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PEDIATRIC BRIEF REPORT

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Feasibility of non-invasive pressure support ventilation in infants with respiratory failure after extubation: a pilot study

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Abstract *Objective:* To evaluate the feasibility and effects of non-invasive pressure support ventilation (NIV) on the breathing pattern in infants developing respiratory failure after extubation. *Design:* Prospective pilot clinical study; each patient served as their own control. *Setting:* A nine-bed paediatric intensive care unit of a tertiary university hospital. *Patients:* Six patients (median age 5 months, range 0.5–7 months; median weight 4.2 kg, range 3.8–5.1 kg) who developed respiratory failure after extubation. *Interventions:* After a period of spontaneous breathing (SB), children who developed respiratory failure were treated with NIV. *Measurements and results:* Measurements included clinical dyspnoea score (DS), blood gases and oesophageal pressure recordings, which were analysed for respiratory rate (RR), oesophageal inspiratory pressure swing (dPes) and oesophageal pressure-time product (PTPes). All data were collected during both periods (SB and NIV). When comparing NIV with SB, DS was reduced by 44% ($P < 0.001$), RR by 32% ($P < 0.001$), dPes by 45% ($P < 0.01$) and PTPes by 57% ($P < 0.001$). A non-significant trend for decrease in $PaCO_2$ was observed. *Conclusion:* In these infants, non-invasive pressure support ventilation with turbine flow generator induced a reduction of breathing frequency, dPes and PTPes, indicating reduced load of the inspiratory muscles. NIV can be used with some benefits in infants with respiratory failure after extubation.

Keywords Turbine flow generator · Work of breathing · Oesophageal pressure · Bilevel positive airway pressure · Child · Clinical trial

Introduction

Non-invasive pressure support ventilation (NIV) has been used as a treatment for acute and chronic respiratory failure in children [1–4]. A recent study showed that NIV is able to unload respiratory muscles safely in children with mean age of 6 years and mean body weight of 22 kg [5]. However data about the use of NIV in infants or its superiority over continuous positive airway pressure (CPAP) are lacking, and many NIV devices, especially turbine flow generators, were not specifically designed for use in patients under 30 kg. When designing this pilot study, we aimed to estimate the feasibility of NIV in infants and its effect on the inspiratory load of the respiratory system of infants.

Materials and methods

The study protocol was approved by the local ethics committee. Patients under 15 kg who had been invasively

Table 1 Characteristics of patients, diagnosis, duration of NIV and settings of the turbine flow generator (VPAP II ST, Resmed, Sydney, Australia)

Patient	Diagnosis	Weight (kg)	Age (month)	Sex	NIV duration	NIV settings		
						PEEP	Pmax	Timax
1	Coarctation of the aorta DORV	4.6	4	M	5 days	7	14	0.5
2	TGA	3.8	5	M	4 days	7	14	0.7
3	VSD	4.2	6	F	28 h	7	13	0.5
4	VSD	5.1	4	M	6 days	6	12	0.5
5	TGA	4.2	0.5	M	9 days	7	15	0.4
6	VSD	4.6	7	F	8 days	7	13	0.5

DORV double outlet right ventricle, *VSD* ventricular septal defect, *TGA* transposition of the great arteries, *PEEP* positive end-expiratory pressure, *Pmax* maximum inspiratory pressure, *Timax* maximum inspiratory time

ventilated for more than 3 days and for whom an extubation was planned within a few hours were eligible. Exclusion criteria included: circulatory failure, absence of an arterial line (as blood gas analysis was part of the study design) or any contraindication to the use of an oesophageal tube. Patients were included after written informed consent was obtained from their legal representatives. The protocol was subdivided into two consecutive periods: spontaneous breathing (SB) for 30 min and NIV for 120 min. Each patient served as their own control.

