

ORIGINAL ARTICLE

Accuracy of the volume and pressure displays of high frequency oscillators

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Objective: To determine the effect of frequency on the accuracy of volume and pressure displays of high frequency oscillators.

Methods: The effect of frequency on the displayed volume of the Stephanie, Dräger Babylog 8000 Plus, and SLE 5000 oscillators was assessed. A sine wave pump delivered a constant tidal volume at frequencies of 5–15 Hz to the patient manifold of the oscillators. The displayed volumes at each frequency were compared with the delivered volume. The effect of frequency on displayed pressure was assessed by connecting the oscillator's patient manifold to a lung model; three types of oscillator were studied (SensorMedics 3100A, SLE 5000, and Stephanie). Airway pressure was measured from the manifold using a pressure transducer and non-compliant tubing; the pressure measuring system had a flat frequency response to 30 Hz.

Results: The SLE 5000 volume display overread the delivered volume (by about 5%), but was not affected by frequency. At 5 Hz, the Dräger Babylog 8000 Plus and the Stephanie underread the delivered volume (by about 20%). Increasing frequency resulted in a greater discrepancy between the delivered and displayed volume with the Stephanie, but a smaller discrepancy with the Dräger Babylog 8000 Plus. Altering frequency had a small effect (maximum difference 6%) on the relation between the displayed and delivered pressure for all three oscillators.

Conclusion: Frequency affects the accuracy of displayed volumes and, to a lesser extent, displayed pressures of high frequency oscillators. The results emphasise that data displayed by new devices should not be uncritically accepted.

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High frequency oscillation (HFO) is now commonly used in neonatal practice, both to try to "rescue" infants with severe respiratory failure¹ and "prophylactically" with the aim of reducing chronic lung disease.² Several types of oscillator are available; in a recently published randomised trial,³ three types of oscillator were used. In such trials and clinical practice, serial recordings are often made of the displayed pressure and used to indicate disease severity and document changes in the infant's condition. The displayed pressure and volume are also used to guide the settings chosen when infants are transferred from one oscillator type to another. It is essential therefore that the displayed values are accurate. Unfortunately, it has been shown that the relation between the displayed and delivered pressure differs between oscillators: some overestimate whereas others underestimate the delivered pressure.⁴ A variety of frequencies are used during HFO, usually between 10 and 15 Hz in neonatal patients, but, if there is carbon dioxide retention despite use of high oscillatory amplitudes, then frequency is reduced below 10 Hz. Oscillator performance is influenced by frequency, as indicated by the inverse relation between frequency and delivered volume.^{5,6} The influence of compliance on the oscillatory pressure waveform at the airway opening and the delivered volume has been shown to be also dependent on the frequency and specific oscillator used.⁷ It is therefore important to determine the accuracy at different frequencies of the pressure and volume displays of high frequency oscillators in current use and this is the aim of this study.

METHODS

Accuracy of volume display

The accuracy of the volume displays of the Stephanie (Stephan Biomedical Incorporation, Gackebach, Germany),

the Dräger Babylog 8000 Plus (Dräger Medizintechnik GmbH, Germany), and the SLE 5000 (Specialised Laboratory Equipment Ltd, South Croydon, UK) oscillators was examined in vitro. In the Stephanie oscillator, the waveform is generated by movements of a piston mounted in the inspiratory/expiratory block, exposing the infant to positive and negative pressures. In the SLE 5000, oscillation is generated through a forward and a reverse jet both controlled by high speed valves. The mechanisms of the other oscillators tested have been described elsewhere in detail.⁶ A constant tidal volume (4 ml) was delivered to the patient manifold using a variable speed, sine wave pump.⁸ This was achieved by connecting the inspiratory connection of the patient manifold to the output of the pump by a 10 cm rigid plastic tube and occluding the expiratory connection of the manifold. The patient connector of the manifold was attached to a 3 mm endotracheal tube with the distal end open to the atmosphere. The output of the sine wave pump was constant over the frequency range (5–15 Hz) studied. The effect of frequencies from 5 to 15 Hz was examined; frequency was increased in 1 Hz increments. At each frequency, the displayed volume was recorded and expressed as a percentage of the 4 ml delivered by the sine wave pump.

