Supporting the hypercapnic patient

Dr Rebecca D’Cruz

Respiratory Consultant

Lane Fox Respiratory Unit, St Thomas’ Hospital
## Disclosures

<table>
<thead>
<tr>
<th>Affiliation / Financial interest</th>
<th>Commercial company</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grants/research support:</strong></td>
<td>Philips, Fisher &amp; Paykel Healthcare, ResMed</td>
</tr>
<tr>
<td><strong>Honoraria or consultation fees:</strong></td>
<td>Fisher &amp; Paykel Healthcare, ResMed, Astra Zeneca</td>
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<tr>
<td><strong>Participation in a company sponsored bureau:</strong></td>
<td>ResMed</td>
</tr>
<tr>
<td><strong>Stock shareholder:</strong></td>
<td>Nil</td>
</tr>
<tr>
<td><strong>Spouse / partner:</strong></td>
<td>Nil</td>
</tr>
<tr>
<td><strong>Other support / potential conflict of interest:</strong></td>
<td>Nil</td>
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</tbody>
</table>
Hypercapnic respiratory failure

**RESPIRATORY MUSCLE CAPACITY**
- COPD
  - Hyperinflation $\rightarrow$ impaired diaphragm contractility
- Obesity-related
  - Reduced muscle strength
  - Reduced ERV
- Neuromuscular
  - Respiratory muscle weakness
  - Impaired chest excursion

**RESPIRATORY MUSCLE LOAD**
- **COPD**
  - Airways inflammation
  - Bronchospasm
  - Sputum
  - Expiratory flow limitation $\rightarrow$ PEEPi
- **Obesity-related**
  - Upper airway obstruction
  - Chest wall compliance
  - Early airway closure $\rightarrow$ PEEPi
- **Neuromuscular**
  - Upper airway obstruction
  - Sputum
  - Chest wall compliance

**NEURAL RESPIRATORY DRIVE**
- Increased ventilatory response
- Inadequate for load-capacity imbalance
- Perceived as breathlessness

D’Cruz J Thorac Dis 2020;12:202-216
Diagnosis

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-
\]

- **Chronic**: pH ↔ PaCO\(_2\) ↑ HCO\(_3^-\) ↑

- **Acute**: pH ↓ PaCO\(_2\) ↑ HCO\(_3^-\) ↔

- **Acute-on-chronic**: pH ↓ PaCO\(_2\) ↑ HCO\(_3^-\) ↑
Case study

- 72 year old
- **PC**: 3/7 breathlessness, cough, green sputum
- **PMH**:
  - Severe COPD (FEV₁ 34%)
  - Frequent exacerbator (≥2)
  - Ischaemic heart disease
- **DH**: LABA/LAMA, SABA PRN, aspirin, statin
- **SH**: Current smoker, lives alone
- Quiet breath sounds
- SpO₂ 100% on non-rebreath mask
- Mild pedal oedema
- BMI 17.2 kg/m²
Examination & Investigations

- Quiet breath sounds
- SpO$_2$ 100% on non-rebreath mask
- BMI 17.2 kg/m$^2$

**Diagnosis:** Acute-on-chronic hypercapnic respiratory failure

**Causes:** AECOPD +/- over oxygenation
Who presents in AHRF?

Diagnosis

- COPD: 67%
- NMD/CWD: 3%
- Cardiac pulmonary oedema: 7%
- ORRF: 8%
- Other: 13%
- No data: 2%

Previous acute NIV

- Yes
- No
- No data

Pre-NIV ABG

- pH: 7.26
- PaCO2 (kPa): 9.3
- PaO2 (kPa): 8.1

BTS National Audit NIV 2019
### BTS acute NIV recommendations

#### Measures within BTS Quality Standard²

<table>
<thead>
<tr>
<th>Measure</th>
<th>2019 (%) achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients should have a documented escalation plan before starting treatment with acute NIV.</td>
<td>83</td>
</tr>
<tr>
<td>Patients who meet evidence-based criteria for acute NIV should start NIV within 60 min of the blood gas result associated with the clinical decision to provide NIV</td>
<td>51</td>
</tr>
<tr>
<td>Clinical progress should be reviewed by a healthcare professional with appropriate training and competence within 4 hours of starting NIV</td>
<td>49</td>
</tr>
<tr>
<td>All patients treated with acute NIV should have blood gas analysis performed within 2 hours of starting acute NIV.</td>
<td>62</td>
</tr>
<tr>
<td>Failure of these blood gas measurements to improve should trigger specialist healthcare professional review within 30 min.</td>
<td>43</td>
</tr>
</tbody>
</table>

