.6% (range 2.9%–28.1%), (Fig. 2) ($P < 0.01$).

Discussion

We have documented a significant increase in CO_2 elimination at the I:E ratio of 1:1 compared to 1:2. This enabled the infants to be subsequently managed at lower amplitudes as we were keen to avoid too low $paCO_2$ levels. Our results are not at variance to previously published pre-clinical data [8, 17]. There was a trend for a lower $paCO_2$ level at the I:E ratio of 1:2 versus 1:1 in one [8]. In the second study [17], tidal volume was kept constant when the I:E ratio was changed. As CO_2 elimination is related to volume delivery [15], it is not surprising that under such circumstances [17] there was no significant effect of changing I:E ratio on $paCO_2$ levels. In contrast, in our study, as shown previously [1],

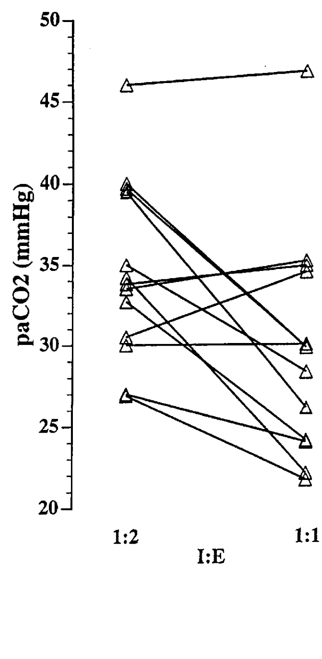

Fig. 1 Comparison of CO_2 levels at two I:E ratios. Each patient is shown by linked data points

Table 1 Comparison of blood gas tensions and volume delivery at two I:E ratios. Results are shown as median (range). $n = 8$

	1:2	1:1
$paCO_2$ (mmHg)	34 (27–46)	30 (22–47)*
paO_2 (mmHg)	65 (48–104)	74 (40–96)
Delivered volume (ml/kg)	2.0 (1.0–3.9)	2.6 (1.2–5.6)**

$*P < 0.05$
$**P < 0.01$

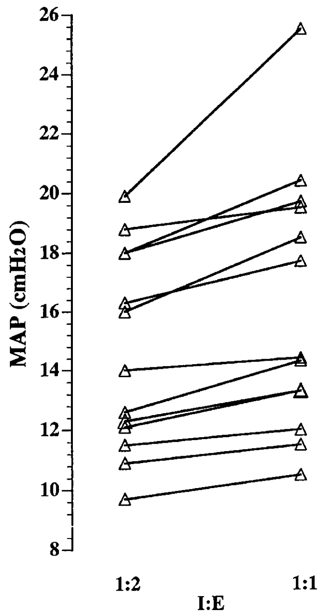

Fig. 2 Comparison of the mean airway pressure levels at two I:E ratios in the in vitro study

volume delivery was significantly greater at the I:E ratio of 1:1 than 1:2 and thus is likely explain to the lower CO_2 tensions experienced at the former I:E ratio. Lower $paCO_2$ levels were not experienced by every infant at the I:E ratio of 1:1, despite higher tidal volume delivery in all infants in whom this was measured. The changes in $paCO_2$ in the infants whose CO_2 elimination was not improved by increasing the I:E ratio to 1:1, however, were small and could be within the error of the measurements. It is interesting, however, that those infants who faired better at the I:E ratio of 1:1 tended to require higher MAPs. We did not demonstrate any change in oxygenation on alteration of the I:E ratio in the in vivo study, but we kept the MAP constant [3].

There has been concern that fast frequencies and the concomitant short expiratory times could lead to gas trapping and hence impaired CO_2 elimination. Dynamic elevation of lung volume has been demonstrated at fast frequencies, but usually during high frequency jet ventilation (HFJV) [2, 16]. In a comparative study of HFJV and HFO [2] at 15 Hz and a delivered volume of 2 ml/kg, gas trapping was demonstrated with HFJV, but only during HFO when frequencies above 20 Hz were used [12]. The lack of gas trapping during HFO, despite use of high frequencies, might be due to the high level of MAP splinting the airways open [4], as occurs with high levels of continuous positive airway pressure [14]. In the present population of infants, a high volume strategy was pursued and, perhaps as a consequence, CO_2 retention was usually not increased as the I:E ratio was altered from 1:2 to 1:1.

In the in vitro study, we demonstrated that increasing the proportion of the cycle spent in inspiration was associated with an increase in MAP. Gertsmann et al. [11] also demonstrated that increasing the I:E ratio from 1:2 to 1:1 caused a significant elevation in mean alveolar pressure exceeding proximal mean airway pressure. As MAP is an important determinant of oxygenation during HFO [3], those results suggest that altering the I:E ratio and allowing the MAP to change might be another method of influencing oxygenation during HFO. Raising the MAP by another method but keeping the I:E ratio at 1:2 would have the same effect on oxygenation, but our data suggest CO_2 elimination would remain suboptimal.

We have demonstrated changing the I:E ratio from 1:2 to 1:1 increases volume delivery and CO_2 elimination. An I:E ratio of 1:2 compared to 1:1 may be better for sputum removal, but this is rarely a problem in respiratory distress syndrome. We would, therefore, suggest that routinely maintaining a longer expiratory than inspiratory time during HFO is unnecessary.

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