Accuracy of pressure display

The effect of frequency on the displayed pressure of the SensorMedics 3100A (SensorMedics Corporation, Anaheim, California, USA), the SLE 5000 (Specialised Laboratory Equipment Ltd), and the Stephanie (Stephan Biomedical Incorporation) oscillators was assessed. The ventilators were connected to a lung model, which had a compliance of 0.8 ml/cm H₂O and a resistance of 70 cm H₂O/l/s at a flow rate of 2 litres/min. The model consisted of an endotracheal tube (3 mm) sealed in a rubber bung, which was inserted

into the open neck of a 1 litre conical flask. To assess the effect of frequency on the accuracy of the displayed oscillatory pressure, a reference pressure measuring system was used. The reference pressure measuring system consisted of a pressure transducer (Validyne MP 45, range ± 50 cm H₂O; Validyne Corporation, Northridge, California, USA) and tubing attached to the oscillator manifold at the site of the oscillator's pressure measuring line. To avoid oscillations in the reference pressure measuring line, short (7 cm) non-compliant tubing with an internal diameter of 4 mm was used. The frequency response of the reference pressure measuring system was flat to 30 Hz.⁷ The output of the reference pressure transducer was recorded on a storage oscilloscope with printout facility. The ventilator's displayed pressure was related to the deflection on the storage oscilloscope at each frequency, and the resultant ratio expressed as a percentage of the ratio at 5 Hz; 5 Hz was selected for baseline comparison as this is the highest frequency at which the standard volume measuring device, the pneumotachograph, performs reliably. Throughout the range of frequencies examined, the inspiratory to expiratory ratio was kept constant at 1:1, and the mean airway pressure at 12 cm H₂O. At 5 Hz, the oscillatory amplitude was set at 50 cm H₂O, and the setting then remained unchanged throughout the range of frequencies.

RESULTS

At 5 Hz, there was a discrepancy between the measured and displayed volume for all of the oscillators examined (fig 1); this was smallest for the SLE 5000. Both the Dräger Babylog 8000 Plus and Stephanie underrecorded the volume at 5 Hz by about 20%, but the effect of increasing frequency on the discrepancy between the measured and displayed volumes differed between the two oscillator types (fig 1). Increasing frequency had a variable effect on the accuracy of the displayed pressure of the Stephanie oscillator. As frequency was increased, the display of the SensorMedics and SLE 5000 overrecorded the displayed pressure, but the effect was small (maximum difference 6%; fig 2).

DISCUSSION

We have shown that the accuracy of the volume display of the oscillators studied differed as frequency was increased. The greatest discrepancy between the displayed and delivered volume was seen with the Stephanie oscillator, which incorporates a pneumotachograph to measure flow.

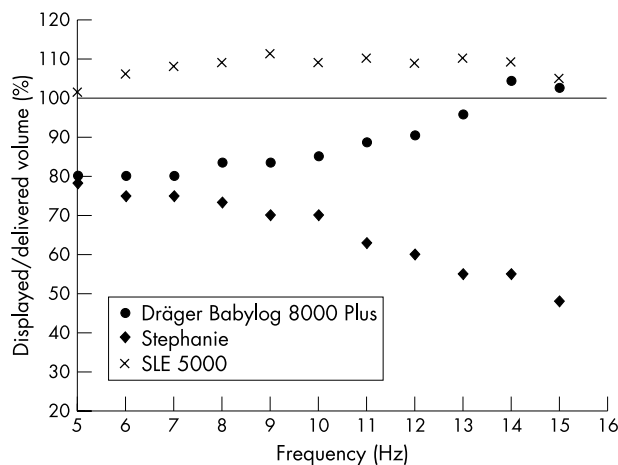


Figure 1 Effect of frequency on the accuracy of the volume display.

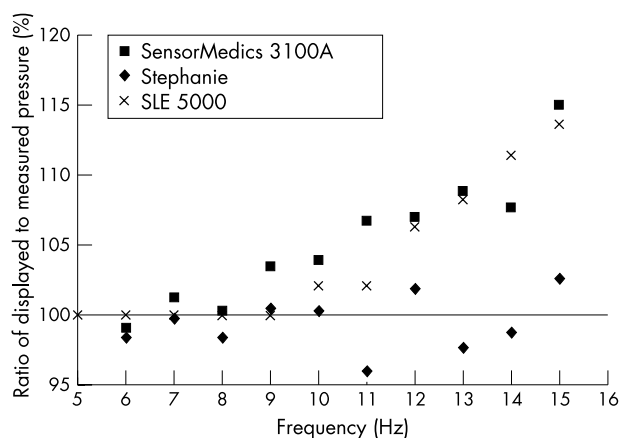


Figure 2 Effect of frequency on the accuracy of the displayed pressure.

