Understanding Advanced PAP Modalities: Review for the Non-Sleep Specialist

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Disclosures

• No relevant financial disclosures

Topics

• Basic terms
• Conventional bi-level PAP
• Adaptive servo ventilation
• Volume assured pressure support
IPAP and EPAP

- **IPAP**
  - Overcome dynamic upper airway resistance (eliminate hypopnea)
  - Augment/rest inspiratory muscles
  - Provide a positive pressure breath (if timed)
  - In VAPS, IPAP servo-controlled with a target $V_t$ or $V_E$

- **EPAP**
  - Prevent closure of upper airway during exhalation
  - Driving pressure to wash out mask

**Back-Up Rate**

- Minimum allowable breaths per minute
Bi-level PAP Modes: S, S/T

- **Spontaneous (S):** machine delivers pressure boost only when patient's own (spontaneous) inspiratory effort sensed
- **Spontaneous/Timed (S/T):** machine-initiated (timed) breaths delivered if patient's own (spontaneous) rate falls below a minimum (back-up rate) level
  - Same terminology used by Respironics and ResMed

When S/T may be Needed

- Severely defective central respiratory control
- Respiratory muscle weakness or ↓ respiratory system compliance results in inspiratory efforts too feeble to reliably trigger
- Central apneas on PAP

Brands

- **BiPAP®:** Philips Respironics bi-level devices
- **VPAP®:** ResMed bi-level devices
How Does Bi-level PAP Work?

Inspiratory Trigger

- IPAP activation when minimal inspiratory flow-rate threshold detected (30 ml/sec)
  - Sensitive to upper airway obstruction
- Trigger delay: time between inspiratory effort and IPAP onset
  - Varies between Bi-level PAP devices

Inhalation

- Inspiratory flow rate, tidal volume depends on:
  - Patient:
    - Inspiratory effort
    - Airway resistance
    - Compliance of lungs/chest wall
  - Machine:
    - Pressure support
    - Ti Min (usually 0.3 secs)
    - Interface leak
Termination of IPAP

• 2 methods for “cycle threshold:”
  – Insp flow drops below threshold
    • Typically 25% of peak flow
  – Ti Max is met

Exhalation

• Passive
• Determinants
  – Respiratory system elastance/compliance
  – AutoPEEP
  – Active exhalation/activation of accessory exp muscles

CPAP Interfaces = Bi-level PAP Interfaces

Nasal pillows  Nasal mask  Full face mask
Conventional Bi-level PAP

<table>
<thead>
<tr>
<th>BPAP S</th>
<th>BPAP S/T</th>
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<tbody>
<tr>
<td>Restrictive Lung Disease</td>
<td>√</td>
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<tr>
<td>OSA</td>
<td>√</td>
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<tr>
<td>Hypoventilation</td>
<td>√</td>
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<tr>
<td>COPD</td>
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<tr>
<td>CSA/CompSAS</td>
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*If worsening diurnal hypercapnia and/or sleep-related desats persist on BPAP S

CMS Bi-level PAP Indications

Case

- ID: 65 M, former smoker: 1.5 ppd x 20 yrs
- CC: “Going downhill”
- HPI: 6 mos progressive:
  - dyspnea on exertion and orthopnea
  - diffuse weakness
  - dysphagia
  - non-restorative sleep
  - daytime fatigue
  - brief AM headaches
• Exam:
  – Vitals: BP: 130/80 RR: 24 BMI 24
  – General: Tired-appearing
  – Lungs:
    • ↓ chest excursion
    • ↓ breath sounds R base
    • thoracoabdominal paradox when supine
  – Extremities:
    • diffuse fasciculations, weakness
• Labs: 7.36/55/59/20 (room air)
• Diagnosis
  – ALS with restrictive lung disease and hypercapnic respiratory failure

• When to start bi-level PAP at night?

**Bi-Level PAP for Restrictive Thoracic Disorders**

<table>
<thead>
<tr>
<th>Neuromuscular disease or severe thoracic cage abnormality</th>
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</thead>
<tbody>
<tr>
<td>Awake PaCO₂ ≥ 45 OR SpO₂ &lt; 88% 60 mins per oximetry OR MIP &lt; -60 cm H₂O or FVC &lt; 50% AND No COPD</td>
</tr>
</tbody>
</table>

**Bi-Level PAP for ALS**

Bi-level PAP S/T vs usual care when:
orthopnea + Pimax < 50% pred and/or symptomatic hypercapnia

Bi-level PAP: improved quality of life, slowed FVC decline in all ALS patients; significant survival advantage only in group with better bulbar function

Bourke SC Lancet Neurol 2006; 5:140
Question
Which of the following OSA patients should be advised to try bi-level PAP?

