Non-Invasive Ventilation in Pediatric Critical Care

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NIV - Definition

• Mechanical respiratory support without endotracheal intubation

• Positive airway pressure (PAP) delivered through an interface

• Usually refers to Continuous (CPAP) or BiLevel (BPAP)

• For this talk I will include Heated Humidified High Flow Nasal Cannula (HHFNC)
NIV - Benefits

General benefits of mechanical ventilation

• Relieves some work of breathing by providing some pressure support
• Stent airway open throughout the respiratory system
• Recruitment and improved oxygenation

General risks of invasive ventilation

• No sedation or paralysis needed
• Intact natural airway clearance mechanisms (no plugging of ETT, ...)
• No mechanical trauma related to ETT placement
NIV – Why include HHFNC?

• Widely used in pediatric emergency / intermediate / critical care settings

• Commonly used in clinical situations where traditional NIV may be considered
  • Bronchiolitis
  • Asthma
  • hypoxemia

• Often used in an attempt to prevent invasive ventilation

• Growing use and popularity in pediatric setting
  • More on potential mechanisms of action of HHFNC later
Common clinical indications for NIV in peds CC

- Relief of significant work of breathing
  - Bronchiolitis
  - Status asthmaticus
  - Pulmonary edema
  - Acute chest syndrome

- Management of respiratory distress / failure
  - Dyspnea despite O2 supplementation
  - Hypoxemia
  - Respiratory acidosis
Other uses of NIV in peds

• Chronic respiratory failure
  • Neuromuscular diseases
    • Duchene
    • SMA
  • CCHS – depends on severity, NIV usually not preferred

• Neonatal respiratory distress syndrome

• Obstructive sleep apnea

• Bridge post extubation

• Not our focus today
Focus for today mostly

• General overview of NIV modalities in pediatrics

• 2 clinical illustrations
  • PAP in pediatric asthma management
  • HHFNC in bronchiolitis
When NOT to use NIV in peds

• Cardiopulmonary arrest / significant altered mental status / unstable patient

• Impaired airway protective reflexes – High aspiration risks

• Facial injuries – precludes interface use

• Pneumothorax without chest tube in place

• Upper GI bleed – need to secure and protect airway
Interfaces
Nasal Cannula

- Difficult to deliver any meaningful airway pressure
- Flow is set, NOT the pressure
- No adequate seal
- Mainly used to deliver supplemental O2 with uncertain FiO2 delivery
Nasal mask

• Frequently well tolerated
• Loss of pressure due to mouth leak
• Preferred interface for treatment of OSA in children
• Allows for social interactions

Not sure why the giraffe has a trunk
Full face mask

- FFM is less tolerated in kids
- Concern for aspiration
  - With vomiting
  - Patient too weak to remove it if needed

- May make kids look older
Total face

- Don’t Smile... it will leak
Helmet

For reference only, not sure how commonly in use
HHFNC
HHFNC
Choice of interface will depend on many factors

- Local availability / experience
- Patient comfort / tolerance
- Adequate fit & size
NIV modalities used in peds CC
CPAP: Continuous positive airway pressure

• Best when primary problem seems to be hypoxemia
  • Great for alveolar recruitment
  • Atelectasis

• OSA / Dynamic airway collapse is a factor

• Does not provide pressure support in inspiratory efforts
BPAP: Bi-Level PAP

• Failed CPAP

• Need increased respiratory support

• Inadequate ventilation

• Higher mean airway pressure than CPAP set at same EPAP
  • Improved oxygenation

• Decrease WOB by assisting with inspiratory efforts
  • Improved ventilation
BPAP: Bi-Level PAP

• Can add BUR but with caution
  • Central sleep apnea in otherwise stable child
    • → OK but not a PICU condition

• NIV with BUR not adequate
  • Obtunded / Absent respiratory effort
    • Opioid overdose / Head trauma
    • Muscle fatigue
  • NIV is not adequate if an airway needs to be secured
Difference between BPAP & NIPPV

• **BPAP**
  • 2 pressure levels: EPAP and IPAP
  • Patient triggers inspiratory breaths
  • Can also added cycled breaths (eg: BiPAP – ST mode in Trilogy vent)
  • BiPAP is a proprietary term

• **NIPPV**
  • Non Invasive Positive Pressure Ventilation
  • Includes other modes of ventilation commonly used invasively but delivered through a non-invasive interface (eg: Assist / Control mode)
Complications with CPAP / BPAP

