BCV for Tiny Lungs

Gary W. Mefford RRT

I was asked recently to provide some articles for a Neonatologist on Biphasic Cuirass Ventilation (BCV). There are several that document the benefits for infants, so I thought I would pull some of them together and provide a review. In this paper I hope to show how BCV can make a huge difference for patients with tiny lungs needing support. We will look at a group of articles documenting some of the benefits obtained via the use of BCV or other similar means of extrathoracic negative pressure applications. Upon rereading these papers, I find the authors express the benefits and reasons for utilizing this intervention in quite compelling terms. If you have seen the damage to an infant's lungs that can be wrought by the efforts required to support their breathing with positive pressure, and feel there's got to be a better way, then you need to learn about BCV. Biphasic Cuirass Ventilation (BCV) is a clinical intervention that can be applied to smaller patients than most realize and applied as a lung tool that offers many new strategic approaches to seriously improving clinical outcomes for tiny lungs. Join me for a few minutes as I share information from these papers and discuss the potential for improving outcomes with infants in the NICU and PICU through the therapies and support functions offered with BCV.

For those unfamiliar with BCV's modes and applications I will review. BCV is the brainchild of the late Dr. Zamir Hayek. Dr. Hayek was a brilliant British Pediatric Pulmonologist and world-renowned expert on Cuirass Ventilation. BCV is a group of cuirass applied cardiopulmonary interventions available only with the Hayek RTX ventilator. The Hayek RTX combines a cuirass or chest shell and flexible foam seal that covers the chest and upper abdomen with a power unit that connects with the cuirass via a pressure delivery hose and a pressure sensing tube. The cuirass creates an air chamber over the chest and abdomen and the RTX power unit controls the pressure within the cuirass to affect the dimensions of the thoracic cavity and thus inflation and deflation of the lungs. Inhalation occurs due to the power unit creating a negative pressure within the cuirass, which in turn gently pulls the chest wall and abdomen outward. The ribs expand and the diaphragm is moved to a lower position creating greater thoracic volume. From this a negative intra-thoracic pressure relative to ambient is created and air is pulled into the lungs just like natural inspiration. Inflation can be static or cyclical. In modes that provide ventilation, the power unit will switch the pressure in the cuirass from negative to positive providing the opposite effect on the thorax causing the lungs to deflate.

The patented technology used in the Hayek RTX noninvasively provides a very safe means of lung recruitment, offers a method for greatly increasing minute ventilation, and can function as a secretion clearance device with assisted cough even for infants. These capabilities enable the RTX to benefit many patients with cardio pulmonary compromise and respiratory distress. It produces effective ventilation in both normal and injured lungs, in clinical conditions marked by increases in pulmonary shunt and/or increased dead space ventilation. Additional benefits of BCV include improved perfusion of pulmonary capillary bed and improvements in cardiac output during ventilation without many of the side effects of other support techniques. BCV can be used as a highly effective means of standalone non-invasive support of lung inflation and/or ventilation. BCV can also be used adjunctively with all modes of intermittent positive pressure ventilation (IPPV) as a means to decrease side effects, and to shorten the duration that IPPV. The Hayek RTX provides either continuous negative, controlled, triggered or synchronized inspiration and expiration. BCV requires no mask or invasive interface. BCV can positively influence alveolar ventilation, oxygenation, lung volume and cardiac output. An inspiratory pressure of -15 cmH2O with an expiratory pressure of +5 cmH2O gives a pressure swing, span or deltaP of 20 cmH2O. Although there is an active expiration, lung capacity does not go below FRC. Cardiac output is not compromised with BCV as mean intrathoracic pressure is never positive thus no negative effect on venous return. The RTX is FDA cleared for all patient groups. BCV is used in hospitals from ICU to discharge as well as at home. BCV is applied via a cuirass sized to the patient. Patients from 1.5 up to 180 kg can Be fitted with one of the 12 sizes of cuirass.

We will begin our look at BCV for tiny lungs with some excerpts from Pediatrics. 1996 Dec;98(6 Pt 1):1154-60.

Continuous Negative Extrathoracic Pressure in Neonatal Respiratory Failure

Samuels MP(1), Raine J, Wright T, Alexander JA, Lockyer K, Spencer SA, Brookfield DS, Modi N, Harvey D, Bose C, Southall DP.

