The Safe Use and Prescription of Medical Oxygen

Luke Howard
Consultant Respiratory Physician
Imperial College Healthcare NHS Trust
&
Co-Chair, British Thoracic Society
Emergency Oxygen Guideline Group
Topics to be covered

• Oxygen physiology
  – How is oxygen delivered and utilised
  – How is carbon dioxide cleared
  – How can oxygen delivery be optimised

• Dangers of oxygen

• BTS Guidelines
  – Monitoring
  – Delivery
"The Oxygen Cascade"
“The Oxygen Cascade”

- $SO_2$ = oxygen saturation (%)
- $PO_2$ = oxygen partial pressure (kPa)
- $PiO_2$ = inspired $P_O_2$
- $PeO_2$ = mixed expired $P_O_2$
- $PeCO_2$ = mixed expired $P_CO_2$
- $PAO_2$ = alveolar $P_O_2$
- $PaO_2$ = arterial $P_O_2$
- $SaO_2$ = arterial $SO_2$
- $SvO_2$ = mixed venous $SO_2$
- $Qt$ = cardiac output
- $Hb$ = haemoglobin
- $CaO_2$ = arterial $O_2$ content
- $CvO_2$ = mixed venous $O_2$ content
The Oxygen Cascade
Gas exchange

What can change?

Oxygen utilisation

- Oxygen carrying & buffering capacity
- Flow

Workshop 2012 – Oxygen Safety
Oxygen Delivery

\[ \text{DO}_2 = Q \times \left\{ \left[ \frac{\text{SaO}_2}{100} \times \text{Hb} \times 1.3 \right] + \left[ \text{PaO}_2 \times 0.003 \times 10 \right] \right\} \]

- Stagnant Hypoxia
- Hypoxaemic Hypoxia
- Anaemic Hypoxia
- Cytopathic Hypoxia
Resting oxygen consumption remains constant until \( \text{PaO}_2 \) falls below 23 mmHg (~3kPa)\(^{\text{Anesthesiology 2001;95:A1123}}\).
Increased metabolic demand

Impaired cardiac reserve
Anaemia
Tissue oedema
Mitochondrial dysfunction
“The Oxygen Cascade”
Dangers of Oxygen Therapy
Hypoxic Pulmonary Vasoconstriction

Reduces the impact of low VQ units
Impaired respiratory mechanics, *eg*, COPD

Alveolar hypoventilation → Hypercapnia

Hypercapnia → Acidosis Coma
Ventilation-perfusion matching and oxygen administration

- Diverts blood flow away from diseased lung
- Uses low oxygen levels in diseased lung to “signal” to divert blood away
- Administering oxygen masks this signal
- Diseased lung is less efficient at clearing carbon dioxide
- When respiratory mechanics are impaired, eg COPD, this inefficiency cannot be compensated for by increasing overall ventilation and carbon dioxide retention occurs
Plant *et al.*, *Thorax* 2000

- 47% of 982 patients with exacerbation of COPD were hypercapnic on arrival in hospital
- 20% had Respiratory Acidosis (pH < 7.35)
- 5% had pH < 7.25 (and were likely to need ICU care)
Risk of Oxygenation in COPD

Plant et al., Thorax 2000, 55: 550-4
Randomised Controlled Trial of Titrated vs High-Flow Oxygen

- Pre-hospital setting
- Tasmania
- 405 patients with presumed exacerbation of COPD
- Titrated arm:
  - Nasal prongs to achieve SpO2 88-92%
- High-Flow arm:
  - 8-10 l/min non-rebreathing mask

Austin et al., BMJ 2010
### Results

**Table 3: Intention to treat analysis. Values are numbers (percentages) unless stated otherwise**

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Control (high flow oxygen)</th>
<th>Active (titrated oxygen)</th>
<th>Treatment effect</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients</td>
<td>21/226 (9)</td>
<td>7/179 (4)</td>
<td>0.42 (0.20 to 0.89)*</td>
<td>0.02</td>
</tr>
<tr>
<td>Confirmed COPD</td>
<td>11/117 (9)</td>
<td>2/97 (2)</td>
<td>0.22 (0.05 to 0.91)*</td>
<td>0.04</td>
</tr>
</tbody>
</table>

**Incidence of ventilation**

<table>
<thead>
<tr>
<th></th>
<th>Non-Invasive ventilation</th>
<th>Invasive ventilation</th>
<th>Treatment effect</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients</td>
<td>19/213 (9)</td>
<td>13/166 (8)</td>
<td>0.88 (0.45 to 1.72)*</td>
<td>0.70</td>
</tr>
<tr>
<td>Confirmed COPD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Invasive ventilation</td>
<td>7</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Invasive ventilation</td>
<td>12</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Length of hospital stay (mean (SD) days)**