#### In-hospital mortality

- **0%**
- **5%**
- **10%**
- **15%**
- **20%**
- **25%**
- **30%**
- **35%**
- **40%**

Reasons for delay in NIV treatment:
- awaiting patient transfer
- not recognising the need for NIV
- delay in blood gas measurements
- lack of beds
- lack of equipment
Initial management of AHRF

1. **Controlled oxygen therapy**
   - $\text{SpO}_2$ 88-92%

2. **Optimised medical therapy**
   - Nebulised bronchodilation
     - 2.5 mg salbutamol
     - 500 mcg ipratropium bromide
   - Prednisolone 30 mg

3. **Treat reversible causes**
   - Antimicrobials
   - Secretion management
   - Diuresis

Davidson et al. Thorax 2016;71:ii1-ii35
Persistent acidaemia

Measurement report
Serial number: 4500
Instrument ID: QF4500
Operator ID: DR.ABG
CCU Local District Hospital

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Normal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.30</td>
<td>[7.350 - 7.450]</td>
</tr>
<tr>
<td>pCO₂</td>
<td>8.9</td>
<td>[4.67 - 6.00]</td>
</tr>
<tr>
<td>pO₂</td>
<td>7.8</td>
<td>[10.67 - 13.33]</td>
</tr>
<tr>
<td>cHCO₃⁻</td>
<td>28</td>
<td>[22 - 26]</td>
</tr>
<tr>
<td>BE</td>
<td>3</td>
<td>[-2.0 - +2.0]</td>
</tr>
<tr>
<td>Na⁺</td>
<td>145 mmol/L</td>
<td>[135.0 - 148.0]</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>104 mmol/L</td>
<td>[98.0 - 107.0]</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>2.20 mmol/L</td>
<td>[1.120 - 1.320]</td>
</tr>
<tr>
<td>SO₂</td>
<td>88.0</td>
<td>[75.0 - 99.0]</td>
</tr>
<tr>
<td>Glu</td>
<td>4.0 mmol/L</td>
<td>[3.3 - 6.1]</td>
</tr>
<tr>
<td>Lac</td>
<td>1.0 mmol/L</td>
<td>[0.4 - 2.2]</td>
</tr>
</tbody>
</table>

Recommendations
25. NIV should be started when pH<7.35 and pCO₂>6.5 kPa persist or develop despite optimal medical therapy (Grade A).

Good practice points
- ABG measurement is needed prior to and following starting NIV.

Davidson et al. Thorax 2016;71:ii1-ii35
Serial arterial blood gas sampling

C2: Local anaesthesia should be used for all ABG specimens except in emergencies (grade A).

91% ABGs not performed with local anaesthetic

Table 4 Pain score and number of venesection attempts

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain score, median (IQR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial</td>
<td>4 (2-5)</td>
<td>187</td>
</tr>
<tr>
<td>Venous</td>
<td>1 (0-2)</td>
<td>205</td>
</tr>
<tr>
<td>Number of arterial attempts, N (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>162</td>
<td>(69)</td>
</tr>
<tr>
<td>2</td>
<td>55</td>
<td>(24)</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>(4)</td>
</tr>
<tr>
<td>4+</td>
<td>7</td>
<td>(3)</td>
</tr>
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</table>

Arterial vs venous pH

Arterial vs venous CO₂

O’Driscoll et al. Thorax 2017;72:i1-i90
Bi-level positive pressure ventilation
NIV vs CPAP: terminology important

Non-Invasive Ventilation
Patient initiated, actively supports ventilation

Role: hypercapnic respiratory failure

Continuous Positive Airway Pressure
Fixed pressure throughout respiratory cycle

Roles: upper airway obstruction, hypoxaemic respiratory failure
NIV in AECOPD

Early use of non-invasive ventilation for acute exacerbations of chronic obstructive pulmonary disease on general respiratory wards: a multicentre randomised controlled trial

236 randomised

118 allocated standard therapy
32 met criteria for intubation
86 treated successfully
24 died 94 survived

118 allocated non-invasive ventilation
18 met criteria for intubation
100 treated successfully
12 died 106 survived