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Objective: In uncontrolled clinical trials, negative extrathoracic pressure has been shown to be an effective respiratory support. We aimed to assess its role in the context of current neonatal intensive care. *Design:* A randomized controlled trial, with sequential analysis of matched pairs of infants. Matching was undertaken by stratified randomization from 15 groups divided according to gestational age, oxygen requirement, and whether patients were intubated at 4 hours of age.

Setting: Two neonatal intensive care units.

Patients: Two hundred forty-four patients (birth weight 1.53 ±0.69 kg (mean ±SD); gestational age 30.4 ±3.5 weeks) with respiratory failure.

Interventions: Patients were randomized at 4 hours of age to receive either standard neonatal intensive care, or standard care plus continuous negative extrathoracic pressure (CNEP, -4 to -6 cmH2O) applied within a purpose-designed neonatal incubator. *Outcome Scores:* Clinical scores were calculated for each infant at 56 days of age, or death if earlier. Scores included measures for mortality, respiratory outcome, the presence of cerebral ultrasound abnormalities, patent arterial duct, necrotizing enterocolitis, and retinopathy. The treatment given for the higher score for each pair was recorded and the cumulative net number of pairs favoring CNEP plotted in the sequential analysis to provide an ethical early termination strategy. Individual components of the outcome score and other secondary measurements were analyzed on completion of the trial.

Results: The sequential analysis reached a decision boundary after 122 out of a possible maximum of 124 pairs were completed. The overall outcome score showed an overall significant benefit for CNEP.
- 5% fewer patients were intubated
- The total duration of oxygen therapy among surviving infants at 56 days was lower
  - CNEP 20.5 days, compared with 38.9 in controls; difference 18.4 days.
- Among all infants, the mean total duration of oxygen therapy was
  - 18.3 days among CNEP-treated infants compared with 33.6 days among the controls difference -15.3 days.

This reduction in mean levels is entirely attributable to substantially fewer patients requiring prolonged oxygen therapy, the median duration of treatment being very similar in the two groups.
- As a result, commensurately fewer surviving infants showed chronic lung disease of prematurity.

Conclusions: The use of continuous negative pressure improves the respiratory outcome for neonates with respiratory failure.

The positives on continuous negative pointed out in this paper:
- The overall outcome score showed an overall significant benefit for CNEP
- 5% fewer patients were intubated
- 18.4 days difference in duration of O2 therapy for infants surviving to 56 days
- 15.3 days difference in duration of O2 therapy for all infants
- Commensurately fewer surviving infants showed chronic lung disease of prematurity.
- The use of continuous negative pressure improves the respiratory outcome for neonates with respiratory failure

Broncho Pulmonary Dysplasia or Chronic Lung Disease of Prematurity places heavy challenges on the patients, caregivers and the system. This paper shows that use of CNEP in these patients can decrease duration of oxygen use and offer potential of improving lives or or even lessening the number of infants with chronic lung disease.

Let's look at another paper:

Efficacy of Noninvasive Biphasic Cuirass Ventilation in Neonates: Comparison with Invasive Positive Pressure Ventilation

Fabien G. et al

The abstract of this paper:

Purpose: In spite of surfactant therapy, bronchopulmonary dysplasia (BPD) remains frequent. A major contributor to this complication is the persistent need, notwithstanding normalized lung mechanics, for respiratory support by invasive positive pressure ventilation(IPPV). Biphasic Cuirass Ventilation (BCV), a non invasive form of respiratory support could thus be an advantageous alternative. Our purpose was to compare efficacy of BCV to IPPV in terms of gas exchange, stability of pulmonary mechanics and hemodynamic status.

This was an animal model study with neonatal piglets. The authors' conclusion was "Hemodynamic status and gas exchange were similar for both modes of ventilation." In considering the clinical implications of their findings the authors state "The use of non invasive biphasic cuirass ventilation may be feasible in preterm infants. Its use may become an alternative for invasive positive pressure ventilation and thus enable a reduction of the frequency of chronic lung disease in preterm infants."

