Reducing our carbon footprint:
The impact of efficient use of fresh gas flow with inhaled anesthetics
and other **GREEN** initiatives in the OR

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UC Carbon Neutrality Initiative (CNI) Fellow
Global warming is already having significant and costly effects:

- More Frequent and Intense Heat Waves
- Loss of Snowpack
- Longer and More Damaging Wildfire Seasons
- Reductions in the quality and quantity of agricultural products
- Health Impacts
  - increased air pollution
  - longer and more intense allergy season.
Healthcare sector represents 8% of US Carbon Footprint

The typical hospital uses as much energy in a year as 3,500 households. This energy consumption has substantial carbon dioxide and operational cost impacts, equal to the emissions of 5,950 cars on the road each year, at an average annual cost up to $4,000,000.

Electricity Rate $0.11/kwh (US National Average 2012)

History of anesthetic gases

1844
Dentist Horace Wells attends a demonstration of nitrous oxide inhalation at an exhibition by Gardner Quincy Colton.

Colton administers nitrous oxide to Wells while another dentist, Dr. John M. Riggs, extracted one of Well's teeth.

1845
Horace Wells attempts to demonstrate anaesthetic properties of nitrous oxide at Massachusetts General Hospital. The anaesthetic was incomplete and judged a failure.

"Gentlemen, this is no humbug"
Dr John Collins Warren, 17 October 1846
Inhaled anesthetics and nitrous oxide are potent environmentally deleterious greenhouse gases (GHGs)

Eger et. al. (2002). The Pharmacology of Inhaled anesthetics

Numerous reagents developed, 4 utilized currently in US

Table 2 Summary of radiative properties, atmospheric lifetimes, and GWP for isoflurane, desflurane, and sevoflurane. *Assuming an average global concentration of OH radicals of 1 × 10^10 molecules cm⁻³. ¹² Using an integration time horizon of 100 yr. ⁴ Using k(OH+CF₃CHIOCHF₂, 272 K) = 1.01 × 10⁻¹⁴, derived from Arrhenius expression in Tokuhashi and colleagues. ¹¹ Converted from HGWP values (relative to CFC-12), using GWP (CFC-12) = 10 890. ⁶ Using k(OH+CF₃CHFOCHF₂, 272 K) = 3.55 × 10⁻¹⁵ cm³ molecule⁻¹ s⁻¹, based on the unweighted average of values from Langbein and colleagues and Oyaro and colleagues (5.7 × 10⁻¹⁵ cm³ molecule⁻¹ s⁻¹, 298 K), and adjusted for temperature dependence according to DeMore. ¹² Using k[OH+CF₃CH₂OCH₂F, 272 K] = 1.79 × 10⁻¹⁴ cm³ molecule⁻¹ s⁻¹, based on Langbein and colleagues (2.7 × 10⁻¹⁴ cm³ molecule⁻¹ s⁻¹, 298 K) and adjusted for temperature dependence according to DeMore.
<table>
<thead>
<tr>
<th>Gas</th>
<th>Lifetime (years)</th>
<th>Global warming potential (time horizon, years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GWP20</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>variable</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>12</td>
<td>72</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>114</td>
<td>289</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>2.6</td>
<td>1230</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>5.2</td>
<td>1980</td>
</tr>
<tr>
<td>Desflurane</td>
<td>2.6</td>
<td>1230</td>
</tr>
<tr>
<td>Sulfur hexafluoride</td>
<td>3200</td>
<td>16300</td>
</tr>
</tbody>
</table>
How does volatile gas get into the environment?
What is the primary determinant of how much volatile gas gets into the environment?

Fresh gas flow (FGF)
• The Anesthesia Quality Institute estimates 65 million anesthetic cases were performed in 2013 and approximately half of these used inhalational anesthetics.

• At UCSF, we utilize > 1200 L of inhalational agents annually, and produce ~4700 carbon dioxide (CO₂) equivalents via inhaled anesthetic agents.

• The total fresh gas flow (FGF) used to administer anesthetic gases primarily determines the volume of anesthetic utilized and thus proportion of inhaled gases that enter the atmosphere.
How does one decide how much FGF to use?

- Extrapolated FGFs for sevoflurane to desflurane and isoflurane, resulting in higher than necessary FGFs.
- At UCSF, current CO₂ absorbent (Litholyme) containing primarily calcium hydroxide is used which does not produce compound A or carbon monoxide, thus safely allowing the utilization of lower FGFs with sevoflurane and other inhalational gases.
  - At SFGH the absorber is Amsorb
  - AT SF VA the absorber is…??