Table 2: Primary outcome and in-hospital mortality

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>NIV</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intention-to-treat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failed (need for IMV)</td>
<td>32/118 (27%)</td>
<td>18/118 (15%)</td>
<td>0.02</td>
</tr>
<tr>
<td>Died</td>
<td>24/118 (20%)</td>
<td>12/118 (10%)</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Subgroup analysis

pH<7.30
Failed           | 16/38 (42%)       | 13/36 (36%)       | 0.64  |
Died             | 13/38 (34%)       | 8/36 (22%)        | 0.31  |

pH>=7.30
Failed           | 16/80 (20%)       | 5/82 (6%)         | 0.01  |
Died             | 11/80 (14%)       | 4/82 (5%)         | 0.06  |

Figure 1: Trial profile

NIV vs usual care: mortality

- Improves pH, PaO\textsubscript{2}, PaCO\textsubscript{2}
- Offsets PEEPi which reduces work of breathing
- Reduced mortality
- Reduced risk of IMV
- Reduced hospital LOS
Delivering non-invasive ventilation

**Indications for NIV**
- **COPD**
  - pH < 7.35
  - pCO2 > 4.5
  - RR > 23
  - If persisting after bronchodilators and controlled oxygen therapy

- **Neuromuscular disease**
  - Respiratory illness with RR > 20 if usual VC < 1 L even if pCO2 > 6.5
  - pH < 7.35 and pCO2 > 6.5

- **Obesity**
  - pH < 7.35, pCO2 > 6.5, RR > 23
  - Or Daytime pCO2 > 6.0 and somnolent

**Contraindications for NIV**
- **Absolute**
  - Severe facial deformity
  - Facial burns
  - Fixed upper airway obstruction

- **Relative**
  - pH < 7.15 (pH < 7.25 and additional adverse feature)
  - GCS < 8
  - Confusion/agitation
  - Cognitive impairment (warrants enhanced observation)

**Indications for referral to ICU**
- AHRF with impending respiratory arrest
- NIV failing to augment chest wall movement or reduce pCO2
- Inability to maintain S ao2 > 85-88% on NIV
- Need for IV sedation or adverse features indicating need for closer monitoring and/or possible difficult intubation as in OHS, DMO

**NIV Not indicated**
- Asthma/Pneumonia
  - Refer to ICU for consideration IMV if increasing respiratory rate/distress
  - Or pH < 7.35 and pCO2 > 6.5

**NIV Setup**
- **Mask**
  - Full face mask (or own if home user of NIV)

- **Initial Pressure settings**
  - EPAP: 3 (or higher if OSA known/expected)

- **IPAP in COPD/OHS/KS**
  - 15 (20 if pH < 7.25)
  - Up titrate IPAP over 10-30 mins to IPAP 20–30 to achieve adequate augmentation of chest/lung movement and slow RR

- IPAP should not exceed 30 or EPAP 8* without expert review

- **IPAP in NM**
  - 10 (or 5 above usual setting)

- **Backup rate**
  - Backup Rate of 16:2. Set appropriate inspiratory time

- **I:E ratio**
  - COPD: 1.2 to 1.3
  - OHS, NM & CWD: 1:1

- **Inspiratory time**
  - 0.8-1.2s COPD
  - 1.2-1.5s OHS, NM & CWD

- Use NIV for as much time as possible in 1st 24 hours.
- Taper depending on tolerance & ABGs over next 48-72 hours

**NIV Monitoring**
- **Oxygenation**
  - Aim: 88-92% in all patients
  - Note: Home style ventilators CANNOT provide > 50% inspired oxygen.
  - If high oxygen need or rapid desaturation on disconnection from NIV consider IMV.

- **Red flags**
  - pH < 7.25 on optimal NIV
  - RR persisting > 25
  - New onset confusion or patient distress

- **Actions**
  - Check synchronisation, mask fit, exhalation port: give physiotherapy/bronchodilators, consider amiolytic

**CONSIDER IMV**

* Possible need for EPAP > 8
  - Severe OHS (BMI > 35), lung recruitment eg hyponia in severe kyphoscoliosis, oppose intracranialPEEP in severe airflow obstruction or to maintain adequate PS when high EPAP required

Davidson et al. Thorax 2016;71:ii1-ii35
Practicalities of acute NIV delivery
Patient selection

COPD & obesity-related respiratory failure

- Optimal medical therapy
- Controlled oxygen therapy 88-92%
- Start NIV if pH<7.35 & PaCO₂ >6.5 kPa persistent/develops

Neuromuscular & chest wall disease

- Trial NIV in acutely unwell with hypercapnia
- Don’t wait for acidosis to develop

Davidson et al. Thorax 2016;71:ii1-ii35
Staff & monitoring to facilitate NIV adherence & early detection of NIV failure

**Figure 2.5 Availability of monitoring in different clinical areas**

- **NIV started**
- **NIV continued**
The success of NPPV depends largely on the patient’s acceptance and compliance, and winning patient acceptance and compliance depends partly on the way the NPPV is applied by the clinician. Thus, the clinical team’s training and experience is important.

