Reducing the carbon footprint of anaesthetic gasses

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Overview

• Review of anaesthesia
• Atmospheric science
• Review of the agents used for inhalational anaesthesia
• Tools that might help reduce the CO$_2$e
• Administrative components
Overview of anaesthesia

Anaesthesia

- Local anaesthesia
  - Local administration

- Regional anaesthesia

- General anaesthesia
  - Total intravenous anaesthesia
    - TIVA
  - Inhalational anaesthesia
Practical components of anaesthesia

Sedation analgesia and relaxation
Practical components of anaesthesia

Maintenance of homeostasis
Vascular access
Monitoring
Cardiovascular and respiratory control
Temperature control
Fate of all of these components

• **Disposables**
  – Combustion

• **Intravenous drugs**
  – Metabolised
  – Unused residue combusted

• **Packaging**
  – Recycled

• **Inhalational agents**
  – Exhaled into the atmosphere unchanged

Combustion of 1kg PVC produces 3kg CO₂

Combustion of 1kg paper 2.1-2.6 kg CO₂
Inhalational anaesthetic agents

Sevoflurane
GWP 130
Bottle (250ml) 44kg CO$_2$e

Isoflurane
GWP 510
Bottle (250 ml) 190 kg CO$_2$e

Desflurane
GWP 2540
Bottle (240 ml) 886 kg CO$_2$e

Nitrous oxide
GWP 310
Cylinder (3.4 kg) 1054 kg CO$_2$e
Water vapour

CO₂

Solar emission

Transmission to Earth’s surface

Visible 0.3-0.7μm

Wavelengths of incoming solar and outgoing thermal radiation

0.1μm 1.0μm 10 μm 100 μm

Solar emission

Transmission to Earth’s surface

Visible 0.3-0.7μm

Spectral intensity

Radiative Forcing

+2.83 Wm⁻² in 2016

Atmospheric window

Sevo.
Iso.
Des.
HFC
CFC
HCFC

Water vapour

IR absorption and re-emission to Earth’s surface

CO₂

CH₄

N₂O

N₂

HFC
CFC
HCFC

65.4%
18%
6.4%
10.2%

Royal College of Anaesthetists
Atmospheric concentration of inhalational anaesthetic agents

Vollmer et al 2015
Atmospheric concentrations of major GHGs

Carbon Dioxide (CO₂)

Nitrous Oxide (N₂O)

Methane (CH₄)

CFC-12
CFC-11
HCFC-22
HFC-134a
### Inhalational anaesthetic agents

<table>
<thead>
<tr>
<th></th>
<th>IR absorption range (µm)</th>
<th>Tropospheric lifetime (yr)</th>
<th>GWP (_{100})</th>
<th>CO(_2)e Kg (container)</th>
<th>MAC(_{40})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sevoflurane</td>
<td>7-10 µm</td>
<td>1.1</td>
<td>130</td>
<td>44 (250ml)</td>
<td>1.8</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>7.5-9.5µm</td>
<td>3.2</td>
<td>510</td>
<td>190 (250ml)</td>
<td>1.2</td>
</tr>
<tr>
<td>Desflurane</td>
<td>7.5-9.5 µm</td>
<td>14</td>
<td>2540</td>
<td>886 (240ml)</td>
<td>6.6</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>4.5, 7.6, 12.5 µm</td>
<td>110</td>
<td>310</td>
<td>1054 (size E)</td>
<td>104</td>
</tr>
</tbody>
</table>

Peculiar aspects of inhalational anaesthesia

Volatile substituted ethers
Liquids at room temperature
Vapourised and added to the anaesthetic breathing circuit in a concentration from 1-8%
Carrier gas mixture is oxygen/air or oxygen/N₂O 30%/70%
Depth of anaesthesia depends on the exhaled partial pressure (concentration)
Exhaled unchanged recycled via CO₂ absorber and/or scavenged into the atmosphere
Most of the CO₂e of procurement is in disposal of the agent
Fresh gas flow    Patient gas supply

