Continuous Positive Airway Pressure (CPAP) and Work of Breathing

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Foto: Ann-Sofi Ingman
Static pressure-volume curves of lung (PL), Chest wall (PW) and total respiratory system. Arrows indicate static forces.

Chest wall recoil is outward and lung recoil is inward.
Pulmonary physiology

- Lung volume is related to transpulmonary pressure.

- Transpulmonary pressure = alveolar pressure - pleural pressure.

- Compliance is $\frac{\Delta mL}{\Delta cm \, H_2O}$

- Work of breathing = integral of pressure applied and resulting volume change ($W = P \, dV/min/kg$)
Preterm breathing strategy is directed toward control of absolute lung volume:

- High respiratory rate to achieve auto end-expiratory-pressure.
- Active expiration against laryngeal narrowing.
- Tonic activity of diaphragm and intercostal muscles.
Respiratory fatigue in newborns

- Controversy exists about the relative importance of central or peripheral mechanisms that contribute to fatigue (Roussos and Zakyntos. Intensive Care Med 1996)
Work of Breathing

Differentiating Total Work of Breathing into Its Component Parts
Michael J. Banner, Robert R. Kirby and Paul B. Blanch
Chest 1996;109; 1141-1143
How can we help the infant?

CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP)
The Perfect CPAP

- Should keep airway pressure as constant as possible to reduce WOB
  - any deviations in pressure add to WOB done by the patient
- FRC should rise proportionately to the increase in level of CPAP
- This requirement means that the device must have highly variable flow characteristics to be able to
  - accelerate flow on inspiration, without time lag.
  - on expiration pressures should not overshoot, thus maintaining a low WOB.
- Differences in failure rates between studies can possibly be attributable to the performance of the devices used (dePaoli 2003).
5 week old male, 840g, spontaneous breaths with airway pressure measured in nasopharynx

Pressure variations during spontaneous breathing, no CPAP applied.

Argyle nasal prong without CPAP attached

Argyle nasal prong with 4cm CPAP

Jet flow CPAP 4cm
Increased Work of Breathing Associated with Nasal Prongs
Steven L. Goldman, June P. Brady and Fe M. Dumpit
Pediatrics 1979;64;160-164

Pressure
(cm H2O)

Nasal prongs
• without flowmeter
○ with flowmeter

Mask
△ without flowmeter
▽ with flowmeter

\[ W (\text{g-cm/min} \times 10^3) \]

\[ W \quad \text{face mask} \pm SE \]

\[ p < .01 \]
Work of breathing in anesthetized infants increases when a breathing system filter is used

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Total work of breathing (Campbell diagram)

![Airway volume vs esophageal pressure](image)

**Figure 3**
Boxplot showing the difference in the patient’s work of breathing when the T-piece system had a filter between the breathing system and the tracheal tube or no filter.

Increase by
43% (95% CI, 25–138%)
CPAP applied via ET-tube or head box

A new device for administration of nasal continuous positive airway pressure in the newborn: An experimental study

GUNNAR MOA, MD; KJELL NILSSON, MD; HENRIK ZETTERSTRÖM, MD, PhD; LARS O. JONSSON MD, PhD

CRITICAL CARE MEDICINE DECEMBER 1988

New device

Old device
Decreased Imposed Work With a New Nasal Continuous Positive Airway Pressure Device

James F. Klausner, PhD,1 Amy Y. Lee,1 and Alastair A. Hutchison, FRACP2

Fig. 3. Rates of work from representative breaths required to overcome resistance of new NCPAP device (A) and conventional NCPAP device (B).
Physiologic tests for WOB: CLINICAL studies comparing different devices

Pandit et al 2001  Ventilator vs Variable Flow
Courtney et al 2003  Variable Flow vs Variable Flow
Liptsen et al 2005  Bubble vs Variable Flow
Courtney et al 2011  Bubble vs Ventilator

VF > Ventilator
VF 1 > VF 2
VF > Bubble
Bubble ≥ ventilator, when intraprong P is same
Clinical studies using CPAP: system specification

- Early CPAP DR feasibility (Pediatrics 2004)
  → "NeoPuff T-piece for CPAP"

- Coin Study (NEJM 2009)
  → System for CPAP use not specified

- SUPPORT (NEJM 2010)
  → "CPAP administered via T-piece system"
Compare existing systems used for NCPAP care using simulated neonatal breathing
Table 1: CPAP generator, driver and prongs.