So what we gain from this look into comparing PPV with BCV is:
- Similar effects measured as to gas exchange and hemodynamics in normal neonatal lungs
- Use of BCV in this population could well have a beneficial effect on the development of chronic lung disease
- BCV offers the potential to "enable a reduction of the frequency of chronic lung disease in preterm infants"

In another look at treating tiny lungs with negative lung inflation we have:

Negative Extrathoracic Pressure in Treatment of Respiratory Failure in Infants and Young Children

M P Samuels, D P Southall
Br Medj 1989;299:1253-7

This paper looks at 88 infants and young children aged 1 day to 2 years with respiratory failure due to bronchopulmonary dysplasia, neonatal respiratory distress syndrome, bronchiolitis, myopathy, congenital hypoventilation syndrome, pneumonitis, and postoperative phrenic nerve palsy. Their conclusion:

"Negative pressure respiratory support is a non-invasive yet effective treatment for respiratory failure. It may avoid the need for intubation, reduce the pathophysiological consequences of positive airway pressure ventilation and aid extubation."

From these authors' discussion segment:

"Continuous negative extrathoracic pressure and continuous positive airway pressure both increase transpleural pressure, thereby helping to splint open small airways and alveoli and re-expand atelectatic regions. Systemic oxygenation depends, however, not only on alveolar expansion and diffusing capacity but also on adequate pulmonary capillary perfusion with matching of perfusion to ventilation. Positive airway pressure reduces cardiac output, probably by impairing venous return to the right atrium and by increasing pulmonary vascular resistance. Thus at a certain unpredictable point increases in positive airway pressure may cause a fall in effective pulmonary blood flow with a resulting increase in ventilation-perfusion mismatch and worsening of hypoxaemia. Negative extrathoracic pressure, however, increases thoracic volume with less compression of vascular structures and consistently reduces pulmonary vascular resistance, particularly at the pressures used in our patients. In addition, it may dilate pulmonary capillaries and improve ventilation-perfusion matching. This may explain its recently reported value in persistent pulmonary hypertension of the newborn." Bancalari et al reported the physiological effects of negative extrathoracic pressure in infants with the neonatal respiratory distress syndrome. They showed a rise in arterial oxygen pressure, a fall in minute ventilation, and no change in arterial carbon dioxide pressure. Our results confirm the effects on gas exchange, and work in progress supports the idea that negative extrathoracic pressure has predominant effects on ventilation-perfusion matching. The changes in carbon dioxide concentrations, however, suggest that an increase in alveolar ventilation does occur in some patients. In addition, our observations that some patients maintain good respiratory function during the day when treated with negative pressure at night suggests that other mechanisms may also be operating. An increase in the patient's functional residual capacity, an increase in lung compliance, support of a compliant chest wall, or a reduction in diaphragmatic fatigue may all occur as a result of inflation of the lung under negative pressure. In hyaline membrane disease constant negative extrathoracic pressure has been compared with nasal positive airway pressure. Both were effective, although negative pressure produced a more rapid improvement in oxygenation. This may have arisen partly because negative pressure produced a more definitive change in transpleural pressure than a technique relying on the transmission of positive pressure through the nose. In addition, ventilation to perfusion matching may have been enhanced by negative pressure support as discussed above. The presence of an endotracheal tube is associated with increased bronchial secretions, impairment of ciliary clearance, mucus plugging, and upper airway trauma. It also increases the risk of airway and parenchymal infections. All of these factors may contribute to a continuing need for respiratory support after the acute condition has resolved. Both our experience and that of Mokrin and Bancalari has supported the idea that early initiation of treatment for respiratory failure will reduce the need for intubation. Non-invasive means of respiratory support will reduce the incidence of factors that contribute to chronic lung disease, particularly in preterm infants. Fanaroff et al reported that infants with the respiratory distress syndrome treated with negative extrathoracic pressure had less need for positive airway pressure ventilation and a shorter need for supplemental oxygen than infants treated with oxygen alone. Monin et al compared intermittent negative and positive airway pressure ventilation in 115 infants with the respiratory distress syndrome. There was equal oxygen exposure and no difference in the incidence of patent ductus arteriosus, intracranial haemorrhage, or mortality but a significant reduction in the incidence of pneumo-thorax and bronchopulmonary dysplasia in those treated with negative pressure.

Okay, so…This group looked at use of CNEP in NICU and PICU and confirmed previous findings showing "that early initiation of treatment for respiratory failure will reduce the need for intubation. Non-invasive (negative pressure) means of respiratory support will reduce the incidence of factors that contribute to chronic lung disease, particularly in preterm infants."

Are we seeing a trend here?