ET Isoflurane
Scope for choice in anaesthesia

• General anaesthesia vs regional anaesthesia
• Carrier gas oxygen enriched air or $O_2/N_2O$
• Inhalational agents
  – The type
  – The fresh gas flow “low flow anaesthesia”
  – Added intravenous analgesics or sedatives
# Carbon Footprint update for NHS in England

## 2012

### Appendix 1 – Overview of major changes for the 2012 update

To maintain alignment with the latest methods and information available a number of changes have been included in the 2012 update:

<table>
<thead>
<tr>
<th>Update</th>
<th>2012 (MtCO₂e)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthcare services commissioned from outside the NHS are now included</td>
<td>2.3</td>
<td>9%</td>
</tr>
<tr>
<td>Carbon intensity factors for goods and services updated</td>
<td>0.9</td>
<td>4%</td>
</tr>
<tr>
<td>Meter Dose Inhalers (MDIs) now included</td>
<td>1.4</td>
<td>6%</td>
</tr>
<tr>
<td>Anaesthetic gases now included</td>
<td>0.6</td>
<td>2%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5.2</strong></td>
<td><strong>21%</strong></td>
</tr>
</tbody>
</table>
Carbon Footprint from Anaesthetic gas use

Conclusion

These results give total emissions for anaesthetic gases including Nitrous Oxide of an additional 2.5% (0.56 MtCO$_2$e) of NHS carbon footprint for England.

The majority of anaesthesia is in an acute setting. This is 5% of organisation footprint of acute organisations (0.56 MtCO$_2$e of 10.4 MtCO$_2$e). For acute organisations this is comparable with half the emissions from gas used for building energy use (1.17 MtCO$_2$e) and would add around 15% to 25% on the building energy use carbon footprint (2.47 MtCO$_2$e).

Measuring, monitoring and reporting carbon dioxide equivalent emissions, from inhaled anaesthetics, is crucial for reducing emissions.
32. Cylinders that have been returned for refilling should be prepared with care in order to minimise the risks of contamination, in line with the procedures defined in the Marketing Authorisation. These procedures, which should include evacuation and/or purging operations, should be validated.
Calculating the CO$_2$e of anaesthetics

Nitrous oxide cylinders
- Cylinder return data
- Cylinder volumes and temperature
  Cylinders expressed in terms of numbers of litres of uncompressed gas at 15°C
- Universal gas equation number of moles (PV=nRT)
- MW$_t$ N$_2$O 44; calculate the mass of nitrous oxide
- GWP = 310

Entonox®
- 50:50 nitrous oxide : oxygen

Inhalational agents
- Number of bottles x volume x density x GWP
# Anaesthetic agent CO₂e calculator