• Barotrauma
  • Risk of any PPV

• Aspiration risk
  • Airway is not protected

• Gastric distention
  • Increases vomiting and PAP intolerance

• Skin irritation / breakdown

• Nasal mucosa irritation / nose bleeds

• Eye irritation
  • Mostly with poor fitting masks
Review article published in 2011 about NIV use in pediatric acute respiratory failure

Reviewed the evidence for NIV use in various conditions

Predictive factors of NIV failure
  - FiO2 & PaCO2 on presentation and within hours of starting
  - Inadequate patient selection
<table>
<thead>
<tr>
<th>Study</th>
<th>Population (n)</th>
<th>Age (yr)</th>
<th>Success rate (%)</th>
<th>Predictors of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campion et al. [20]^bc</td>
<td>Bronchiolitis (69)</td>
<td>0.1 (0.03-1)^de</td>
<td>83</td>
<td>Apnea, Higher PaCO$_2$ on admission, Higher PRISM score at 24 hrs</td>
</tr>
<tr>
<td>Bernet et al. [24]^b</td>
<td>Pneumonia (14), bronchiolitis (4), postoperative ARF (11), other (13)</td>
<td>24 (0.01-18)^fa</td>
<td>57</td>
<td>FiO$_2$ &gt; 0.8 at 1 hr</td>
</tr>
<tr>
<td>Joshi et al. [26]</td>
<td>Pneumonia or ARDS (29)</td>
<td>13^d</td>
<td>62</td>
<td>Age ≤ 6 yr, FiO$_2$ &gt; 0.6 within the first 24 hrs, PaCO$_2$ ≥ 55 mmHg within the first 24 hrs</td>
</tr>
<tr>
<td>Essouri et al. [27]^b</td>
<td>CAP (23), ARDS (9), ACS (9), immune deficiency (12), postextubation ARF (61)</td>
<td>5.3 (0.04-16)^ef</td>
<td>73</td>
<td>ARDS, High PELOD score</td>
</tr>
<tr>
<td>Lum et al. [31]^b</td>
<td>Pulmonary diseases (129), postextubation ARF (149)</td>
<td>0.7 (0.3-2.8)^fg</td>
<td>76</td>
<td>Higher FiO$_2$ needs at start of NPPV, Higher PRISM score on admission, Sepsis at start of NPPV</td>
</tr>
<tr>
<td>Munoz-Bonet et al. [54]</td>
<td>Pneumonia (20), ARDS (10), postextubation ARF (11), other (6)</td>
<td>7.1 (0.1-16)^g2</td>
<td>81</td>
<td>MAP &gt; 11.5 cm H$_2$O, FiO$_2$ &gt; 0.6</td>
</tr>
<tr>
<td>Mayordomo-Colunga et al. [55]^d</td>
<td>Type I ARF (38), type II ARF (78)</td>
<td>0.9 (0.05-14)^fba</td>
<td>84</td>
<td>Lower RR decrease at 1 hr and 6 hrs, Higher PRISM score at start and at 1 hr, Type I ARF</td>
</tr>
</tbody>
</table>
Illustration: NIV in Severe Pediatric Asthma

• Childhood asthma
  • Airway hyper-reactivity
  • Underlying lung inflammation
  • Can progress to irreversible changes / airway remodeling

• Severe asthma exacerbation
  • Bronchospasms
  • Mucus plugging
  • Severe airflow obstruction
  • Increased WOB
  • Respiratory insufficiency
  • Can progress to respiratory failure
Illustration: NIV in Severe Pediatric Asthma

• Risk factors for severe asthma
  • Prior ICU admission / intubation / mechanical ventilation / sudden onset
  • Frequent SABA use / poor control / non-compliance
  • Teenage boys / Poor perception of symptoms severity

• Above criteria NOT inclusive of all patients who die from asthma
Challenges of Ventilation in Pediatric Asthma

• Asthma is an obstructive disease
  • Air trapping
  • Prolonged expiratory times

• Intubation may worsen airway irritation and hyper-reactivity

• When to start NIV?
  • Severe work of breathing
  • Respiratory acidosis – usually late in presentation
  • Hypoxemia – may not need NIV
  • Metabolic acidosis – can occur due to increased work of respiratory muscles
  • Failure of response to management
Benefits of NIV in Pediatric Asthma

