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T. Hoehn
A. Busch
M. F. Krause

Comparison of noise levels caused by four different neonatal high-frequency ventilators

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T. Hoehn (✉) · A. Busch · M. F. Krause
Neonatal Intensive Care Unit,
University Children's Hospital,
Mathildenstrasse 1, D-79106 Freiburg,
Germany

Present address:
T. Hoehn
Department of Neonatology, Charité,
Campus Virchow-Klinikum,
Humboldt University, Augustenburger
Platz 1, D-13353 Berlin, Germany,
email: thomas.hoehn@charite.de,
Tel.: + 49-30-45 06 64 13,
Fax: + 49-30-45 06 69 22

Abstract *Objective*: To test the hypothesis that neonatal high-frequency ventilators create different noise levels depending upon ventilator settings and device-specific properties.
Materials: Three neonatal ventilators with built-in high-frequency options (*Babylog 8000*, *Infant Star*, *Stephanie*) and an exclusive high-frequency oscillator (*SensorMedics 3100A*).
Measurements: Noise levels were recorded by a microphone and measured by a decibel recording device at a defined distance from a test lung.
Results: Noise levels were highest for the *SensorMedics* and the *Babylog* (70 dB and 62 dB, respectively). Whereas the *SensorMedics* increased noise production with amplitude, the *Babylog* remained at a constant level. The *Infant Star* (52 dB) and the *Stephanie* (54 dB) were significantly less noisy at their maximum levels of amplitude (40 mbar and 50 mbar, respectively).
Conclusion: Most levels recorded were below those measured within an incubator without the use of a ventilator. We conclude that neonatal high-frequency ventilators do not represent a major contribution to noise levels for newborns in neonatal intensive care units (NICUs).

Key words High-frequency ventilation · Noise production · Newborn · Neonatal intensive care unit · Decibel

Introduction

Theoretical advantages, decreased lung injury and improved gas exchange in experimental models of neonatal respiratory failure have led to a widespread use of high-frequency ventilation (HFV) in neonatal intensive care units (NICUs) [1]. In subgroups of low birth weight infants a reduced incidence of bronchopulmonary dysplasia (BPD) has been shown when HFV is used early in the course of respiratory distress syndrome (RDS) [2]. Recent reports indicate further advantages of HFV in a combined therapy with the use of inhaled nitric oxide – a synergistic effect has been demonstrated in the treatment of persistent pulmonary hypertension of the newborn (PPHN) [3, 4].

High-frequency ventilators are classified as oscillators provided the expiration is actively performed by the device. In oscillatory devices (regardless of whether they are piston- or diaphragm-equipped) this is accomplished by the outward movement of the piston/diaphragm. All other devices rely on the passive recoil of the lung tissue or apply some kind of Venturi effect at the expiratory limb of the ventilatory circuit in order to facilitate expiration.

The level of noise created in NICUs is an item that has only recently been focused on in the neonatal literature [5, 6]. Although there is agreement that a reduction of noise in the NICU is desirable, it is less clear which technical devices contribute to its origin, and to what degree. Since there is growing awareness of noise and its

Table 1 Comparative Noise Levels

Typical Decibel [dB(A)] Values Encountered in Daily Life and Industry	
Rustling leaves	20 dB(A)
Room in a quiet dwelling at midnight	32
Soft whispers at 5 feet	34
Men's clothing department of large store	53
Window air conditioner	55
Conversational speech	60
Household department of large store	62
Busy restaurant	65
Typing pool (9 typewriters in use)	65
Vacuum cleaner in private residence (at 10 feet)	69
Ringing alarm clock (at 2 feet)	80
Loudly reproduced orchestral music in large room	82
Beginning of hearing damage if prolonged exposure over 85 dB(A)	
Printing press plant	86
Heavy city traffic	92
Heavy diesel-propelled vehicle (about 25 feet away)	92
Air grinder	95
Cut-off saw	97
Home lawn mower	98
Turbine condenser	98
150 cubic foot air compressor	100
Banging of steel plate	104
Air hammer	107
Jet airliner (500 feet overhead)	115