<table>
<thead>
<tr>
<th>Agent</th>
<th>Number of bottles issued from pharmacy</th>
<th>CO₂e (Tonnes)</th>
<th>Percent of total CO₂e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isoflurane</td>
<td>1000</td>
<td>191</td>
<td>6</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>1000</td>
<td>49</td>
<td>2</td>
</tr>
<tr>
<td>Desflurane</td>
<td>100</td>
<td>89</td>
<td>3</td>
</tr>
<tr>
<td>Anaesthetic N₂O</td>
<td>1000</td>
<td>1132</td>
<td>38</td>
</tr>
<tr>
<td>Portable Equanox N₂O</td>
<td>1000</td>
<td>352</td>
<td>12</td>
</tr>
<tr>
<td>Maternity Manifold Entonox N₂O</td>
<td>1000</td>
<td>1154</td>
<td>39</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anaesthetic Nitrous oxide</th>
<th>Number of returned cylinders</th>
<th>CO₂e (Tonnes)</th>
<th>Percent of total CO₂e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size E</td>
<td>30</td>
<td>190.74</td>
<td>19.74</td>
</tr>
<tr>
<td>Size F</td>
<td>30</td>
<td>1132.05</td>
<td>113.20</td>
</tr>
<tr>
<td>Size G</td>
<td>200</td>
<td>351.73</td>
<td>35.17</td>
</tr>
<tr>
<td>Size J</td>
<td>0</td>
<td>38.00</td>
<td>3.80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mobile Entonox Nitrous oxide</th>
<th>CO₂e (Tonnes)</th>
<th>Percent of total CO₂e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entonox EA</td>
<td>190.74</td>
<td>19.74</td>
</tr>
<tr>
<td>ENTINOX SIZE CD</td>
<td>1132.05</td>
<td>113.20</td>
</tr>
<tr>
<td>ENTINOX SIZE D</td>
<td>351.73</td>
<td>35.17</td>
</tr>
<tr>
<td>ENTINOX SIZE ED</td>
<td>38.00</td>
<td>3.80</td>
</tr>
<tr>
<td>ENTINOX SIZE EX</td>
<td>38.00</td>
<td>3.80</td>
</tr>
<tr>
<td>ENTINOX SIZE F</td>
<td>38.00</td>
<td>3.80</td>
</tr>
<tr>
<td>ENTINOX SIZE HX</td>
<td>38.00</td>
<td>3.80</td>
</tr>
<tr>
<td>Maternity Manifold N₂O</td>
<td>1153.98</td>
<td>115.40</td>
</tr>
</tbody>
</table>

- **Isotrurane**: 191 Tonnes (6%)
- **Sevoflurane**: 49 Tonnes (2%)
- **Desflurane**: 89 Tonnes (3%)
- **Anaesthetic N₂O**: 1132 Tonnes (38%)
- **Portable Equanox N₂O**: 352 Tonnes (12%)
- **Maternity Manifold Entonox N₂O**: 1154 Tonnes (39%)

UK medical gas supplier N₂O CO₂e

CO₂e Tonnes

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂e Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>300,000</td>
</tr>
<tr>
<td>2006</td>
<td>250,000</td>
</tr>
<tr>
<td>2007</td>
<td>200,000</td>
</tr>
<tr>
<td>2008</td>
<td>150,000</td>
</tr>
<tr>
<td>2009</td>
<td>100,000</td>
</tr>
<tr>
<td>2010</td>
<td>50,000</td>
</tr>
<tr>
<td>2011</td>
<td>0</td>
</tr>
<tr>
<td>2012</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>0</td>
</tr>
<tr>
<td>2014</td>
<td>0</td>
</tr>
<tr>
<td>2015</td>
<td>0</td>
</tr>
</tbody>
</table>
Accounting for the change of CO$_2$e

Less general anaesthesia and more regional and local anaesthesia
Move away from nitrous oxide/oxygen to oxygen enriched air
Low flow anaesthesia
  - Lower fresh gas flow
  - Greater intraoperative recycling of exhaled agents
  - Less wastage
Still a residual use of nitrous oxide
Annual data

- Way of plotting trends
- Historical data
- Not contemporaneous
- Unlikely that it will change behaviour
Real time CO$_2$e calculator

- Know the fresh gas flow (litres per min) and the vapouriser setting (%) 
- Assume that inhaled agent behaves as ideal gas 
- Know the temperature and the GWP of each agent 
- Calculate the mass of agent used from the volume 
- Mass used x GWP = CO$_2$e 
- Know the unit cost then calculate the cost per hour of the inhalational component of anaesthesia
CO2 kg/H equivalent
1.9
Cost per hour
£0.24
Equivalent car travel per hour
28 km
Isoflurane

CO2 kg/H equivalent
2.5
Cost per hour
£2.58
Equivalent car travel per hour
10 km
Sevoflurane

CO2 kg/H equivalent
5.0
Cost per hour
£4.46
Equivalent car travel per hour
328 km
Desflurane
Anaesthesia Impact Calculator