<table>
<thead>
<tr>
<th>Generator and driver</th>
<th>Description and used settings</th>
<th>Nasal interface 3.4 kg simulation</th>
<th>Nasal interface 1.3 kg simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AirLife (Cardinal Health, IL, US)*</td>
<td>CPAP generated by jet. Freshgas flow adjusts CPAP level.</td>
<td>AirLife Infant Nasal Prongs Large (ID 3.5 mm)</td>
<td>AirLife Infant Nasal Prongs Medium (ID 3.1 mm)</td>
</tr>
<tr>
<td>Bubble CPAP (Fisher and Paykel, Auckland, NZ)*</td>
<td>CPAP generated by water seal. Level of submersion adjusts CPAP level. Freshgas flow of 6</td>
<td>BC 4540 (ID 3.5 mm)</td>
<td>BC 4030 (ID 2.9 mm)</td>
</tr>
<tr>
<td>Benveniste (Valve Dameca, Copenhagen, DK and Prongs Firma H. Mortensen, DK)*</td>
<td>CPAP generated by jet that hits orifice. Freshgas flow adjusts CPAP level.</td>
<td>C.P.A.P. Canula Large (ID 2.5 mm)</td>
<td>C.P.A.P. Canula Medium (ID 2.5 mm)</td>
</tr>
<tr>
<td>Universal Generator set (Hamilton Medical, SLE UK)*</td>
<td>CPAP generated by jet. Freshgas flow adjusts CPAP level.</td>
<td>SLE Nasal Prongs Large (ID 3.5 mm)</td>
<td>SLE Nasal Prongs Medium (ID 3.0 mm)</td>
</tr>
<tr>
<td>Infant Flow and Sindi (Viasys Healthcare, CA, US)</td>
<td>CPAP generated by jet that hits angled edge. Freshgas flow adjusts CPAP level.</td>
<td>Infant Flow Large (ID 3.5 mm)</td>
<td>Infant Flow Medium (ID 3.0 mm)</td>
</tr>
<tr>
<td>Medijet (Medin Medical Innovations, DE)</td>
<td>CPAP generated by jet. Freshgas flow adjusts CPAP level.</td>
<td>Nasal prongs no 1200-03 x-large (ID 3.6 mm)</td>
<td>Nasal prong no 1200-02 medium (ID 2.9 mm)</td>
</tr>
<tr>
<td>Neopuff (Fisher and Paykel, Auckland, NZ)</td>
<td>CPAP generated by restricting outflow with valve. Valve adjusts CPAP level. Freshgas</td>
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<td></td>
</tr>
</tbody>
</table>
Mechanical lung model (ASL 5000)
Mechanical lung model (ASL 5000)

Imposed WOB = Expiratory Imposed WOB + Inspiratory Imposed WOB

NeoPuff 4 cm H2O Breath profile from 3,5 kg infant
Breath profiles used

Recorded flow from a healthy male newborn with a body weight of 3.4 kg. Sample from Moa et al.

Recorded flow from a healthy preterm (26 weeks) female at 28 weeks corrected age with a weight of 1.3 kg on recording.
Effect of leak
System summary

<table>
<thead>
<tr>
<th>System</th>
<th>Total iWOB</th>
<th>Use of Prongs</th>
<th>Increasing CPAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>AirLife</td>
<td>+</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Bubble CPAP</td>
<td>++</td>
<td>↑↑↑</td>
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<tr>
<td>Benveniste</td>
<td>++</td>
<td>↑↑↑↑</td>
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<tr>
<td>Hamilton universal</td>
<td>++</td>
<td>↓</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>Infant flow</td>
<td>+</td>
<td>↓↓</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>Medijet</td>
<td>+++</td>
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Conclusions

- Large variations in pressure stability and iWOB exist between the different devices
- Clinical significance, if any, needs to be assessed
Effect on work of breathing of different continuous positive airway pressure devices evaluated in a premature neonatal lung model