During the weaning process, a pressure transducer (Codman Microsensor, Johnson & Johnson, Le Locle, Switzerland) with a frequency response over 10 kHz [6] and a diameter of 0.7 mm was placed through the nostril into the distal part of the oesophagus. The pressure signal was sampled at 125 Hz and recorded on a personal computer. The position of the transducer was ascertained by an occlusion test [7]. Extubation criteria were (a) level of consciousness compatible with spontaneous breathing, (b) transcutaneous oxygen saturation $\geq$95% with FiO_2 $\leq$0.4 (in the absence of a persistent right to left intracardiac shunt) and (c) normocapnia with positive end-expiratory pressure (PEEP) $\leq$5 cmH_2O and peak pressure $\leq$18 cmH_2O with the ventilator set to pressure support. From extubation onwards, oesophageal pressure was recorded continuously. After extubation, the children were breathing spontaneously with supplemental oxygen if required. After a 30-min period of spontaneous breathing, the decision to start NIV was taken if one of the following criteria was fulfilled: dyspnoea score $\geq$4, tachypnoea or FiO_2 >0.35 to ensure transcutaneous oxygen saturation >95% in the absence of a persisting cyanotic heart defect. The dyspnoea score used was described by Downes and Raphaely [8]. NIV was delivered with a VPAP IIST (Resmed, North Ryde, Australia) set to pressure support with PEEP. Ventilation was provided through an appropriately sized prototype silicon nasal mask (C. Sullivan, Sydney, Australia). This type of mask has four holes on its top, creating an air leak to minimise CO_2 re-breathing. The VPAP IIST delivers pressure support even with a high air leak. These technical aspects precluded any accurate inspiratory flow or volume measurement. The settings of the VPAP IIST (PEEP, maximal inspiratory pressure, maximal inspiratory time) are shown in Table 1. During the study period (SB and NIV) the dyspnoea score was calculated every 10 min. Arterial blood gases were measured 20 min after the beginning of each period of the study. Under SB, ten consecutive breaths were analysed every 10 min and were used as values for $t-2$, $t-1$ and $t0$, respectively. During NIV, ten consecutive breaths were analysed every 10 min (after a period of 20 min to allow stabilisation of the breathing pattern) and were used as repeated measures ($t1$ to $t10$). At each time interval, RR, dPes and PTPes were calculated from the oesophageal pressure curve for ten consecutive breaths as follows: RR equals 60 divided by the time interval measured between the beginning of two consecutive breaths; dPes is the difference between the oesophageal pressure at the beginning of inspiration and its lowest inspiratory value; PTPes was calculated by multiplying the RR by the area subtended by the inspiratory oesophageal pressure curve without taking into account the thoracic static recoil pressure, as described by others [3, 9]. Data were analysed using two-way repeated analysis of variance with Bonferroni correction. Data are expressed as mean $\pm$ standard deviation (Fig. 1).

Results

Two girls and four boys with median age of 5 months (range 0.5–7 months) and median weight of 4.2 kg (range 3.8–5.1 kg) were included (Table 1). Two patients had persistent cyanosis due to a congenital heart defect at the time of the investigation. Signs of acute respiratory distress were present shortly after extubation in all patients. This was mostly due to interstitial pulmonary oedema

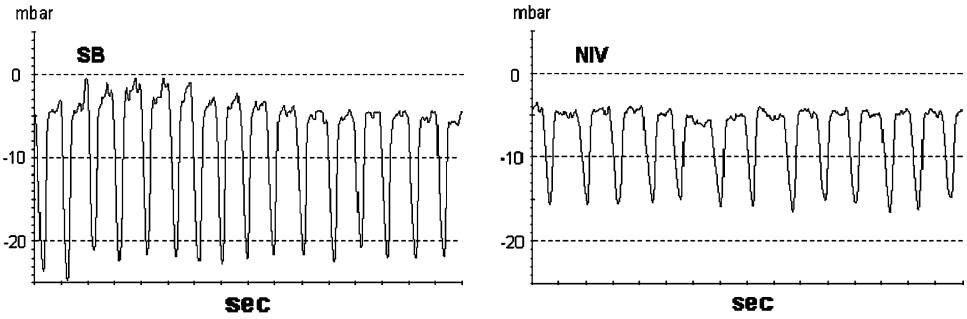

Fig. 1 Typical tracings of oesophageal pressure in a patient in spontaneous breathing (*left*) and with NIV (*right*). There is a clear reduction in respiratory rate, dPes and PTPes between spontaneous breathing and NIV

after bypass despite diuretic therapy. After the end of the protocol, NIV was maintained for a mean duration of 5.5 days (range 28 h to 9 days).