Delivered volume during HFO has been measured in research studies using a pneumotachograph.⁹ The accuracy of such a system has been compared with simultaneous measurements by plethysmography,¹¹ and a good correlation ($r = 0.92$) was found. That correlation, however, required that the system had a suitable frequency of response. Unless that is taken into account, pneumotachographs may underrecord at high frequencies.¹² The Dräger Babylog 8000 Plus and SLE 5000 oscillators use thermistors to measure flow. A hot wire anemometer (thermistor) monitoring system has been shown to provide reliable measurements of tidal volume at the airway opening.¹³ Our results suggest that during HFO, volume measurement using thermistors is more accurate than the use of a pneumotachograph, as there was greater linearity of response across the range of frequencies tested.¹²

Differences in the accuracy of the pressure display with increasing frequency were also found, although the effect was relatively small (fig 2). The displayed pressures were compared with the recordings from the reference pressure measuring system. We do not feel that the differences in the performance of the pressure measuring system with increased frequency accounted for the results, as we have previously shown that the system had a flat frequency response up to 30 Hz.⁸ In addition, all three oscillators were compared with the same reference system, and yet differences in the accuracy of their displays were seen as frequency was increased. A possible explanation for the differences seen is that, as frequency was increased, oscillations may have been set up in the tubing incorporated into the oscillator's pressure measuring system, which ran from the manifold to the pressure transducers within the oscillator. Standard circuits were used with all three oscillators, which incorporated relatively long tubing but, between the oscillator types, the length and diameter varied, which would influence pressure waveform damping and hence may explain the differences in the accuracy of their pressure displays seen with increasing frequency. Alternative explanations are differences in impedance characteristics of the pressure transducer tubing from the patient manifold to the oscillator pressure transducer or differences in the characteristics of the pressure transducer incorporated into the oscillator.

For consistency, an inspiratory to expiratory ratio of 1:1 was used with all of the oscillators. The inspiratory to expiratory ratio has been shown to influence the intratracheal and intra-alveolar pressure during HFO.¹⁴⁻¹⁶ The SensorMedics can be used with an inspiratory to expiratory ratio of 1:1 or 1:2. It has, however, been previously shown that, at an inspiratory to expiratory ratio of 1:2, the mean

alveolar pressure is lower than the displayed mean airway pressure, whereas at a ratio of 1:1 the displayed and actual pressures are about equal.⁴ It has been suggested that at a 1:1 ratio, there will be a similar relation between the displayed and actual pressures with other sine wave generators.⁴ The Dräger Babylog 8000 Plus, however, has been shown to display lower pressures than the intrapulmonary pressures. This means that, if there is a switch from a SensorMedics 3100A to a Dräger Babylog 8000 Plus oscillator at a displayed pressure of 12 cm H₂O, this could result in a 5–8 cm H₂O abrupt increase in the actual distending pressure.⁴ Similar differences in the relation between the displayed oscillatory amplitude pressure and the transpulmonary pressure swings may occur between the oscillators. This would mean that the differences we found in the accuracy of the displayed pressure between oscillators with increasing frequency would further compound the problems encountered on transferring from one oscillator to another.

In conclusion, at the frequencies used in clinical practice, the accuracy of the volume and pressure displays of neonatal oscillators varies as frequency is increased. These results emphasise that data displayed by new devices cannot be accepted uncritically and that results from different devices cannot be considered interchangeable. It cannot be assumed that, if an infant is transferred from one oscillator type to another at the same settings, the same volumes and pressures will be delivered. We would therefore recommend that careful assessment of chest vibration is made throughout, and the infant's blood gases are checked shortly after such a transfer has taken place, so that, if necessary, appropriate changes in settings are rapidly made to return the infant's blood gases to the predetermined range. Further development of accurate and frequency independent volume monitoring techniques is essential to optimise use of HFO ventilation.

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