Notwithstanding the many potentials discussed in this article let's boil down some of the key positives pointed out from their experience and those cited from various other sources in their conclusion:

- Negative pressure produced a more rapid improvement in oxygenation
- Negative pressure respiratory support is a non-invasive yet effective treatment for respiratory failure
- May avoid the need for intubation, reduce the pathophysiological consequences of positive airway pressure ventilation, and aid extubation."
- Negative extrathoracic pressure increases thoracic volume with less compression of vascular structures and consistently reduces pulmonary vascular resistance
- (Negative extrathoracic pressure) may dilate pulmonary capillaries and improve ventilation-perfusion matching
- Some patients maintain good respiratory function during the day when treated with negative pressure at night
- An increase in the patient's functional residual capacity, an increase in lung compliance, support of a compliant chest wall, or a reduction in diaphragmatic fatigue may all occur as a result of inflation of the lung under negative pressure
- Infants with respiratory distress syndrome treated with negative extrathoracic pressure had less need for positive airway pressure ventilation and a shorter need for supplemental oxygen than infants treated with oxygen alone

It is hard to say it any better. This paper clearly delineates many of the benefits of negative pressure lung inflation.

The next paper documents the use of BCV in a medically very challenging infant with history of prematurity and low birth weight:

Biphasic Cuirass Ventilation in an Infant with Severe Respiratory Failure

Keiko Nishiyama, Makiko Komori, et al
Journal of Anesthesia (2009) 23:166-167

Figure 1

Few studies have reported the effect of biphasic cuirass ventilation [BCV] in infants. BCV is a noninvasive, ideal technique for mechanical ventilation that overcomes the shortcomings of conventional mechanical ventilation. Moreover, BCV prevents complications associated with endotracheal intubation, and patients can have conversations and eat meals while receiving BCV. When used in infants, BCV permits attachment between children and their mothers. We describe our experience with a male infant with chronic pulmonary disease associated with severe respiratory failure who responded well to BCV. Mechanical ventilation was performed for 3 days after birth in a 1367-g-weight infant, who was born with transient tachypnea at 29 weeks of gestation. Supplemental oxygen was given until 34 days after birth. The infant was in the neonatal intensive care unit until 39 weeks of age corrected for gestation. At discharge from the neonatal intensive care unit, chest radiography showed that atelectasis of the upper right lobe persisted, in association with emphysema-like changes. Wilson-Mikity syndrome was thus diagnosed. Bronchiolitis caused by rhinovirus developed 4 months after birth, and mechanical ventilation was needed. Airway pressure release ventilation (APRV)[4,5] was therefore performed for about 2 weeks. At the introduction of APRV, the patent's airway pressure was maintained at 28 cmH2O to prevent retraction of the chest wall. The lung collapse and hypoxemia were attenuated. The trachea was therefore extubated. Nasal noninvasive positive-pressure ventilation was first performed to treat the persisting atelectasis. Stable positive pressure was not achieved because of a poorly fitting nasal mask. A skin ulcer developed at the site of attachment, interfering the infant's feeding. Two weeks after the extubation, BCV was started, with the use of a Respiratory Therapy External (RTX; Medivent, London, UK) device. Airway pressure was maintained by the intermittent use of continuous negative pressure. Four weeks after extubation, however, bronchiolitis due to respiratory syncytial virus developed. The infant again required mechanical ventilation and received APRV for 8 weeks. Then, BCV continuous negative pressure was again intermittently applied. Because of the chronic respiratory disorder, continuous negative pressure was used while the infant was nursing. Sputum removal was promoted by performing BCV in the clearance mode. Then a continuous negative pressure of −7 cmH2O was applied for 24 h to expand the thorax. Respiratory muscle retraction subsided, and the atelectasis showed marked attenuation on chest X-ray films. The infant was able to become attached to his mother and drink milk from a bottle while wearing the appliance; his nutritional status was good (Fig. 1). Six weeks after the reintroduction of BCV, mechanical ventilation was no longer needed, even while the infant was nursing. As compared with other types of noninvasive mechanical ventilation, BCV is easily fitted to the patient and does not require sedation. BCV can also be used intermittently as physical therapy and is easily accepted by the hospital staff, as well as by patients' families. We are now assessing the possibility of performing BCV at home in infants who have acute respiratory infections.

In this letter to the editor this group describes what for them was a clear demonstration of the therapeutic application of BCV on a very challenging infant.