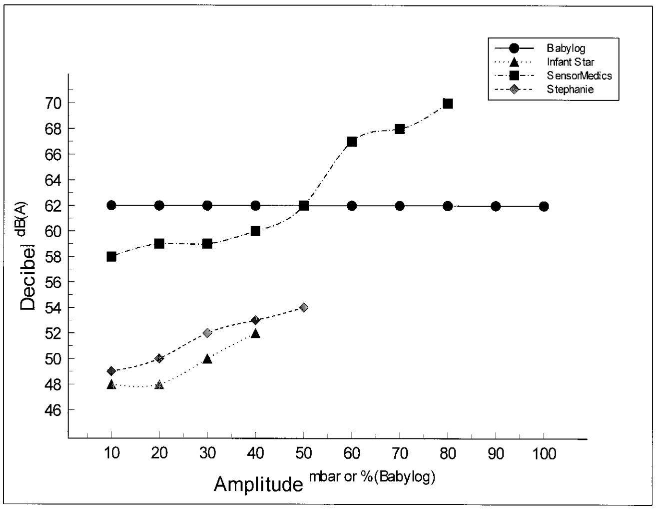

Fig. 1 Noise levels [decibel(A)] at various levels of amplitude and constant frequency (10 Hz) for the four devices *Babylog*, *Infant Star*, *SensorMedics* and *Stephanie*

potential hazardous effects on premature neonates, the contribution of HFV devices to noise levels on NICUs warrants investigation.

Material and methods

Four ventilators with either an exclusive HFV mode or with a built-in HFV option and approved for use in neonates were investigated.

The *Babylog 8000* (Draeger, Luebeck, Germany) with its high-frequency option is a flow-interruption device. This combined machine incorporates a conventional ventilator and requires high inspiratory flow rates (up to 30 l/min) during the HFV mode. Oscillations are created by an expiratory valve, maximum mean airway pressure (MAP_{max}) is 25 mbar and amplitude is expressed as a percentage of the maximum.

The *Infant Star* (Infrasonics, San Diego, USA) is also a high-frequency flow-interruption device combined with a conventional ventilator (MAP_{max} 25 mbar, amplitude 0–40 mbar). A Venturi placed at the exhalation valve assists the return of pressures to expiratory baselines, inadvertent gas trapping is supposedly avoided by this method.

The *Stephanie* (Stephan, Gackenbach, Germany) is a high-frequency oscillatory device of the piston type (MAP_{max} is 25 mbar, amplitude 0–50 mbar). Inspiratory time is variable between 33% and 50%. This is achieved by a modification of the piston's position. A conventional ventilator is incorporated within this device, high-frequency oscillatory ventilation (HFOV) can be combined with an underlying conventional rate of ventilation.

The *SensorMedics 3100A* (SensorMedics, Yorba Linda, USA) is a high-frequency oscillatory device of the diaphragm type (MAP_{max} 40 mbar, amplitude 0–80 mbar). Inspiratory time can be varied with the position of the diaphragm. This device does not contain an additional conventional mechanical ventilator.

The sound level meter used was a type 2607 (Brüel & Kjaer, Copenhagen, Denmark) with the compatible microphone manufactured by the same company. The range of frequencies recorded was limited by a filtering device to levels in the range between 22.5 Hz and 22,500 Hz. Measurements were made with the use of a test lung. During all recordings the microphone was positioned such that it was 10 cm away from the test lung and 60 cm away from the mechanical ventilator being examined. Frequency was kept stable at 10 Hz for all ventilatory devices, inspiratory time was not modified (between 30 and 33% depending on the possible setting of the device). Amplitude was modified throughout the available spectrum from zero to maximum. Units of amplitude vary with the device used. Most ventilators indicate pressure levels (mbar), the *Babylog* expresses amplitude as a percentage of pressure (%).

Results

The noise levels recorded cover a wide range depending on the ventilatory device used and the amplitude applied. Most ventilators produced increased levels of noise with higher amplitudes – except the *Babylog*, which kept steady decibel levels throughout the whole range of amplitudes. Both the *Infant Star* and the *Stephanie* produced low noise levels at an amplitude of 10 mbar (48 dB and 49 dB). For a summary of comparative noise levels see Table 1.