CO2 kg/H equivalent

<table>
<thead>
<tr>
<th>CO2 kg/H equivalent</th>
<th>Cost per hour</th>
<th>Equivalent car travel per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9</td>
<td>£0.31</td>
<td>132 km</td>
</tr>
<tr>
<td>2.5</td>
<td>£2.65</td>
<td>115 km</td>
</tr>
<tr>
<td>5.0</td>
<td>£4.53</td>
<td>433 km</td>
</tr>
</tbody>
</table>

Isoflurane
Sevoflurane
Desflurane
An hour’s CO$_2$e

Minute volume divider in 1985 to circle with absorber 2017

- 900 km travel in a car emitting 160 g/km
- 22 km travel in a car emitting 160 g/km
CO$_2$e of different forms of anaesthesia

IPCC GWP$_{100}$ for Clinical Pathways

- PNB+GIH (N=12)
- MIXED (N=3)
- GIH (N=10)
- TIVA (N=11)
- PNB+(TIVA/MAC) (N=10)
- MAC (N=12)

Kg CO$_2$e

PNB=Peripheral Nerve Block
GIH= Inhaled General Anaesthesia

Sherman, Tunceroglu, Parvatker, Sukumar, Dai, Eckelman
The bigger picture

• Travel for staff and patients
• Devices; single use or reusable?
• Use of energy and electricity
• Keeping patients warm in the operating room
• Recycling
A day’s anaesthesia related CO$_2$e (kg)

- More recycling less combustion
- AGSS off OOH
- AHU setback OOH
- Convective to conductive
- Consumables
- Isoflurane to sevoflurane
- From nitrous to oxygen/air
- Car to active transport
End tidal control

GE Aisys CS²

- Vapour use adjusted to achieve the desired $E_{\text{agent}}$
- Reduces vapour use
- Displays the cost
- Reduces cost; £51k pa
  - Benefit at 3-4 years
- Values for cost are very similar to those obtained from the free app
- App provides $\text{CO}_2\text{e}$
Administrative components

Protecting resources, promoting value: a doctor’s guide to cutting waste in clinical care

November 2014

PQIP
Perioperative Quality Improvement Programme

GIRFT
Getting It Right First Time

NHS Improvement

RCOA
Royal College of Anaesthetists

ACSA
Anaesthesia Clinical Services Accreditation

Guidelines for the Provision of Anaesthesia Services (GPAS)
Guidelines for the Provision of Anaesthesia Services

- Work with estates to minimise energy use
  - Including AGSS and OR ventilation and lighting
- Reduce resource use
  - Low flow anaesthesia
    - Avoid nitrous oxide within reason
    - Desflurane low flow as a matter of course
    - TIVA
  - Minimise drug and disposable wastage
- Recycling to avoid combustion of waste or landfill

GPAS 2016 Further steps
Choosing Wisely

1. **Day surgery** should be considered the default for most surgical procedures (except complex procedures)

2. Patients do **not need to come into hospital the day before surgery** if they have had the appropriate preoperative assessment and preparation

3. Most patients **do not need routine preoperative tests** before minor or intermediate surgery.

4. For many patients the chance of harm after an operation may be reduced if they **improve fitness, stop smoking, reduce alcohol intake** and in some cases **reduce weight** in the weeks or months before their surgery.

http://www.choosingwisely.co.uk/i-am-a-clinician/recommendations/#1476651640539-f279ec69-9e40
Summary

• The overall impact of anaesthesia is small on a global scale compared with other GHGs.
• The proportion of the CO$_2$e health care delivery attributable to anaesthesia is significant.
• There is scope for informed choices of practice.
• Reducing or eliminating the use of nitrous oxide is the largest single contribution one can make.
• The Impact Calculator can help with those choices.
• Need systems and processes in place.
Measurement tools

Annual carbon footprint of anaesthetic agents and nitrous oxide


Smart phone app to calculate the real-time CO$_2$e of inhalational anaesthesia

- iOS search Anesthetic Impact Calculator
  - Sleekwater Software / Kevin Scott
- Android search Anaesthetic Impact Calculator
  - Sleekwater Software / Kevin Scott