This case provides a typical example of the effects of BCV use in children with respiratory related support needs. Here we see the failure of NIPPV to achieve the clinical goals for the patient. The all too common mask fit with facial skin issues and the fact that the patient couldn't feed naturally during mask support prevented the patient from improving. During use of Continuous Negative he was able to bottle feed in his mother's arms. Natural nutritional intake, mother child bonding while the baby receives breathing support. Revolutionary! One line in this that stands out for me is "Respiratory muscle retraction subsided, and the atelectasis showed marked attenuation on chest X-ray films." Here is described the effect seen so often. That is relatively rapid relief of respiratory distress, often accompanied by onset of a series of good naps, then frequently followed by general improvement of respiratory status. Offering the potential of this type of dramatic turnaround makes BCV a very exciting intervention to apply.

In this case BCV kept reoccurring atelectasis at bay, provided support of breathing and facilitated the ultimate weaning from PPV. These are typical results with BCV. The next paper we draw from documents BCV use in a group of respiratory failure infants.

Negative Pressure Ventilation via Chest Cuirass to Decrease Ventilator-Associated Complications in Infants with Acute Respiratory Failure: A Case Series

Klonin H., Cheifetz I.M. et al
Respiratory Care, May 2000,Vol 45 No. 5: 486 – 490
http://www.rcjournal.com/contents/05.00/05.00.pdf

Abstract: Pulmonary and nonpulmonary complications of invasive positive pressure ventilation are well documented in the medical literature. Many of these complications may be minimized by the use of noninvasive ventilation. During various periods of medical history, negative pressure ventilation, a form of noninvasive ventilation, has been used successfully. We report the use of negative pressure ventilation with a chest cuirass to avoid or decrease the complications of invasive positive pressure ventilation in three critically ill infants at two institutions. In each of these cases, chest cuirass ventilation improved the patient's clinical condition and decreased the requirement for more invasive therapy. These cases illustrate the need for further clinical evaluation of the use of negative pressure ventilation utilizing a chest cuirass.

In this paper three cases in which the Hayek Oscillator, the predecessor to the RTX, was used to dramatically improve the course of illness with BCV.

Case 1 describes a 6-month-old male infant worsening respiratory failure with peripheral oxygenation saturations of 80% on a fraction of inspired oxygen (FIO2) of 0.60. Chest radiograph revealed a lingular infiltrate. Bronchoscopy confirmed the diagnosis of Pneumocystis carinii pneumonia. Presented to PICU with a respiratory rate of 60 breaths per minute, severe intercostal retractions, grunting, and nasal flaring. Arterial oxygen saturation 96% on face mask with FIO2 of 1.0. The patient was initiated on continuous negative airway pressure (–6 to –8 cm H2O) using a Hayek Oscillator. Shortly after initiating continuous negative pressure via chest cuirass, the patient's respiratory rate decreased to 40 breaths per minute. The FIO2 was weaned from 1.0 to 0.80 while maintaining oxygen saturation above 95%. Over the next several hours the patient's oxygen saturation again decreased to, 90% with the FIO2 remaining at 0.80. The infant's ventilatory support was, therefore, changed to intermittent NPV with a ventilatory rate of 40 breaths per minute and peak inspiratory and expiratory pressures of –18 cm H2O and –2 cm H2O, respectively. On these settings, the patient had decreased work of breathing, as evidenced by decreased retractions, grunting, and nasal flaring. The FIO2 delivered via face mask was weaned to 0.60 while maintaining oxygen saturation 95%. Subsequently, the patient improved with routine supportive care. The infant had progressive normalization of respiratory effort, respiratory rate, and oxygenation. He did not require further admission to the intensive care unit during his hospital course.

Case 2 describes a 4-month-old former 26-week premature male infant with history of Chronic Lung Disease of Prematurity with increasing respiratory distress. He intubated and ventilated. Post extubation this patient developed atelectasis, tachypnea and grunting. BCV was started at -30 to in an attempt to decrease his work of breathing and to improve the atelectasis. In addition, routine use of the Secretion Clearance mode was utilized. After two days the left lung re-expanded, the next day the right lung expanded. His lungs subsequently remained expanded and he was able to be discharged in another two days.