It is recommended that NIV services have “trained and experienced staff available to support the service on a 24/7 basis”. Patients who are treated with acute NIV are seriously ill with complex problems and require enhanced nursing care. A staffing ratio of one nurse to two NIV patients for at least the first 24 hours of treatment is recommended.
Equipment: device

Acute

Home
Equipment: device

Acute

Home
Equipment: interface
Equipment: Circuit

Ventriculator

Single limb

Leak

Mask

Ventriculator

Active exhalation valve

Mask

Ventriculator

Double limb

Mask
Pressure targeted ventilation

- IPAP and EPAP
- Back up rate (BUR)
- Inspiratory time (Ti)
- Entrained oxygen
- Repeat ABG 1h after starting / change in settings & every 4h

*Possible need for EPAP > 8
Severe OHS (BMI > 35), lung recruitment e.g. hypnosis in severe kyphoscoliosis, oppose intrinsic PEEP in severe airway obstruction or to maintain adequate PS when high EPAP required

Davidson et al. Thorax 2016;71:ii1-ii35
Review 1-hour post-setup

- IPAP 20 EPAP 6 BUR 18 Ti 0.8
- Good chest wall movement & AE
- Rises and falls with ventilator breaths: “synchronising”
- ABG: pH 7.34 PaCO₂ 7.5 PaO₂ 7.8 HCO₃⁻ 28
Review 1-hour post-setup

- IPAP 20 EPAP 6 BUR 18 Ti 0.8
- Good chest wall movement & AE
- Rises and falls with ventilator breaths: “synchronising”
- ABG: pH 7.34 PaCO$_2$ 7.5 PaO$_2$ 7.8 HCO$_3^-$ 28

#Bleep: “Not tolerating NIV”
Troubleshooting Top Tips

- Inadequate PS
- Leak
- Asynchrony
- Pressure sore

[Diagram showing pressure changes over time with labels for IPAP and EPAP, and a CPAP mask with waveforms indicating inspiratory and expiratory pressures.]
**Troubleshooting Top Tips**

**Inadequate PS**
- **Mask**
  - Full face mask (or non-rebreather of NIV)
- **Initial Pressure settings**
  - EPAP: 3 (or higher if OSA known/expected)
  - IPAP: In COPD/CHF/NS 15 (20 if pH < 7.35)
- **Backup rate**
  - Backup Rate of 16-20. Set appropriate inspiratory time
  - I/E ratio
    - COPD 1:2 vs 1:3
    - CHF, NM & CCH: 1:1
  - Inspiratory time
    - 0.8-1.2 x COPD
    - 1.1-1.5 x CHF, NM & CCH
- **Pressure sore**
  - Use IPV for as much time as possible in 1° of sleep
  - Taper depending on tolerance & add is 60 etc. over next 4-72 hours
  - SEEK AND TREAT REVERSIBLE CAUSES OF AHRF

**Leak**
- **Asynchrony**
- **Pressure sore**

*Possible need for EPAP > 8*
- Severe CHF (BMI > 35), lung recruitment or hypoaxia in severe kyphoscoliosis, oppose/minimal PEEP in severe airflow obstruction or to maintain adequate PS when high EPAP required
Troubleshooting Top Tips

**Inadequate PS**

- Look, listen, feel
- Interface size
- Facial anatomy
- Strap tightness

**Leak**

- 

**Asynchrony**

- 

**Pressure sore**

- 

Brill et al. *Breathe* 2014 10: 230–242
Troubleshooting Top Tips

Inadequate PS

Leak

Asynchrony

Pressure sore
Troubleshooting Top Tips

- **Inadequate PS**
- **Leak**
- **Asynchrony**
- **Pressure sore**

---

- Reduce mask leak
- Adjust trigger sensitivity

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Prematurely cycled breath

Auto-triggered breath

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Ramsay et al. Thorax 2015;70:946-952
Troubleshooting Top Tips

- Inadequate PS
- Leak
- Asynchrony
- Pressure sore
Troubleshooting Top Tips

- Inadequate PS
- Leak
- Asynchrony
- Pressure sore
Sedation

Not recommended except by experienced senior clinicians in critical care environment

