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Non-invasive ventilation in acute respiratory failure in children: a review

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Introduction

Non-invasive ventilation (NIV) is defined as any form of ventilatory support applied without the use of an endotracheal tube. Whilst it was described as early as 1840s and used clinically in the 1950s with the polio epidemic, its popularity increased in the mid-1990s due to improvement in mask technology linked to the treatment of obstructive sleep apnoea. Nowadays, NIV is increasingly used to support not only patients with chronic respiratory failure but also those with acute respiratory failure who may benefit from early NIV (in particular non-invasive positive pressure ventilation or NPPV). It has changed the attitude and approach of pulmonologists and intensivists, though questions remain as to its potential and limitations in acute use.

Studies of NIV (which includes use of CPAP as well as non-invasive positive pressure ventilation or NPPV) in children are few, but it has an expanding role in children with increased respiratory load (due to cardiopulmonary disorders, upper airway obstruction or chest wall deformities), ventilatory muscle weakness (due to neuromuscular diseases or spinal cord injury), failure of neurological control of ventilation (central hypoventilation syndrome) and increasingly, in certain settings of acute respiratory failure. The first part of the following discourse will focus on studies of its use in acute settings in children. The second will discuss on some practical aspects and tips of its use particularly in children.

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Goals of NIV

The goals are listed in Table 1:

Table 1. Goals of NIV

1.	To reduce the $PaCO_2$ by augmenting alveolar ventilation through unloading of inspiratory muscles, thereby increasing tidal volume and decreasing breathing frequency
2.	To ensure adequate PaO_2 and oxygenation by preventing alveolar collapse and decreasing intrapulmonary shunting.
3.	To reduce excessive dyspnoea
4.	To sustain life until the underlying problem can be reversed

Advantages and limitations of NIV

The advantages and limitations of NIV/NPPV in acute respiratory failure are listed in Tables 2 and 3 respectively:

Table 2. Advantages of NIV in acute respiratory failure

1.	Avoid complications of tracheal intubation
2.	Increase patient comfort
3.	Preserves airway defence mechanisms against infection
4.	Preserves speech and swallowing

Table 3. Limitations of NIV in acute respiratory failure

1.	Less efficient than invasive ventilation (leaks, dead space)
2.	Adequate interface may be difficult
3.	Difficult to use around the clock
4.	There needs to be adequate respiratory effort and co-operation from the child

Though *hypercapnic* respiratory failure is the primary indication for NPPV, in acute *hypoxaemic* respiratory failure such as heart failure and pneumonia, there often is a component of *secondary hypercapnia* from muscle fatigue that could be helped by NPPV.

Studies in Adults

In adults, studies have shown that early use in acute exacerbation in chronic obstructive airways disease (COAD) and cardiogenic pulmonary oedema significantly decreases rate of intubation. In a prospective, randomised trial[1] of NIPPV versus endotracheal intubation in 64 patients with acute hypoxaemic respiratory failure, failure rate of NPPV was 30%. The best success rate occurred in those with pulmonary oedema. Pneumonia and ARDS were negative predictors for NIPPV success. Success of NIPPV as often obvious after 1 hour of ventilation accordingly to the study.

This and other studies reinforced the importance of patient selection in acute hypoxaemic respiratory failure. It was best for cardiogenic pulmonary oedema, good for pneumonia only with COPD component and successful in immunosuppressed only for less severe groups. It was not good for ARDS, lung fibrosis and community acquired pneumonia. **When there is metabolic acidosis or haemodynamic instability, NPPV is likely to be unsuccessful.**

Studies in Children

In children with primary acute respiratory failure, there is a lack of well designed, controlled experiments of noninvasive modes of respiratory support, despite its expanding use. There are fewer than 10 papers describing efficacy in uncontrolled case series. There is more evidence of its use in acute respiratory failure in children with neuromuscular diseases.

Fortenberry et al[2] first described NPPV in acute hypoxaemic respiratory failure in 28 children (mostly with pneumonia) using BiPAP® with nasal mask. They showed significant improvement in respiratory rate, PaO_2 and $PaCO_2$. Three later required intubation and the only side effect noted was ulcer over the nasal bridge. Others have also shown similar results using BiPAP® in prospective and retrospective studies in children with hypoxaemic respiratory failure,[3] status asthmaticus,[4,5] upper airway obstruction[6] and infants with bronchiolitis.[7] These were prospective or retrospective case studies of 10-34 infants and children, and showed NPPV (using bilevel pressure support) improved clinical scores, respiratory rate, $PaCO_2$ and decreased need for intubation.