A. 54 W newly diagnosed very severe OSA (AHI 117) eliminated in lab by CPAP 12
B. 54 W newly diagnosed very severe OSA (AHI 117) eliminated in lab by CPAP 17
C. 54 W known severe OSA (AHI 117) requiring CPAP 12 yet poorly tolerant of therapy

Bi-Level PAP for OSA
• Not superior to CPAP in PAP naive OSA¹
• Comfort option if ↑ CPAP ≥ 15 cm H2O²
• "Rescue" for those CPAP noncompliant?

¹Gay P. Sleep 2006; 29:381
²Kushida CA. Sleep 2006; 29:375

Bi-Level PAP will “rescue” some non-compliant OSA Pts

Bi-Level PAP for OSA

OSA diagnosis

AND

CPAP “tried and proven ineffective”

Other Bi-Level PAP Candidates in OSA Spectrum

OSA

Complex sleep apnea

"Overlap Syndrome" COPD + OSA

"Pickwickian"

Obesity Hypoventilation Syndrome

• BMI > 31 kg/m²

• Awake hypercapnia (PaCO₂ > 45 mm Hg)

• No other causes for hypoventilation
  • Severe COPD
  • Chest wall disorders
  • Hypothyroidism
  • Neuromuscular disorder
  • Congenital central hypoventilation syndrome

• Sleep disordered breathing
Obesity Hypoventilation Syndrome

- 2 types:
  - CPAP responders
  - CPAP non-responders

Piper AJ. Thorax 2008; 63:395

CPAP vs Bi-Level PAP in OHS

Excluded IF ON CPAP: SpO₂ < 80% > 10 mins w/o apnea; REM PRCO₂ ≥ 10; afternoon to morning PCO₂ ≥ 10 if awake PCD₂ > 55

For OHS without severe nocturnal hypoxemia or CO₂ retention on CPAP, equivalent 3-month outcomes with CPAP vs Bi-level PAP

Piper AJ. Thorax 2008; 63:395

CPAP to eliminate obstructive apneas/hypopneas

- SpO₂ < 89%

- Bi-level PAP S

- SpO₂ < 89%

- Bi-level PAP S + O₂

For OHS without severe nocturnal hypoxemia or CO₂ retention on CPAP, equivalent 3-month outcomes with CPAP vs BiPAP

Piper AJ. Thorax 2008; 63:395

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**Bi-Level PAP S for Hypoventilation Syndrome**

- Awake PaCO$_2 \geq 45$
- No COPD
- PaCO$_2 \uparrow \geq 7$ during sleep or immediately upon awakening
- OR
- SpO$_2 \leq 88\%$ for $\geq 5$ minutes during PSG not caused by OSA

**Bi-Level PAP S/T for Hypoventilation Syndrome**

- Awake PaCO$_2 \uparrow \geq 7$ mm Hg despite BPAP S
- OR
- SpO$_2 \leq 88\%$ for $\geq 5$ minutes during PSG not caused by OSA while on BiPAP S

**Case: Bi-level PAP and COPD**

- 66 M Severe COPD.
- Advair, Spiriva, Albuterol prn.
- O2 2LPM
- s/p pulm rehab
- Class III dyspnea.
- 2 hosp over past 24 mos
- PCO$_2$ 61
- ESS 12
- Refer for bi-level PAP?
GOLD: No clear recommendation for bi-level PAP

Bi-level PAP and COPD

- Inconsistent impact on:
  - Gas exchange
  - PFTs
  - Survival
  - Dyspnea
  - Exercise tolerance
  - Sleep
  - Morbidity

Adherence 37-57%

McEvoy RD. Thorax 2009; 64:561

BPAP + O2: Survival advantage, yet no change PaCO2; PFT, worse QOL

McEvoy RD. Thorax 2009; 64:561
COPD: Are we Aiming Too Low?