• May help avoid intubation

• Delay intubation until patient responds to pharmacotherapy

• Relieves work of breathing
  • Inspiratory support relieves respiratory muscles effort
    • Only with NIV modes with pressure supported breaths (not with CPAP)

• Off-sets auto-PEEP
Auto-PEEP: Consequence of airway obstruction

• Bronchospasm & mucus plugging
  • Narrowed airways
  • Increased airway resistance

http://www.medicalook.com/Lung_diseases/Bronchospasm.html

https://www.memorangapp.com/flashcards/31291/Asthma%2F+COPD/
Auto-PEEP: Consequence of airway obstruction

• Increased Airway Resistance
  • Increased WOB

• Time Constant = Compliance x Raw

https://www.slideshare.net/zareert/compliance-resistance-work-of-breathing
Auto-PEEP: Consequence of airway obstruction

- Prolonged Time Constant
  - Incomplete exhalation

- Air Trapping

http://erj.ersjournals.com/content/6/Suppl_16/5.figures-only
Auto-PEEP: Consequence of airway obstruction

• Air trapping
  • Hyperinflation
  • Auto-PEEP

Fig 18: Flow–volume loop: i) normal and ii) auto – PEEP

Fig 16: Flow time scalar: i) Normal constant flow, ii) Obstructive airway disease, highlighting low PEF, concavity and auto-PEEP.
Auto-PEEP: Consequence of airway obstruction

- Auto-PEEP / Hyperinflation
  - Increased Work of Breathing
- Work of breathing = Pressure x Volume

https://neonatalresearch.org/2012/06/15/pulmonary-compliance-changes-after-surfactant-2/

https://www.physicsforums.com/threads/pressure-volume-curve-for-lung-doesnt-make-sense.454191/
Auto-PEEP: Consequence of airway obstruction

- Auto-PEEP / Hyperinflation
- Increased Work of Breathing
Auto-PEEP: Consequence of airway obstruction

- Bronchospasms & mucus plugging
  → Small airways obstruction
    → Increased airway resistance
      → Prolonged time constants
      → Incomplete exhalation
        → Air trapping
          → Hyperinflation / Auto-PEEP

→ Breathing at Elevated
  → Lung volumes
  → End Expiratory Pressure
  → Airway resistance
    → Increased work of breathing
NIV benefits in Acute Severe Pediatric Asthma

• NIV stents airway open including small airways
  • Decreased airway narrowing
  • Directly alleviating some of the airway obstruction
    → Decreased airway resistance

• Enhances exhalation
  • Allows for respiration at less hyper-inflated lung volumes
    → Decreases auto-PEEP
    → Decreases elastic recoil resistance to inhalation

• PEEP
  → Offsets some of the additional work required by the auto-peep

• Pressure support
  → Relieves some inspiratory effort
Brief Review of literature: NIV in Childhood Asthma
Case series and Case reports of NIV in children with severe Asthma showing some potential benefit as well as good patient tolerance

Noninvasive positive-pressure ventilation in pediatric status asthmaticus.

Atakhosla OA¹, Simakarambono N, Hadley Jr EF, Hopkins RL

Abstract
OBJECTIVE: To describe the use of noninvasive positive-pressure ventilation in children with status asthmaticus.

DESIGN: Brief report.

SETTING: Pediatric intensive care unit in two tertiary institutions.

SUBJECTS: Children with severe acute asthma and hypercarbic respiratory failure.

INTERVENTIONS: Noninvasive positive-pressure ventilation using a bipap positive-pressure (BiPAP) device.

MEASUREMENTS AND MAIN RESULTS: Three children, ages 9-11, and 15 yrs, were treated for hypercarbic respiratory failure caused by status asthmaticus using BiPAP. The duration of pediatric intensive care unit admission was 48 hrs, and the duration of therapy ranged from 12 to 17 hrs. Inspiratory positive airway pressure ranged from 10 to 14 cm H2O (8.96-1.37 kPa), with a mean of 12 cm H2O (1.18 kPa). Expiratory positive airway pressure ranged from 4 to 5 cm H2O (0.39-0.49 kPa), with a mean of 5 cm H2O (0.49 kPa). Pulse oximetry was monitored continuously until resolution of symptoms. The mean values for respiratory rate, pH, and CO2 tension were compared at initiation, 3-4 hrs, and >12 hrs after initiation. BiPAP treatment resulted in improved respiratory status as shown by an increase in PaO2 from a mean of 7.26 kPa at initiation to 7.36 kPa after 3-4 hrs and after 12 hrs, respectively. However, respiratory rate showed a steady decrease from a mean of 31.7 breaths/min on admission to 24 breaths/min at 3-4 hrs and 19 breaths/min at >12 hrs of BiPAP therapy. CO2 (tension (Pco2)) decreased from a mean value of 54.6 mm Hg (7.28 kPa) on admission to 36.4 mm Hg (4.85 kPa) at 3-4 hrs of therapy; the mean Pco2 after >12 hrs of treatment was 39.8 mm Hg (5.31 kPa).