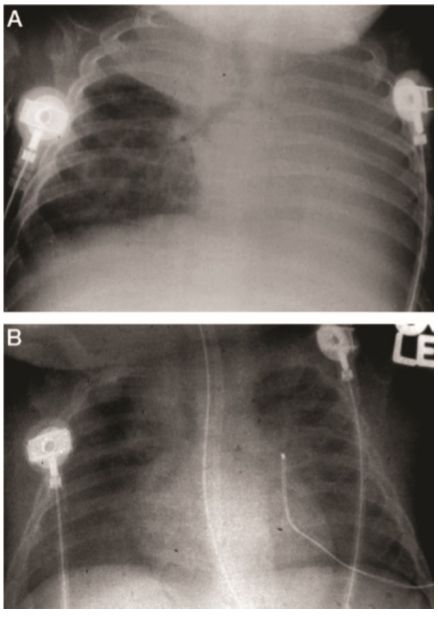

Figure 2

Case 3 describes a 16 month infant with respiratory failure and bronchiolitis obliterans. Severe atelectasis and airway plugging, and was requiring daily bonchoscopic clearance. This patient failed conventional mechanical ventilation, was advanced to positive pressure high frequency oscillatory ventilator. Development of arrhythmias and hemodynamic instability resulted in placing the patient on ECMO. Poor oxygenation with a pulmonary compliance of 0.35 mL/cm H2O/kg observed.

Following day 18 of the ECMO course BCV was initiated in Control Mode at -25/5 at 30 cycles per minute with I:E 1:1 along with PPV CPAP 5 PS 10. The patient was also provided two cycles of secretion clearance q2h. Good chest movement was observed and hemodynamic stability was maintained. Large volumes of secretions resulted and were cleared with routine suctioning. After 24 hours on BCV dynamic compliance doubled to 0.72 mL/cm H2O/kg. After the next 24 hours oxygenation improved adequately for the patient to be decannulated from ECMO. This infant was able to be extubated from PPV after three more days weaned to nasal O2 and returned to referring hospital.

In the author's discussion of these cases they provide the following considerations:

- Chest cuirass NPV may be used to avoid the potentially deleterious effects of invasive PPV
- The potential beneficial effects of NPV can be divided into several categories,
  - reduced airway complications
  - improved pulmonary parenchymal inflation at reduced airway pressures
  - reduced cardiovascular compromise
  - decreased sedation requirements
  - improved enteral nutrition
- By eliminating the need for intubation, the potential airway complications associated with invasive PPV can be completely avoided
- Barotrauma, also associated with PPV, can be avoided by the use of NPV
- Not only does NPV avoid the detrimental effects that PPV can have on hemodynamics, NPV may actually improve the patient's hemodynamic status
- NPV may minimize sedation requirements, as it is generally well tolerated by most patients
- Additionally, enteral feeding is usually well tolerated in patients treated with NPV alone

"Chest cuirass NPV may provide a partial solution that avoids many of the pitfalls of previous ventilation strategies."

The next article documents BCV use helping overcome the challenges presented in infants with acute symptoms of Cystic Fibrosis (CF).

Negative extrathoracic pressure in infants with cystic fibrosis and respiratory failure.

Klonin H, Campbell C, Hawthorne J, Southall D.P., Samuels M.P
Paediatric Pulmonology 30: 260-264 (2000)

This paper describes results of the application of Continuous Negative on 3 patients with infant onset of some of the severe pulmonary system challenges of Cystic Fibrosis. The

presentation and treatment of the respiratory failure symptoms described in this group provide additional clear examples of how BCV can offer significant improvement, even in infants with severe compromise.

From the opening of this paper:

> A small proportion of infants with cystic fibrosis and bronchiolitis suffer prolonged and severe courses, with up to a 60% mortality when mechanical ventilation is required. Hospital admission may be prolonged, with significant morbidity and sequelae. However, the outlook for infants who require ventilation may be better than previously thought. Nevertheless, the Cystic Fibrosis Foundation consensus report (1993) states that "because clearance of secretions from small airways by endotracheal suctioning is less effective than coughing, all possible measures should be instituted to limit the duration of intubation."
>
> We report on 3 infants who had cystic fibrosis diagnosed by sweat tests in early infancy, 2 with genotype confirmation. All developed severe and prolonged wheezing illnesses and deteriorated clinically despite maximal medical therapy, including bronchodilators, steroids, antibiotics, and, when indicated, antireflux therapy. In order to avoid endotracheal intubation or tracheostomy, we applied trials of continuous negative extrathoracic pressure (CNEP)…(usually −4 to −8 cm H2O).

The authors go on to describe in detail the clinical course of these 3 very sick CF patients and how they benefitted from Continuous Negative use.