*Dreher M. Thorax 2010; 65:303*

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Low</th>
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<tbody>
<tr>
<td>IPAP</td>
<td>29</td>
<td>15</td>
</tr>
<tr>
<td>EPAP</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Rate</td>
<td>18</td>
<td>8</td>
</tr>
</tbody>
</table>

*High Intensity* bi-level PAP: Greater ↓ PCO2, dyspnea and ↑ PAP adherence versus traditional, "low intensity" bi-level PAP

**Bi-level PAP and COPD**

- Potential candidates (all):
  - Diurnal hypercapnia
  - Sleep-related desaturation despite meds, O2
  - Disturbed sleep
  - Daytime sleepiness

**CMS: Bi-Level PAP for COPD**

- **BPAP S**
  - ABG: PaCO2 ≥ 52
  - Oxi: SpO2 ≤ 88% for ≥ 5 mins on min 2L O2
  - OSA ruled out

- **BPAP ST**
  - Acute:
    - ↑ PaCO2
    - SpO2 ≤ 88%
  - On BPAP S
    - At 61-90 days
      - PaCO2 ≥ 52
      - Sleep hypoxemia

Symptoms of sleep-related hypoventilation documented
Central Sleep Apnea

- Hypercapnic CSA
  - “Won’t breathe”
    - Congenital Central Hypoventilation Syndrome
  - “Can’t breathe”
    - Neuromuscular disorders
    - Chest wall syndromes

- Hypocapnic CSA
  - Cheyne-Stokes
  - Complex sleep apnea
  - Opioid-related
  - High-altitude-related
  - Medical condition-related

Optimize underlying condition + CPAP vs Bi-level S/T of ASV type

Standard Bi-level S/T

Complex Sleep Apnea = Treatment Emergent Central Sleep Apnea

- 85-95% Normal
  - OSA
  - Diagnostic CPAP

- 5-15% OSA CSA
  - CSA resolves on CPAP (35%)
  - CSA persists on CPAP (65%)

Adaptive Servo Ventilation “ASV”

- Bi-level PAP S/T devices
- Dynamic (breath-by-breath) adjustment of inspiratory pressure support and back-up rate to normalize complicated breathing patterns relative to a pre-determined target
- Expiratory pressure adjusted to maintain upper airway patency
Adaptive Servo Ventilation Devices

- ResMed VPAP® ADAPT SV™
- Philips Respironics BiPAP® auto SV™

Meeting target?

Yes

Minimum PS

No

↑ PS +/- Rate

Proprietary algorithms

Adaptive Servo Ventilation

Inhalation

Exhalation

Normal breaths

Decrescendo phase

Central apnea

Crescendo phase

Counter proportional pressure delivery to smooth respiratory pattern
ASV: Parameters to Set

- EPAP (to elim obstruction)
  - Auto-adjusting in latest devices, so min, max values needed
- IPAP
  - Min
  - Max
- Rate
- Interface

ASV: Impact on AHI in CHF-CSA

ASV ↓ AHI 31/h (-25 to -36) over baseline and 12-23 compared to CPAP

ASV: Impact on LVEF

ASV improves LVEF by 6.2% (3.9-8.3)

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ASV in CHF: Other Impacts

• ↑ 6-min walk distance (32.8 m) with ASV
• No diff: arousal index, SF-36 vitality score

Sharma BK. Chest 2012; 142:1211

Ongoing Studies of Long-term Impact of ASV in CSA-CHF

• SERVE-HF¹
• ADVENT-HF²

¹http://clinicaltrials.gov/ct2/show/NCT00733343
²http://clinicaltrials.gov/ct2/show/NCT01128816

ASV In Practice

• Cheyne-Stokes in CHF:
  – AASM:¹ CPAP → ASV
  – Reality: ASV

• CompSAS:
  – AASM:¹ Insufficient data
  – Reality: ASV

¹Aurora RN. Sleep 2012; 35:17
CMS: Bi-Level PAP (S or S/T) for CSA

| CSA on PSG | AND | Sleepiness or disrupted sleep | AND | Improvement of the sleep disordered breathing on bilevel PAP |

2013

<table>
<thead>
<tr>
<th>CPAP</th>
<th>BPAP S</th>
<th>BPAP ST</th>
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<tbody>
<tr>
<td>$1047</td>
<td>$2372</td>
<td>$5929</td>
</tr>
</tbody>
</table>