CONCLUSION: In three children with severe status asthmaticus, BiPAP seemed to improve ventilation and gas exchange, culminating in resolution of hypercarbic respiratory failure. A prospective, randomized, and controlled study is required to determine its role in pediatric status asthmaticus.

Noninvasive positive pressure ventilation for the treatment of status asthmaticus in children.

Carroll CJ, Schwartzen CA

Abstract
BACKGROUND: Noninvasive positive pressure ventilation (NPPV) has been used safely and effectively to improve gas exchange and to treat respiratory failure in a variety of disease states. Although this technique has some benefits in the treatment of status asthmaticus in adults, the use of NPPV in pediatric patients with asthma has not been described.

OBJECTIVE: To describe the use of NPPV in the treatment of pediatric status asthmaticus.

METHODS: Retrospective review of children admitted to the intensive care unit with asthma who received NPPV as part of their treatment between October 2002 and April 2004. Before and after initiation of NPPV, data were collected regarding degree of respiratory dysfunction.

RESULTS: Of seventy-nine children admitted to the intensive care unit during the study period for treatment of status asthmaticus, 5 children (mean ± SD age 9.6 ± 4.7 years) were treated with NPPV. Four of the 5 children were morbidly obese, with a mean ± SD body mass index of 32 ± 5. A statistically significant improvement in respiratory rate (43 ± 20 vs 31 ± 10/min, P < 0.03) and Modified Pulmonary Index Score (13.4 ± 1.8 vs 11.4 ± 1.5, P = 0.03) after initiation of NPPV. The mean ± SD duration of therapy was 33.2 ± 23.9 hours, and children tolerated this therapy well, requiring little or no analgesics.

CONCLUSIONS: NPPV was well tolerated in this series of children with status asthmaticus and can improve subjective and objective measures of respiratory dysfunction. NPPV may be an adjunctive treatment in the treatment of status asthmaticus in children.
RCT published in 2004
- 20 children randomized to BiPAP for 2 hours with cross over
- Noticed decreased signs of WOB
  - Respiratory rate
  - Accessory muscle use
  - Dyspnea
Review of the evidence of NIV in pediatric asthma published in 2015

- NIV can be used with improvement
- Evidence is not conclusive
• 2016 Cochrane Review of NPPV as add on therapy in acute pediatric asthma

• 2 RCTs with 20 participants in NPPV and 20 in control group
• BiPAP was used (not CPAP)
• High risk of bias
• Some improvements in asthma symptom scores
• Data missing for meta-analyses

• Conclusion:
  • Current evidence is insufficient
Illustration: HHFNC & Bronchiolitis

• Bronchiolitis
  • Clinical syndrome
    • Children under 2 years
    • Viral illness that usually starts with upper respiratory symptoms (colds)
      • RSV / Human Metapneumo V / Rhino V / Parainfluenza /
      • Followed by lower respiratory tract illness (not a URI)
        • Wheezing / crackles / increased WOB
  • Pathophysiology
    • Viral infection of small bronchi & bronchioles epithelium
    • Edema / mucus / sloughed epithelium
    • Small airways obstruction / atelectasis
    • +/- bronchoconstriction
      • +/- response to SABA
  • Treatment
    • Supportive care
Complications
- Dehydration
- Aspiration pneumonia
- Apnea
  - < 2 months old infants
  - Higher risk for respiratory failure
- Respiratory failure
  - Hypoxemia
    - Mucus plugging
    - Atelectasis
    - V/Q mismatch
    - Increased work of breathing
    - +/- hypercapnia
- Secondary bacterial infection
Bronchiolitis & HHFNC

• HFNC
  • Often used to avoid intubation
  
  • Air is heated & humidified
    • High flows are tolerated
  
  • Maximum flow is determined by size of cannula
    • Size of cannula is determined by patient size
  