As amplitude increased to the maximum setting of 40 mbar (*Infant Star*) and 50 mbar (*Stephanie*), recorded noise levels were 52 dB and 54 dB, respectively (see

Fig. 1). As previously indicated, decibel levels with the use of the *Babylog* remained constant with an increase in amplitude, 62 dB were measured throughout the whole range of amplitudes. The highest noise levels recorded in this investigation were derived from the *SensorMedics*. At low amplitudes decibel levels were comparable to those of the *Babylog* (i.e. 58–59 dB at amplitudes of 10–30 mbar). With amplitudes greater than 60 mbar, the noise levels of the *SensorMedics* approached 70 dB, and were the highest quantified for any ventilatory device in this series (68 dB at 70 mbar, 70 dB at 80 mbar) [Fig. 1].

Measurements were also conducted within a newborn infant isolette (*Incubator 8000*, Draeger, Luebeck, Germany) with the built-in fan running, but without an additional ventilatory device connected to the isolette. This sound level was consistently at 65 dB(A).

Discussion

In a model of neonatal HFV applied to a test lung by the use of four different high-frequency ventilators, we have shown that the noise levels created by the ventilators are very much device-specific. Furthermore decibel levels increased with the use of higher amplitudes in the majority of devices tested.

In order to adapt physical measurements of noise levels to the specific capabilities of the human auditory system, three diagrams representing perception of noise have been defined [dB(A), dB(B), dB(C)]. The majority of measurements in the literature are performed using the dB(A) scale, which we used, for comparability reasons, in our present study. The dB(A) scale is logarithmic, which means an increase of 3 dB actually doubles noise intensity. The latter increase is regarded as the minimal change in sound pressure level which is detectable by adult humans [7].

Noise is known to lead to alterations in mood, sleep and concentration in patients and animals [8]. At least in adults, exposure to noise affects the autonomic nervous system and hypothalamic-pituitary axis [9]. Little is known about these potentially hazardous effects in premature and term infants requiring intensive care treatment [10]. Although the ototoxic effect of aminoglycosides in neonates has been looked at with regard to a potential hearing loss [11], a synergistic effect of noise and ototoxic medications in neonates can only be extrapolated from looking at studies in adults [12].

One of the reasons that prompted this investigation, were noise levels created by the *SensorMedics*. This device was perceived as being much louder than various other high-frequency ventilators by our staff. This observation emphasizes the important difference between objective noise measurements and subjective perception of noise. Subjective ratings of noise perception correlated well with the recorded decibel levels in a study comparing noise levels during HFV and conventional ventilation [8]. This is not necessarily the case with all devices, since the spectrum of noise created throughout the range of frequencies may be entirely different between devices [7].

Little is known about the perception of noise by either term or premature infants. From studies in adults it is evident that both light and sound levels in intensive care units can result in sleep disorders and possibly circadian rhythm disruption [13]. Sleep deprivation in patients with respiratory failure may, therefore, impair recovery and delay weaning from mechanical ventilation.

Noise levels within an incubator – with its built-in air circulation device running – were higher than the majority of high-frequency ventilators even at high amplitudes. This exposes neonates – as long as they are cared for inside an incubator – to much higher levels of noise than recommended by the US Environmental Protection Agency. Recent recommendations have proposed not to exceed sound levels over 45 dB [14].

Certain limitations of the present investigation have to be kept in mind. Variations in clinical practice include the use of isolettes versus open units with radiant warmers, in the case of isolettes the integrated fan would be an additional source of noise. The use of different ventilatory circuit systems would also imply a variation of the distance between patient and ventilator. The recommendations of the US Environmental Protection Agency are designed to prevent unnecessary noise in the proximity of newborn infants. Warnings related to prolonged exposure above 85 dB(A) were established for adults (see Table 1). However, there is evidence that 3-month-old infants have higher mean thresholds of the minimum audibility of sounds than 1-year-old infants or adults do [15].

We conclude that high-frequency ventilators do produce higher levels of noise with an increase in amplitude. Most levels recorded were below those measured within an incubator without the use of a ventilator. With the exception of the *SensorMedics* in the range of high amplitudes (> 60 mbar), high-frequency ventilators do not contribute significantly to noise levels occurring in the proximity of patients in a NICU. Further research is required with regard to the long-term hearing function of premature and full-term infants treated with various forms of HFV.

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