<table>
<thead>
<tr>
<th></th>
<th>All patients</th>
<th>Confirmed COPD</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.9 (5.6) (n=226)</td>
<td>5.5 (5.9) (n=179)</td>
<td>-0.45 (0.57)†</td>
<td>0.19</td>
</tr>
</tbody>
</table>

**Arterial blood gases (30 min) (confirmed COPD patients)**

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD) pH</th>
<th>Mean (SD) carbon dioxide (mm Hg)</th>
<th>Mean (SD) bicarbonate (mmol/l)</th>
<th>Mean (SD) oxygen (mm Hg) (arterial only)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.29 (0.14) (n=19)</td>
<td>7.35 (0.16) (n=19)</td>
<td>32.3 (10.1) (n=19)</td>
<td>98.4 (46.1) (n=14)</td>
</tr>
</tbody>
</table>

COPD = chronic obstructive pulmonary disease.
*Relative risk (95% CI).
†Mean difference (SE).
Danger 2: Alveolar Gas Equation and “Rebound Hypoxia”

- \[ \text{PAO}_2 = \text{PlO}_2 - \text{PaCO}_2 / \text{RER} \]

- \[ \text{PAO}_2 = (100 - \text{PlN}_2) - \text{PaCO}_2 / \text{RER} \]

- **Case study:**
  - COPD exacerbation at home - on air
  - Seen by ambulance crew – given high flow oxygen
  - Brought to ER – oxygen removed
Rebound Hypoxia

FiN₂ 0.79 - Alveolar gases (kPa)

- Nitrogen
- Oxygen
- Carbon dioxide

PaO₂ 6.5 kPa
PaCO₂ 7.5 kPa
Rebound Hypoxia

FİN₂ 0.15 - Alveolar gases (kPa)

- PaO₂ 32 kPa
- PaCO₂ 10 kPa

- Nitrogen
- Oxygen
- Carbon dioxide
Rebound Hypoxia

FiN₂ 0.79 - Alveolar gases (kPa)

- Nitrogen: 8.5 kPa
- Oxygen: 10 kPa
- Carbon dioxide: 3.5 kPa (PaO₂)
- Carbon dioxide: 10 kPa (PaCO₂)

Workshop 2012 – Oxygen Safety
Oxygen Delivery

\[ DO_2 = Q \times \left\{ \frac{SaO_2}{100} \times Hb \times 1.3 \right\} \]

- Stagnant Hypoxia
- Hypoxaemic Hypoxia
- Anaemic Hypoxia
- Cytopathic Hypoxia
\[ \text{DO}_2 = Q \left( \frac{\text{SaO}_2}{100} \times \text{Hb} \times 1.3 \right) + \left( \text{PaO}_2 \times 0.003 \times 10 \right) \]

High flow oxygen:
- Decreased cardiac output
- Decreased coronary flow (~20%)
- Increased systemic vascular resistance

Circulatory effects of decreasing oxygen??
Capillary
Dangers 3,4,5....: High-Flow Oxygen?

- Coronary vasoconstriction (↓flow by <23%)
- Increased Systemic Vascular Resistance
- Reduced Cardiac Index
- Possible reperfusion injury post MI and mild-moderate stroke
- Hypoxic lung injury

Kaneda T et al. Jpn Circ J 2001; 213-8
Thomaon aj ET AL. BMJ 2002; 1406-7
Ronning OM et al. Stroke 1999; 30
McNulty, PH et al. JAP 2007; 102; 2040-45.
Retrospective analysis of ICU mortality

- 36,307 patients in 50 Dutch ICUs

De Jonge et al., Crit Care 2008

Figure 2

Standardised mortality ratio (SMR) by partial oxygen pressure (PaO₂) (kPa). PaO₂ values were taken from blood gas analysis with lowest PaO₂/fraction of oxygen in inspired air (FiO₂) ratio in the first 24 h after intensive care unit (ICU) admission. PaO₂ values are categorised as quintiles. Error bars represent 95% confidence intervals.
J-shaped Relationship in $\text{PaO}_2/\text{FiO}_2$ vs Standardised Mortality

**Figure 3**

Standardised mortality ratio (SMR) by fraction of oxygen in inspired air ($\text{FiO}_2$). $\text{FiO}_2$ values were taken from blood gas analysis with lowest partial oxygen pressure ($\text{PaO}_2$)/$\text{FiO}_2$ ratio in the first 24 h after intensive care unit (ICU) admission. $\text{FiO}_2$ values are categorised as quintiles. Error bars represent 95% confidence intervals.