Summary:
Adaptive servo ventilation

- Performs breath-by-breath analysis and adjusts pressure and rate accordingly; minimum expiratory pressure to maintain upper airway patency
- Indications: hypocapnic central sleep disordered breathing syndromes
- Efficacious modality for AHI, LVEF in CSA/CHF; long-term implications unclear

Volume-Assured Pressure Support

- Bi-level PAP S/T devices
- Automatic adjustment of IPAP to maintain a consistent delivered volume
- Concept: provide greater volume stability in the face of changes with pt effort, chest wall compliance, and airways resistance
- Expiratory pressure adjusted to maintain upper airway patency
**Volume-Assured Pressure Support Devices**

- Philips Respironics
  - BIPAP® AVAPS™
- ResMed VPAP®
  - iVPAPS™

**Volume-Assured Pressure Support: Potential Indications**

- Neuromuscular disease
- COPD
- Obesity hypoventilation syndrome

**VAPS**

- Seeks consistent tidal volume by automatically adjusting IPAP between IPAP_{min} and IPAP_{max}
  - V_{t} < target: IPAP ↑
  - V_{t} > target: IPAP ↓
VAPS: Parameters to Set

- Target tidal volume
- EPAP (to elim obstruction)
- IPAP
  - Min
  - Max
- Rate
- Interface

Defining Target Tidal Volume
Respironics AVAPS

- 110% resting tidal volume
- 8 ml/kg ideal body weight

<table>
<thead>
<tr>
<th>Height</th>
<th>Ideal weight</th>
<th>Vent if ml/kg</th>
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</thead>
<tbody>
<tr>
<td>59'</td>
<td>52.0 kg</td>
<td>420 ml</td>
</tr>
<tr>
<td>61'</td>
<td>55.5 kg</td>
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<tr>
<td>63'</td>
<td>59.0 kg</td>
<td>470 ml</td>
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<tr>
<td>65'</td>
<td>62.5 kg</td>
<td>500 ml</td>
</tr>
<tr>
<td>67'</td>
<td>66.0 kg</td>
<td>530 ml</td>
</tr>
<tr>
<td>69'</td>
<td>70.5 kg</td>
<td>560 ml</td>
</tr>
<tr>
<td>71'</td>
<td>74.0 kg</td>
<td>600 ml</td>
</tr>
<tr>
<td>73'</td>
<td>78.0 kg</td>
<td>640 ml</td>
</tr>
</tbody>
</table>

AVAPS vs Bi-level S/T in OHS

Murphy PB. Thorax 2012; 67:727
AVAPS vs Bi-level: Other Reports

- Neuromuscular diseases\(^1\)
  - Bi-level PAP S/T vs VAPS:
    - No diff: SpO\(_2\) parameters, AM PaCO\(_2\), leaks, comfort

\(^1\)Crescimanno G. Respirology 2011; 16:672

Volume Assured Pressure Support

- Too early to tell what the role for this technology will be.

Follow-up for Bi-level PAP

- 61-90 days
- Review
  - Clinical experience
  - Download for adherence, leaks, AHI
  - Oximeter
  - ABG
Summary

- Conventional bi-level PAP
  - Independently adjusted IPAP and EPAP to prevent obstruction and augment ventilation
  - OSA: if pressure intolerance on CPAP
  - OHS: if persistent hypoventilation on CPAP
  - ALS: mortality improvement in better bulbar function group; FVC < 50% pred
  - COPD: role uncertain

Summary

- Adaptive servo ventilation:
  - Breath-to-breath PS adjustment to stabilize breathing pattern
  - EPAP to eliminate obstructive events
  - For hypocapnic CSA
  - CHF
    - Best modality to lower centrals
    - Improves LVEF
    - Unknown long-term impact on patient
  - Expensive

Summary

- Volume assured pressure support:
  - PS adjustment to guarantee volume delivery
  - EPAP to eliminate obstructive events
  - For hypercapnic syndromes
  - At least equivalent to bi-level PASP S/T; role unclear
  - Expensive
"Before I came here, I was confused about this subject. Having listened to your lecture, I am still confused -- but on a higher level."
– Enrico Fermi

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