Conventional ICU ventilators have also been used for NPPV in children, including Servo 300 (Siemens) in hypoxaemic respiratory failure in 4 leukaemic children[8] and Evita 2 dura (Dräger) in 42 children with hypoxaemic or hypercarbic respiratory failure.[9]

The largest report so far was by Essouri et al who retrospectively reviewed their 5-year experience of NPPV in the PICU.[10] It involved 114 children aged 15 days to 17 years. As described in BTS guidelines,[11] NPPV was applied intermittently for 2-4 hours two to four times per day, using conventional ICU ventilator (Evita 2 dura, Dräger) with Pressure Support + PEEP. If there was good compliance, patient was allowed to use NPPV for longer periods during first 24 hours or until improving. They concluded that NPPV can be effective in improving/reversing acute respiratory distress in selected children (community acquired pneumonia and infection in immunosuppressed) at an early phase of acute respiratory failure, but there is a high risk of failure in ARDS. Moreover, improvement of $PaCO_2$ and respiratory rate after 2 hours of NPPV were predictive factors of NPPV success. Others[10] have shown that FiO_2 level at 1 hour predicted NPPV success.

NPPV has also been successfully used in acute respiratory failure in children with neuromuscular disorders. BiPAP® has been shown to increase success in weaning in children with SMA type I intubated for acute respiratory failure.[12] Its use however is often an indication to start long term NPPV in such children. Table 4 is a summary of the types of diseases in adults and children when NIV is used.

Table 4. Use of NIV in adults and children. Bold letters indicate the more common indications

	Adults	Children (Limited experience)
Hypercapnic respiratory failure	**COAD exacerbations** Asthma Cystic fibrosis Upper airway obstruction	Asthma, bronchiolitis Cystic fibrosis Upper airway obstruction
Hypoxemic respiratory failure	**Cardiogenic pulmonary oedema** **Pneumonia** **Immunocompromised**	Pneumonia Immunocompromised
Others	**Restrictive diseases** **Weaning for DNR patients**	**Restrictive diseases (Neuromusculars)** Weaning

Factors for Success

Factors for success of NPPV in Severe Hypoxaemic Respiratory Failure are listed in Table 5 and discussed below.

Table 5. Factors for success of NPPV in childhood Hypoxaemic Respiratoy Failure

1. Patient selection
2. Properly timed intervention
3. Comfortable, well fitting interface
4. Patient coaching & encouragement
5. Careful monitoring
6. Skilled & motivated team

Patient Selection

- Alert and cooperative
- No need for ETT to protect airways (coma, acute abdomen, impaired swallowing) or remove excessive secretions
- No haemodynamic stability or life threatening refractory hypoxemia (PaO_2 <60 mmHg on $FiO_2$1.0)
- No uncontrolled air-leak
- No acute facial trauma
- Properly fitted mask

Timing

"Start early but not too early" is the principle. Adult studies show that success rate is lower if pH <7.25, $PaCO_2$ >12 kPa, Apache score >29 or Glasgow coma score <11.[13] It is too late if patient is on the verge of respiratory arrest, is severely hypoxaemic (PaO_2/FiO_2 <50-75), is comatose or hugely agitated or if medically unstable (e.g. has GI bleed, shock). In considering timing, one has to take into account one's unit's 'door to mask' time.

Comfortable, Well Fitting Interface

In children, a fitting interface often is the key to success of NPPV. The choices for commercially available interfaces are limited, especially in the young child. Custom-made interfaces are not available in the acute setting. The following points are relevant in the choice of interface:

- Nasal mask: less dead space, less claustrophobia, minimise complications if vomiting, allows oral intake without removing mask, clearer vocalisation. Use of chin strap often enough to control mask leaks.
- Face mask: preferred in severe respiratory failure as dyspnoeic patients are mouth-breathers, better in improving minute ventilation.
- In youngest children, nasal masks can be used as face masks.
- After short adaptation period, it should be firmly applied on face by a paediatric head cap to minimise air leaks without causing skin injury.
- Piastra introduced the "helmet" in his study, but dead space is increased and there is trigger time delay with this interface.[8]

Tips in Adjusting Interface

- Avoid tight uncomfortable fit as patient tolerance is key to success. Small leak is tolerated if VT is adequate (≥7 ml/kg).
- When secure mask, one should leave enough

space to pass 2 fingers beneath head straps. Masks with air cushion fit best & do not require tight strapping. “Duoderm” can be used to plug air leaks.

Patient Coaching and Encouragement

There should be reassurance and adequate explanation of what to expect to the child and parent, and they should be instructed to call the nurse if needs arise e.g. in repositioning the mask.

Careful Monitoring

The first 30-60 min is the most labour intensive, and success during this period is predictive for success of trial of NIV. The following aspects should be monitored. Fauroux[14] has shown that non-invasive monitoring by SpO_2, RR, tidal volume and subjective response of dyspnoea and comfort by visual analogue scale in CF children reflects good synchrony with ventilator and is as good as invasive monitoring with oesophageal, gastric pressures and diaphragmatic EMG. Other aspects that should be monitored include clinical status, RR, HR, SpO_2, ECG, NIBP, secretion clearance, mental state, accessory muscles. Continuous ET or $TcCO_2$ is helpful. Arterial blood gases (ABG) should be done within 1 hour, then 2-6 hourly; improvement in ABG in 1st hour likely indicates success. Ventilatory settings, FiO_2, leak should be monitored, as well as side effects such as skin integrity, GI, nasal symptoms.