There was no significant difference in DS, RR, PTPes or dPes during SB ($t-2$ versus $t-1$, $t-2$ versus $t0$, $t-1$ versus $t0$) or during NIV (any association of $t1$ to $t10$). For all parameters, we observed complete stabilisation during NIV. DS, RR, PTPes and dPes were significantly reduced at any time under NIV as compared with any time under SB (Fig. 2). DS was reduced by 44% from 6.2 ± 1.7 at $t0$ to 3.5 ± 1.5 at $t1$. RR was reduced by 32% from 56.1 ± 12.6 c/min at $t0$ to 37.9 ± 9.8 c/min at $t1$ ($P < 0.0001$). dPes was reduced by 45% from 21.4 ± 5.3 cmH_2O at $t0$ to 11.8 ± 2.3 cmH_2O at $t1$ ($P < 0.0001$). PTPes was reduced by 57% from 370.1 $cmH_2O/s/min \pm 122.7$ at $t0$ (SB) to 159.6 $cmH_2O/s/min \pm 60.6$ at $t1$ (NIV) ($P < 0.0001$). A slight but non-significant decrease of $PaCO_2$ was observed (50.2 ± 11.5 mmHg under SB, 44.1 ± 4.1 mmHg under NIV). No patient needed reintubation.

Discussion

The major finding in our study is the improvement in the breathing pattern of infants submitted to NIV using a turbine flow generator in the post-extubation phase, as documented by a reduction of dyspnoea score. Analysis of the oesophageal pressure curves showed a concomitant significant reduction of RR, dPes and PTPes under NIV as compared with SB, which indicates a load reduction of respiratory muscles. Although NIV had no significant effect on $PaCO_2$ in this study, several authors suggest that

