Tidal Breathing in Preterm Infants Receiving and Weaning from Continuous Positive Airway Pressure

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Objective To compare tidal breathing on different continuous positive airway pressure (CPAP) devices and pressures and to serially measure tidal breathing during weaning off CPAP using electromagnetic inductive plethysmography.

Study design Using electromagnetic inductive plethysmography, tidal breathing was measured in 29 preterm infants receiving CPAP, gestational age 28 ± 2 weeks. Variable-flow nasal CPAP (nCPAP), bubble CPAP (bCPAP) at pressures of 5, 7, and 9 cmH_2O, nasal bi-level positive airway pressure (nBiPAP) system at pressures of 5, 7/5, and 9/5 cmH_2O, and unsupported breathing were studied. Twenty-one infants had weekly tidal breathing measurements on and off nCPAP.

Results Minute volume (MV/kg) was similar between all devices (0.30-0.33 L/kg/min). On bCPAP, weight corrected tidal volume (V_T/kg) was the least, changing little with increasing pressures. On nCPAP and nBiPAP, V_T/kg increased with increasing pressure and the respiratory rate (fR) decreased. The delivered pressure varied slightly from the set pressure being most dissimilar on nBiPAP and similar on bCPAP. Compared with unsupported breathing, all devices decreased V_T/kg, MV/kg, and phase angle, but did not alter fR. Serial tidal breathing measurements showed decreasing difference for V_T/kg over time on and off nCPAP.

Conclusions At different pressure settings, on all CPAP devices the measured MV/kg was similar either through increasing V_T/kg and decreasing fR (nCPAP and nBiPAP) or maintaining both (bCPAP). Serial tidal breathing measurements may aid weaning from CPAP. *(J Pediatr 2014;164:1058-63)*.

Continuous positive airway pressure (CPAP) has been used since 1971[1] in preterm infants to treat respiratory distress syndrome (RDS), to reduce apnea of prematurity, and to prevent extubation failure.[2] There are suggestions that early treatment of RDS with CPAP reduces the need for intubation and the incidence of bronchopulmonary dysplasia.[3-5] There are several devices available for infants to generate and deliver CPAP,[6,7] and although short binasal prongs are most suitable to deliver nasal CPAP (nCPAP), it is not known which is the most suitable CPAP generator.[6]

Several studies have compared different CPAP generators and their ability to improve lung function and breathing patterns in preterm infants,[8-18] but have provided contradictory results. So far, no study has compared the effects of bubble CPAP (bCPAP), variable flow CPAP, and nasal bi-level positive airway pressure (nBiPAP) on tidal breathing variables in preterm infants.

Tidal breathing measurements in infants during nCPAP are difficult to perform as pneumotachography or other airflow sensors rely on a leak-free CPAP interface seal and, therefore, cannot be performed while infants are receiving CPAP through nasal prongs where leaks have been shown to often exceed 90%.[19] Most tidal volume (V_T) measurements on CPAP have been performed using respiratory inductive plethysmography,[8,9,11,12,14,15,17] but the accuracy of volume measurements with respiratory inductive plethysmography is limited if the breathing pattern is variable as in preterm infants[20] and results in lower V_T compared with other techniques.[21] In this study, we used the noninvasive technique of electromagnetic inductive plethysmography (EIP), which measures volume changes of an infant's chest and abdomen via recording of thoraco-abdominal movements. It does not require an airway connection or patient-dependent calibration. EIP has been validated in preterm and term infants[22,23] and has been used successfully in infants without respiratory support between 29 and 42 weeks postmenstrual age.[21-23]

Although tidal breathing measurements are routinely used to guide weaning in intubated infants,[24] infants on CPAP are weaned by "trial and error" with wide variation of practice.[25] The most effective strategy of weaning infants from CPAP is not known.[26,27]

bCPAP	Bubble CPAP	nBiPAP	Nasal bi-level positive airway pressure
CPAP	Continuous positive airway pressure	PEEP	Positive end expiratory pressure
EIP	Electromagnetic inductive plethysmography	RDS	Respiratory distress syndrome
FiO_2	Fraction of inspired oxygen	t_{PTEF}/t_E	Time to peak tidal expiratory flow as a proportion of expiratory time
fR	Respiratory rate	V_T	Tidal volume
MV	Minute volume	V_T/kg	Weight corrected tidal volume
nCPAP	Variable flow nasal CPAP		

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Our aim was to compare the effects of 3 CPAP devices that are commonly used in neonatal units in the United Kingdom at different pressure settings on tidal breathing in preterm infants and to assess changes in tidal breathing measurements during weaning from CPAP.

Methods

Infants born at 34 weeks gestation or less, receiving nasal CPAP and clinically stable were eligible. Exclusions included congenital anomalies, neuromuscular disease, or surgical conditions, lack of parental consent, or if the attending team deemed the baby unsuitable for study due to clinical or social reasons. The study was approved by the South East Wales Research Ethics Committee, with informed written consent from the parents.