  • Flow > 6 L/min may generate PEEP = 2-5 cm H2O
  
  • For children < 2 yrs, Flow is usually < 8 L
    • For older children and adults – flow can go up to 60 L
Bronchiolitis & HHFNC

• Evidence, recommendations & guidelines are still lacking

• However HFNC cannot be escaped in any peds environment
  • Ease of availability
  • Non invasive nature
  • Possibility of use in various settings (ER, step down, PICU, transport,...)
  • Ease of titration (or perceived ease at least)

• Titrated clinically (often synonymous with subjectively)
  • Respiratory rate
Bronchiolitis & HHFNC

• Titrated clinically
  • Often synonymous with subjectively

• Generally seem to separate:
  • Signs of increased WOB
    • Respiratory rate
    • Retractions
    • Patient comfort
      • Titrated the flow
  
• Hypoxemia
  • Titrate the O2 concentration
  • Different from FiO2
HFNC

• Reported benefits
  • Improved patient comfort
  • Improved oxygenation

• Clinical outcomes uncertain
HFNC – Patient Comfort

• Nasal prongs
  • Soft
  • Smaller
  • More pliable

http://camamamilla.mornster.dk/2017/08/17/goddag-optiflow/
https://westmedinc.com/flo-easy/
HFNC – Heated & Humidified Air

• Humidification
  • Humidifies and loosens secretions
    • Improves airway clearance
      • Decreases airway resistance
        • Decrease WOB
    • Avoids epithelial injury

• Heating
  • Allows for higher flow rates to be used
HFNC – Washout of Nasopharyngeal Dead Space

• The nasopharynx space is an anatomic dead space

• High flow of O₂ leads to efficient wash out of air in nasopharynx
  • Improves efficiency of ventilation
  • Enhances O₂ delivery

• While infants have less dead space since sinuses are not completely pneumatized
  • It is a larger fraction of their tidal volume

HFNC – Washout of Nasopharyngeal Dead Space

- High nasal flow, unimpeded at mouth, fills the upper airways – storing O$_2$ during exhalation and flushing CO$_2$

- High mask flow, impeded by pressure at the mouth - stores less O$_2$ in the upper airways during exhalation and adds prosthetic dead space

HFNC – PEEP and O2 Delivery

• Although variable, HFNC can provide some PEEP (not CPAP)
  • Relieves some WOB by
    • Offsetting auto-PEEP
    • Decreasing inspiratory effort
  • Provide respiratory support
  • Help in alveolar recruitment
  • Prevent / decrease atelectasis

• HF rate leads to less ambient room air to be involved in tidal volume
  • Improved mode of O2 delivery compared with other open circuits
Brief Review of literature: HFNC in Children
Observational study of
- 13 infants < 12 months with bronchiolitis
- HFNC at 2 & 8 L

Measured
- Lung volumes
- Intrathoracic pressures
- Resp Rate
- SpO2
- FiO2

Found improvement in parameters at 8 L
Cochrane review in 2014

Insufficient evidence for effectiveness of HFNC in bronchiolitis

HFNC is well tolerated
Cochrane review in 2014
• Looking for RCTs comparing HFNC with other NIV modes in children
• No studies met their search criteria
Heated humidified high-flow nasal cannula therapy in children.

Hutchings FA¹, Hilliard TN¹, Davis PJ².

Abstract
Heated humidified high-flow nasal cannula therapy (HHHFNC) was originally described as a mode of respiratory support in premature neonates and is now increasingly used in the management of acute respiratory failure in older infants and children. Heating and humidification of gas mixtures allow comfortable delivery of flow rates that match or exceed the patient's inspiratory flow rate. Emerging evidence from observational studies suggests that the use of HHHFNC therapy may be associated with reduced work of breathing, improved ventilation efficiency and a decreased need for intubation in children with respiratory insufficiency. There are several proposed mechanisms of action, and the potential for provision of unpredictable positive distending pressure has caused concern. Randomised controlled trial evidence comparing clinical outcomes with those achieved using other forms of respiratory support is, however, awaited. We review the proposed mechanisms of actions, indications, advantages and complications of HHHFNC therapy in children and describe our approach to its use in the paediatric ward environment.

KEYWORDS: General Paediatrics; Intensive Care; Respiratory

PMID: 25452315 DOI: 10.1136/archdischild-2014-306590