Davidson et al. Thorax 2016;71:ii1-ii35
Weaning from NIV

• Priority = resolution of acidaemia
• Maximise use in first 24 hours
• Increase day-time self-ventilation periods over 2-3 days
• Discontinue overnight
• Monitor pH and TcCO$_2$ / PaCO$_2$
• Document pre-discharge ABG
Follow-up: high-risk cohort

Mortality

<table>
<thead>
<tr>
<th>Treated with NIV</th>
<th>Mortality ≤30 days</th>
<th>Mortality ≤90 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>20.2%</td>
<td>27.7%</td>
</tr>
<tr>
<td>No – not clinically indicated</td>
<td>4.3%</td>
<td>9.1%</td>
</tr>
<tr>
<td>No – patient declined</td>
<td>38.0%</td>
<td>48.0%</td>
</tr>
<tr>
<td>No – NIV not available</td>
<td>16.0%</td>
<td>16.0%</td>
</tr>
<tr>
<td>No – reason unclear</td>
<td>11.5%</td>
<td>18.2%</td>
</tr>
<tr>
<td>Patient intubated directly</td>
<td>24.1%</td>
<td>27.6%</td>
</tr>
<tr>
<td>Not known</td>
<td>9.4%</td>
<td>15.0%</td>
</tr>
<tr>
<td>Total</td>
<td>6.7%</td>
<td>12.0%</td>
</tr>
</tbody>
</table>

- While COPD was overwhelmingly the main cause of death at 30/90 days (71%/67% of deaths), cardiovascular disease was the next most common cause (9%/11% of deaths).

Readmissions

- **One-quarter (24%)** of the patients were **readmitted at least once** for any reason within 30 days of discharge.
- **Nearly half (43%)** of the patients were **readmitted at least once** for any reason within 90 days of discharge.
- **Twelve percent** of the patients were readmitted at least once **owing to COPD** within 30 days of discharge.
- **Twenty-three percent** of the patients were readmitted at least once **owing to COPD** within 90 days of discharge.

- Outpatient review 2-4 weeks & 3 months post-discharge
- Inhaler technique
- Smoking cessation
- Early pulmonary rehabilitation
- Optimise comorbidities
- ABG / CBG

Stone et al. RCP COPD Audit Programme; 2017
GOLD Report 2023
Non-invasive positive pressure ventilation for the treatment of severe stable chronic obstructive pulmonary disease: a prospective, multicentre, randomised, controlled clinical trial

Figure 2: Kaplan-Meier estimate of cumulative all-cause mortality during the first year after randomisation (primary outcome)
The p value results from a log-rank test of the between-group difference.

Murphy et al. JAMA 2017;317(21):2177-2186
Home mechanical ventilation: Obesity

Stable:
- CPAP and NIV comparable
- CPAP more cost effective, accessible outside specialist units

Post-AHRF:
- Specialist review

Masa et al. AJRCCM 2015 192;1:86-95
Home mechanical ventilation: NMD

- Clinical trials challenging
- Chronic respiratory failure inevitable
- Refer all to specialist ventilation service

Effects of non-invasive ventilation on survival and quality of life in patients with amyotrophic lateral sclerosis: a randomised controlled trial

Figure 2: Survival from randomisation
A: all patients; B: patients with normal or moderately impaired bulbar function; C: patients with severe bulbar impairment.

Bourke et al. Lancet Neurol 2006; 5: 140-47
Patient & Clinician guide to HMV

HMVip

Improving lives
Making a difference

Home Mechanical Ventilation in Partnership

Clinician Section

Welcome to the clinicians section:

- HMV Pathway
- Research & Evidence

Back to homepage

- About HMVip
- Meet the HMVip Team
- What is HMV?
- Patient stories
- Carers – what to expect
- Top tips for carers

HMViP.co.uk
Lane Fox Clinical Respiratory Physiology Research Centre

Prof Nicholas Hart, Dr Patrick Murphy, Prof Joerg Steier, Prof Louise Rose, Dr Michael Cheng, Dr Rebecca D’Cruz, Dr Georgios Kaltsakas, Dr Phil Marino, Dr Michelle Ramsay, Dr Shelley Srivastava, Dr Eui-Sik Suh, Ms Gill Arbane

Kings College London Centre for Human & Applied Physiological Science

Prof Steve Harridge, Dr Gerrard Rafferty, Dr Caroline Jolley, Prof John Moxham

guysandstthomas.nhs.uk/referral-guide/lane-fox-respiratory-service