From their discussion:

> The placement of an artificial airway and the administration of intermittent positive pressure ventilation (IPPV) are both associated with complications. These include high rates of infection, and barotrauma may be a problem for patients with underlying bronchiectasis.
>
> Continuous supervision is required by skilled personnel within the PICU to maintain an airway free from secretions. In contrast, negative pressure ventilation may be safely applied outside the PICU and indeed within the patient's home, as in case 2. The patient can communicate, cry, cough, and swallow while undergoing negative pressure ventilation. The use of noninvasive respiratory support has not previously been described for severe wheezing in infants with cystic fibrosis. Face or nasal mask IPPV has been used for severe respiratory failure or in end-stage respiratory disease as a bridge to transplantation in older patients. Our 3 patients all had severe, acute, and chronic respiratory symptoms that appeared to contribute to their failure to thrive and warranted further respiratory support. Nasal mask IPPV or CPAP is more difficult to apply to infants and young children, usually because they are less tolerant of any facial appliance. As we knew that CNEP was well-tolerated at this age, we considered this to be worthy of a treatment trial for these patients. In Case 3, the infant subsequently needed intubation for more severe clinical deterioration, although it was our impression that using CNEP/ECWO reduced the duration of intubation. These techniques provide effective respiratory support on extubation and enabled us to wean ventilation earlier than would otherwise have been possible. Case 1 was considered for a tracheostomy, which is a procedure with its own morbidity and mortality in infants. This was avoided by the use of negative pressure ventilation. Case 2 clearly thrived in negative pressure ventilation when all else had failed. Achieving adequate growth and weight gain are important indicators of successful treatment in chronic respiratory failure. We consider using CNEP in any patient with moderately severe respiratory distress where intubation might be indicated. Our largest experience is in patients with acute bronchiolitis. Assessment of improvement is based on clinical parameters, including respiratory and heart rates, chest wall retractions, oxygen requirement, and transcutaneous PCO2. Patients receive negative pressure ventilation outside the PICU and do not necessarily have indwelling arterial lines. Capillary or arterial blood gas analysis may be used in assessing the patient's course when noninvasive blood gas monitoring shows unfavorable trends. We aim to start treatment before hypercapnia develops, as a rising level of carbon dioxide implies exhaustion which may limit the effectiveness of CNEP. We do not offer CNEP to patients in an impending arrest situation or where the disease process is thought to be progressing too rapidly to warrant a trial of negative pressure ventilation. This is in line with current trials of noninvasive positive pressure ventilation. CNEP works by recruitment of alveoli and improvement in ventilation/perfusion matching. Negative extra-thoracic pressure of any sort provides a distending pressure on both airways and alveoli by increasing the transpulmonary pressure gradient. It may differ from positive airway pressure by avoiding compression of the pulmonary vascular bed. In the infant, it may also stabilize the easily collapsible chest wall, overcoming small airway closure and reducing air trapping. Two of our patients showed an increase in respiratory system compliance in CNEP, which may have resulted from improved airway conductance or lung compliance. This was associated with a decrease in WOB and gave the clinical impression that they were more comfortable. In patients with chronic obstructive airways disease, intermittent negative pressure ventilation has been thought to increase muscle strength and endurance, decrease hypercapnia, improve functional reserve of the respiratory muscles, and decrease inspiratory muscle fatigue. In patients with cystic fibrosis and acute or chronic respiratory failure, the same mechanisms may operate. ECWO has decreased muscle fatigue and improved blood gases in adult patients with chronic obstructive airways disease. Like CNEP, it also operates around a negative baseline, but may provide more control of functional residual capacity by maneuvers such as changing the end expiratory chamber pressure; this may prevent or decrease hyperinflation. Furthermore, ECWO has a physiotherapy mode that may be particularly useful in cystic fibrosis. High-frequency chest compression is associated with increased mucus clearance and a long term improvement in lung function in patients with cystic fibrosis. A 29-year-old woman with cystic fibrosis also had improved weight gain with high-frequency chest compression, similar to our case 2. We feel this may be associated with decreased WOB, due to the extra support provided by noninvasive respiratory support. Noninvasive positive pressure ventilation using BiPAP was prospectively studied in a pediatric population with acute respiratory failure, but the average age of children was 11 years, and the youngest was 6 months. Although we are experienced with face mask ventilation in our unit, we have found that infants with copious secretions tolerate poorly the presence of the face mask and high gas flows. Thus we feel that nasal CPAP would not have been as effective in our patients because it was harder to apply and maintain, particularly with longer periods of treatment or respiratory support used at home. In conclusion, negative pressure ventilation provided useful support to 3 infants with acute respiratory failure associated with severe chronic wheezing symptoms in cystic fibrosis. It was not associated with any apparent adverse effects. Further experience

with these techniques of respiratory support is warranted, as well as research into the role of ECWO as a physiotherapeutic aid in CF.