The EIP system, FloRight (Volusense AS, Oslo, Norway), was described in detail previously.[21-23] Briefly, it includes a volume sensor and a snug elastic vest worn by the infant, which covers the chest and abdomen and contains powered coils. These coils use a weak electric current of 100 mA to induce an electromagnetic field. The size of the electromagnetic field changes with tidal breathing and is sensed by an antenna, which is placed above the infant. The changes in the electromagnetic field are proportional to the changes in the volume of the infant's chest and abdomen. A reference volume with a corresponding reference magnetic field was used to calibrate the device.[21]

All measurements were performed with the infant lying supine in an incubator. The appropriately sized vest for each infant was identified by measuring the chest circumference. No infant was sedated for the study.

Tidal breathing was measured while the infant was receiving nasal CPAP provided by 3 CPAP devices at 3 pressure settings each and also while breathing without respiratory support. The 3 CPAP devices were the Infant Flow System (EME, Brighton, United Kingdom; nCPAP), the Infant Flow SiPAP System (Care Fusion, Warwick, United Kingdom; nBiPAP), and a bCPAP system (Fisher and Paykel Healthcare Ltd, Berkshire, United Kingdom; bCPAP). Each device was set up according to manufacturers' instructions and the device-specific short bi-nasal prongs were used. The largest size prongs which fit into the nostrils without blanching were used.

The CPAP pressures for nCPAP and bCPAP were 5, 7, and 9 cmH_2O positive end expiratory pressure (PEEP) and for nBiPAP PEEP 5 cmH_2O, peak inspiratory pressure 7/PEEP 5 cmH_2O, backup rate 30/min, inspiratory time 0.3 seconds, and peak inspiratory pressure 9/PEEP 5 cmH_2O, backup rate 30/min, inspiratory time 0.3 seconds. A Graseby capsule was taped to the abdomen of the infants to sense respiration and used with nBiPAP at pressures of 7 and 9/5 cmH_2O.

The pressure delivered was continuously monitored using the auxiliary pressure port of a differential pressure transducer (RSS100 HR; Hans Rudolph, Shawnee, Kansas). The order of the CPAP devices was randomized using sealed envelopes. Each setting and breathing without respiratory support was studied for 15 minutes if tolerated by the infant. If an infant had recurrent desaturations (below 85%) or bradycardias (below <100 beats per minute) on a setting, the recording was discontinued and the infant was placed back on the original CPAP setting. During data collection, the fraction of inspired oxygen (FiO_2) was adjusted to maintain the oxygen saturation between 92% and 98%.

After the initial measurements, the infants were followed up weekly during weaning off nasal CPAP. The infants were weaned by their clinician by increasing the time spent off CPAP as tolerated. Measurements were performed for 15 minutes with and without nCPAP delivered by the Infant Flow System. The order was randomized at the first follow-up and then alternated weekly. The last measurement was performed when the infant was weaned off nasal CPAP.

Of the 15-minute recording, minute 13-14 was used for analysis. If the infant was unsettled during this minute, minute 12-13 was used. If the recording had to be abandoned earlier than 15 minutes the penultimate minute of recording was used. The following variables were calculated for each breath with the EIP device software: V_T, respiratory rate (fR), minute volume (MV), time to peak tidal expiratory flow as a proportion of expiratory time (t_{PTEF}/t_E), and phase angle.[20,21] The number of sighs in 1 minute were calculated manually. A sigh was defined as a breath with an inspiratory time more than 1.5 times the mean V_T.

Statistical Analyses

Sample size was based on similar studies comparing changes in V_T achieved with different CPAP devices. A sample size of 28-32 patients is required to attain a statistical power of 0.8 when one assumes a 20% difference between the V_T measured on 2 different devices to be significant with a $P < .05$. Statistical analysis was performed using SPSS (version 16.0, IBM, Chicago, Illinois). Single value *t* tests were used to compare each delivery pressure with the expected pressure. For each other variable of interest, two-way ANOVA was used to compare each device and pressure setting. The Bonferroni correction was applied to mitigate the inaccuracies that may result from multiple testing. Consequently, 9 values for each variable were compared within the analysis. Only complete cases were analyzed, which led to 3 of the 29 cases being excluded from the analysis. One-way repeated measures were used to compare each of the 9 CPAP measurements with the case when no CPAP was employed. A paired Student *t* test was used to compare inspiratory time/kg with and without CPAP each week over the follow-up period. The statistical significance for individual tests was set at $P < .05$.

Results

Parents of 52 infants were approached, 13 declined consent, and 39 infants were recruited. Out of these, 3 withdrew, 3 were transferred out, and 4 were weaned off CPAP before