**Figure 4**

Standardised mortality ratio (SMR) by lowest partial oxygen pressure ($\text{PaO}_2$)/fraction of oxygen in inspired air ($\text{FiO}_2$) ratio (kPa) in the first 24 h after intensive care unit (ICU) admission. $\text{PaO}_2/\text{FiO}_2$ ratio values are categorised as quintiles. Error bars represent 95% confidence intervals.
Danger 6: High-Flow Oxygen Delays Diagnosis of Deterioration

Time

SpO₂

FiO₂ 0.3

FiO₂ 1.0

A-a gradient

Trigger
BTS Guidelines
How to Approach the Patient on ‘100% Oxygen’ in hypercapnic failure

• Patient conscious:
  – Change to 35% Venturi Device

• Patient drowsy:
  – Leave the patient on high-flow oxygen then,
  – Start NIV with Oxygen / call ICU
Step up and down through oxygen delivery devices

To avoid rebound hypoxia

In case of higher respiratory rates/flows

Venturi 2
Blue
Venturi
White
Venturi 1
Yellow

Nasal cannulae 1 L/min
Nasal cannulae 2 L/min
Nasal cannulae 4 L/min

or simple face mask at 5–6 L/min
or simple face mask 7–10 L/min

Reservoir mask at 15 L/min oxygen flow

If reservoir mask required, seek senior medical input immediately
Step up and down through oxygen delivery devices

Venturi 24% 2–4 l/min
Blue

Venturi 28% 4–6 l/min
White

Venturi 80% 12–15 l/min
Green

Nasal cannulae 1 l/min

Nasal cannulae 2 l/min

Nasal cannulae 4 l/min

or simple face mask at 5–6 l/min

or simple face mask 7–10 l/min

Reservoir mask at 15 l/min oxygen flow

If reservoir mask required, seek senior medical input immediately

Pre-hospital
Step up and down through oxygen delivery devices

- **Blue**: Venturi 24% 2–4 l/min
- **White**: Venturi 28%
- **Yellow**: Venturi 35% 8–10 l/min
- **Red**: Venturi 40% 10–12 l/min
- **Green**: Venturi 60% 12–15 l/min

Once stable:

- Nasal cannulae 1 l/min
- Nasal cannulae 2 l/min
- Nasal cannulae 4 l/min

- or simple face mask at 5–6 l/min
- or simple face mask 7–10 l/min

Reservoir mask at 15 l/min oxygen flow

If reservoir mask required, seek senior medical input immediately
Oxygen prescription

Model for oxygen section in hospital prescription charts

<table>
<thead>
<tr>
<th>Drug OXYGEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circle target oxygen saturation</td>
</tr>
<tr>
<td>□ 88–92% □ 94–98% □ Other ______</td>
</tr>
<tr>
<td>Starting device/flow rate _______</td>
</tr>
<tr>
<td>PRN/continuous (refer to O₂ guideline)</td>
</tr>
<tr>
<td>□ Tick here if saturation not indicated *</td>
</tr>
<tr>
<td>Date and signature</td>
</tr>
<tr>
<td>Print name</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Date administered</th>
</tr>
</thead>
<tbody>
<tr>
<td>06</td>
</tr>
<tr>
<td>09</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>18</td>
</tr>
<tr>
<td>22</td>
</tr>
</tbody>
</table>
Respiratory rate, oxygen saturation and oxygen therapy

Clinical review required if saturation is outside target range. Observation frequency_____

<table>
<thead>
<tr>
<th>Continuous oxygen / PRN / Not on oxygen therapy</th>
<th>Target range: 88-92%</th>
<th>94-98%</th>
<th>Other____</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Example</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>08.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory rate</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen saturation %</td>
<td>94%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen device or air</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen flow rate l/min</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your initials*</td>
<td>LW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen saturation %</td>
<td></td>
<td></td>
<td></td>
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<td>Oxygen device or air</td>
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</tbody>
</table>

*All changes to oxygen delivery systems must be initial[led by a registered nurse or equivalent.

If the patient is medically stable and in the target range on two consecutive rounds, report to a registered nurse to consider weaning off oxygen.

*Codes for recording oxygen delivery on observation chart

| A | Air (not requiring oxygen, or weaning or on "PRN" oxygen) | H28 | Humidified oxygen at 28% (also H35, H40, H60 for humidified oxygen at 35%, 40%, 60%) |
| N | Nasal cannulae                                           | RM  | Reservoir mask                                        |
| SM| Simple mask                                              | TM  | Tracheostomy mask                                      |
| V24| Venturi 24%                                               | CP  | Patient on CPAP system                                 |
| V40| Venturi 40%                                               | NIV | Patient on NIV system                                  |
| V28| Ventri 28%                                                | OTH | Other device:________________________________________ |
| V35| Venturi 35%                                               |     | (specify which)                                        |

Figure 18 Chart 4: Working example of respiratory section of observation chart for hospital use.