Skilled and Moltivated Team

There should be a protocol in place for the use of NIV in acute settings. National guidelines such as BTS[11] should be adapted locally. In most cases, a short trial of NPPV is allowed, but clinicians need to know when to stop and switch to IMV otherwise patients could have a worse outcome. There must be advance directives as to when to discontinue NIV, who to intubate, CPR decision.

Practical Aspects of NIV in Children

1. Choice of the ventilatory mode. Both pressure targeted and volume targeted NPPV modes have been used in children with similar success.[14] The performance of the ventilator and the settings are probably more important for the success of NPPV than the ventilatory mode. Pressure Support (PS) with flow trigger has been used with Siemens 300 with success.[8] Pressure Support with flow trigger has also been used with Evita 2 with success.[10]
2. Synchrony of patient effort and ventilator is crucial to successful unloading of respiratory muscles which will be reflected as decreased diaphragmatic work of breathing. Asynchrony will increase work of breathing, cause patient to “fight the ventilator”, lead to ventilation-perfusion mismatch and ultimately failure of NIV. The four phases of breathing (inspiration, inspiratory trigger, termination of inspiration and expiration) should ideally be synchronised.
3. Flow trigger should be set at most sensitive without auto-triggering to breath at the lowest work of breathing. Adequate triggering will decrease work of breathing, as reflected by less negativity in oesophageal and gastric pressures, while inadequate trigger will not.
4. Inspiratory pressure delivery slope should be set at highest level tolerated by patient.
5. Adjust settings according to respiratory rate, tidal volume, SaO_2, end-tidal CO_2 or $TcCO_2$ and patient comfort by Visual Analogue Scale. Increase back up rate if patient not breathing sufficiently. This is especially important for volume targeted ventilation.[15]
6. Use humidifier, but turn off the heater as nasal warming of inspired air is still intact.

Sample Protocol of Implementing NPPV in Acute Settings in Children

1. Sit patient to 45º. Choose a fitting mask. It is better to start with full facemask in the acute setting.
2. Explain the principles of NPPV to patient and parents.
3. Initial: PEEP 0, PS 10 cmH_2O. Turn off humidifier, turn off alarms. Titrate FiO_2 to SaO_2 >90%.
4. Hold mask gently on face till patient comfortable and in synchrony. Explain & reassure.
5. Secure mask (2 fingers space), PEEP slowly to 3-5 cmH_2O, PS increased to obtain largest (>5-7ml/kg) exhaled tidal volume and patient

comfort. Excessive PSV may lead to dysynchrony.
6. Set most sensitive inspiratory trigger without auto-triggering.
7. Set highest peak inspiratory flow for patient comfort.
8. Adjust expiratory flow to 35% of peak inspiratory flow.
9. Set back up rate to avoid apnoea. Set alarms: low pressure, high RR, apnoea alarm.
10. Ask patient/parent to indicate needs.
11. Adjust settings according to respiratory rate, tidal volume, SaO_2, end-tidal CO_2 or $TcCO_2$, and patient comfort by Visual Analogue Scale.
12. If trial with PS non conclusive, try volume control (AC/VT) ventilation or increase back up rate (to lessen patient's inspiratory efforts to trigger).
13. If fail, consider invasive methods of ventilation.
14. In weaning: back up rate stopped, PS to CPAP. If O_2 <40%, $PaCO_2$ normal (4.5-6 kPa), stop NIV.

Failure (Intubation) criteria:[10]

1. Recurrent apnoea
2. Inability to improve gas exchange or dyspnoea
3. Haemodynamic instability despite fluids and vasoactive drugs
4. Major agitation or altered consciousness with GCS <10
5. Aspiration or excessive bronchial secretions
6. Intolerance to mask, lack of co-operation

Conclusion

Non-invasive ventilation, especially non-invasive positive pressure ventilation has become more widely used in acute respiratory failure in children though there is paucity of controlled trials. Timely use in selected groups of patients is important for success, and it is unlikely to be helpful in ARDS or in those with haemodynamic instability. Importance of synchrony is emphasized though there are limitations of interfaces and ventilators available for children. Finally, users must have their own adapted protocol and know the point of failure and when to switch to invasive ventilation.

Futher research is needed to define patient selection and the criteria for starting NPPV, as well as the long term benefit of NPPV in children. Better interfaces and ventilators in terms of adequate triggers, alarms and tidal volumes also need to be developed for children.

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