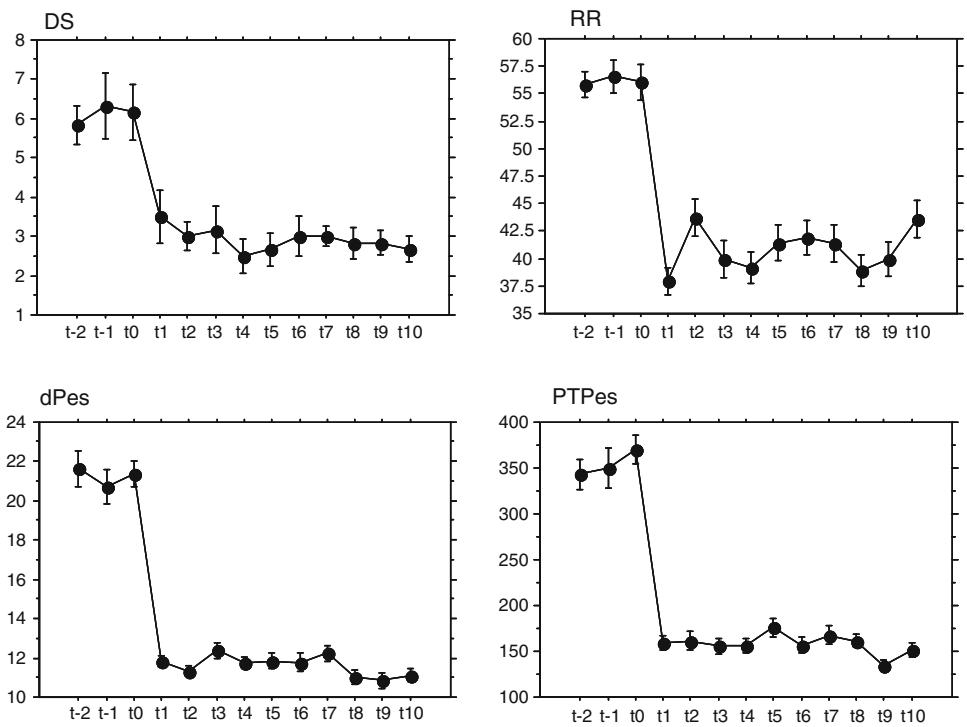

Fig. 2 Evolution over time (10-min intervals) of DS, RR, dPes and PTPes (*dots* indicate mean, *bars* indicate standard errors of the mean, SEM). Units: RR, c/min; dPes, cmH_2O; PTPes, $cmH_2O \times s^{-1} \times min^{-1}$. SB values are $t-2$, $t-1$ and $t0$. NIV values are $t1$ to $t10$. For all parameters (DS, RR, dPes and PTPes), all values under NIV (from $t1$ to $t10$) were significantly different from values under SB ($t-2$, $t-1$ or $t0$) (all $P < 0.0001$). For all parameters (DS, RR, dPes and PTPes), there was no significant difference between SB periods ($t-2$ versus $t-1$, $t-2$ versus $t0$, $t-1$ versus $t0$) or between NIV periods (any association between periods from $t1$ to $t10$)

NIV can reduce the $PaCO_2$ in children with hypercapnia [10, 11]. The present study shows that NIV is able to reduce the inspiratory load of the respiratory system in infants. As the device used in this study was developed to be used in adults or children over 30 kg, these results are important to support its use also in infants.

Although non-invasive pressure support ventilation is increasingly used in adults, few data exist in infants and children with body weight <10 kg [2, 3]. The evaluation of the efficacy of NIV in infants remains a challenge, as large randomised controlled trials are particularly difficult to perform in such patients. Oesophageal pressure has been used for many years as an index of the oxygen cost of breathing and of the inspiratory muscle load, but no direct correlation can be made between PTPes or dPes and work of breathing because the linearity of this relationship has not been clearly demonstrated. Recently, nasal continuous positive airway pressure was shown to unload respiratory muscles in infants with bronchiolitis [3]. In a retrospective study, NIV consisting of either nasal continuous positive airway pressure or bilevel positive airway pressure decreased both the rate of ventilator-associated pneumonia and the duration of oxygen requirements [12]. Our results are concordant with these studies, showing that NIV can be used with benefits in infants.

Some limitations of this study have to be underlined. If isolated from other parameters, the reduction of DS could have been biased by a subjective observer assessment. However it is clearly supported by the reduction of RR, dPes and PTPes. The observed improvement of the breathing pattern is most probably related to the use of NIV rather than to the effect of time, as supported by statistical analysis. To assess this point more precisely, it would have been necessary to include a third period of study of spontaneous breathing after the period of NIV or design a cross-over study. In our opinion, it would have been ethically questionable to interfere with patient therapy regarding a vital function support or to withdraw NIV only for scientific reasons, as the medical team had positive experiences with NIV to avoid re-intubation, to reduce the duration of intubation and possibly to reduce the rate of ventilator-associated pneumonia. Further, we observed that these patients needed NIV for several days after completion of the study protocol. This study was not designed to investigate any change in mortality or reintubation rate related to NIV in this age class. As most patients had palliative or curative surgery for congenital cyanotic heart defects with residual intracardiac shunt, heart rate and oxygenation were not analysed. The reduced spectrum of diseases reflects the usually predominant population in our unit and may introduce a bias in the present results.

Conclusion

In infants with respiratory failure after extubation, the application of NIV through a nasal mask with a turbine flow generator (VPAP II ST) induced reduction of dyspnoea score, RR, dPes and PTPes, indicating a reduction of breathing effort. In these infants, we did not observe deleterious effects of NIV. However the narrow recruitment of our patients precludes generalisation of these results to other respiratory diseases. Although most devices commonly used for NIV in children were originally developed for adults, this study, demonstrating improvement of some physiological parameters, supports the use of NIV in pressure support in infants.

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