The mentioned improvement in compliance along with immediate patient response warrants a closer look in the 2 patients on whom pulmonary compliance was collected. The following is that information:

Patient 1

- Respiratory rate decreased from 40 to 24 breaths per minute
- Pulmonary function tests were performed using the PEDS Pulmonary Function Evaluation System (Mas, Inc., Hatfield, PA). This involved an esophageal balloon, face mask, and pneumotachograph to calculate tidal volume, minute volume, inspiratory and expiratory resistance, dynamic compliance, and pulmonary energetics at 0, –4, –8, and –12 cm H2O over a 1-hr period and then 24 hr later (in –8 cm H2O).
- These showed a rise in pulmonary compliance
  - 0.37 mL/cm H2O /kg baseline,
  - 0.82 at –4 and –12 cm H2O
  - 0.92 at 24 hr
- decrease in pulmonary resistance
  - 91.8 cm/L/sec baseline
  - 69.5 at –4 cm H2O
  - 55.3 at –12 cm H2O
  - 29.7 at 24 hr
- In work of breathing (WOB)
  - 0.24 kg.cm/kg at baseline
  - 0.11 at –4 cm H2O
  - 0.10 at –12 cm H2O
  - 0.08 at 24 hr

Patient 2

CNEP at –6 cm H2O

- Obviously more comfortable, with decreased nasal flaring and rib retractions
- Produced more secretions in CNEP
- Respiratory rate dropped from 60 to 30 breaths per minute
- Heart rate decreased from 150 to 130 beats per minute
- Transcutaneous PCO2 readings remained at the upper limit of normal
- Pulmonary function testing using a face mask and pneumotachograph revealed that his dynamic compliance in natural quiet sleep rose
- Pulmonary Compliance rose from 72.6 to 91.8 ml/cm H2O in CNEP

BCV has been well demonstrated to lower pulmonary artery pressure in respiratory failure in a group of adults. The following article shows that same effect of CNEP in infants with Persistent Pulmonary Hypertension of Newborn (PPHN).

Continuous negative pressure in the treatment of infants with pulmonary hypertension and respiratory failure.

J Perinatol. 1989 Mar;9(1):43-8.
Sills JH, Cvetnic WG, Pietz J.

Abstract: We report the successful use of continuous negative pressure (CNP) with standard intermittent mandatory ventilation (IMV) in five patients suffering from respiratory failure and persistent pulmonary hypertension of the newborn (PPHN). These infants all fulfilled criteria for use of extracorporeal membrane oxygenation (ECMO) with PaO2 less than 40 torr, alveolar-arterial oxygen difference (AaDO2) greater than 620 mm Hg, and oxygenation index (OI) greater than 50. Despite a considerable amount of conventional ventilation with mean airway pressures (PAW) between 14 and 26 cm water, none of these patients were able to improve oxygenation. All infants demonstrated significant improvement in ventilation requirements after initiation of CNP as reflected by a decrease in PAW, proximal inspiratory pressure (PIP), and IMV. Oxygenation dramatically improved in all infants. All five patients survived without any pulmonary or neurological complications at discharge. Availability of CNP may circumvent the need for ECMO in infants with severe lung disease and PPHN.

As the lung is recruited with negative pressure so is the pulmonary vasculature. There is zero potential of this beneficial natural effect of spontaneous inspiration that is enhanced by negative pressure support of the lungs when positive pressure is used in support of breathing. Frequent dramatic improvements in gas exchange and markers of respiratory distress are experienced by patients following close on application of BCV. Increased rates of recovery from respiratory compromise occur routinely with BCV application. Using BCV for tiny lungs opens new strategic intervention options that as seen in the papers reviewed here can and often does change the course of infant cardio-pulmonary illness for the better.

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Mr. Mefford's list of publications on BCV can be downloaded at https://app.box.com/s/7f810fe3ef3ca6b06dc3