**Current guidelines on lowest acceptable FGFs**

<table>
<thead>
<tr>
<th></th>
<th>Desflurane</th>
<th>Isoflurane</th>
<th>Sevoflurane</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2 MAC hours</td>
<td>0.5 L/min</td>
<td>0.5 L/min</td>
<td>1 L/min</td>
</tr>
<tr>
<td>&gt; 2 MAC hours</td>
<td>0.5 L/min</td>
<td>0.5 L/min</td>
<td>2 L/min</td>
</tr>
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Compound A = nephrotoxic in rodents
Current guidelines on lowest acceptable FGFs

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<td>0.5 L/min</td>
<td>0.5 L/min</td>
<td>2 L/min</td>
</tr>
</tbody>
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Mean FGF (L/min)

- **SEVO**: 2.4 ± 1.5
- **ISO**: 1.4 ± 0.6
- **DES**: 1.7 ± 0.8

n=372
Practice patterns assessed via survey

During maintenance of anesthesia, what is your estimate of FGF (in L/min) of gas that you utilize or would utilize for the vapors listed below?

- Desflurane
- Isoflurane
- Sevoflurane

% Residents

L/min

<0.5
0.5 - 0.99
1.0 - 1.49
1.5 - 1.99
2.0 - 2.5
> 2.5
Simulation

Table 1. Order of Magnitude Estimation of Anesthetic Drug Used per Case and Over a 35-Year Career When 2 L/min or 1 L/min Is Used for the Maintenance Phase of Anesthesia

<table>
<thead>
<tr>
<th>Technique</th>
<th>Delivered isoflurane per patient (L)</th>
<th>Delivered isoflurane, career (L)</th>
<th>Isoflurane uptake per patient (L)</th>
<th>Isoflurane uptake, career (L)</th>
<th>Total career isoflurane waste/contamination (L)</th>
<th>Career efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-min induction</td>
<td>2.4</td>
<td>42,000</td>
<td>0.35</td>
<td>6125</td>
<td>35,875</td>
<td>15%</td>
</tr>
<tr>
<td>2 L/min maintenance</td>
<td>5.4</td>
<td>94,500</td>
<td>1.3</td>
<td>22,750</td>
<td>71,750</td>
<td>24%</td>
</tr>
<tr>
<td>1 L/min maintenance</td>
<td>4.28</td>
<td>74,900</td>
<td>1.26</td>
<td>22,050</td>
<td>52,850</td>
<td>29%</td>
</tr>
<tr>
<td>Technique difference,</td>
<td>1.12</td>
<td>19,600</td>
<td>0.04</td>
<td>700</td>
<td>18,900</td>
<td></td>
</tr>
<tr>
<td>maintenance only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Career anesthetics modeled as 500 annual inhaled anesthetics over 35 years. GASinan simulation used to calculate total anesthetic vapor delivered and total taken up. Model assumes a 90-minute isoflurane anesthetic for a 70-kg adult with a goal of 1 minimum alveolar concentration. Fresh gas flow is 8 L/min for the first 15 minutes then either 2 or 1 L/min for the remaining 75 minutes. Differences in isoflurane uptake between 2 L/min and 1 L/min models are attributable to less rebreathing in the 2 L/min model and therefore slightly larger inspired and alveolar anesthetic concentrations.

- **Desflurane**
  - $160 / 240 ml bottle

- **Isoflurane**
  - $51 / 250 ml bottle

- **Sevoflurane**
  - $136 / 250 ml bottle

RED BOOK
Goals

- Incorporate FGFs and mLs inhaled anesthetic used per case into UCSF Medical Center Electronic Medical Record (EMR)
- Assess current FGFs utilized by UCSF anesthesia providers in Moffitt-Long operating rooms
- Understand practice habits to improve resource utilization & costs
- Encourage behavioral change and efficient and mindful use of FGF
Other strategies to **GREEN** the OR

- **Turn off the lights**
- **Recycling**
- **Reuse**

**REDUCE**
- Proper waste segregation
- Reusable sharps container
- Fluid waste management
- Energy expenditure
- LED surgical lamps
- Greener equipment packaging
- Reusable hard case
- Just-in-time model to reduce overage

**REUSE**
- Reprocessing of single-use devices
- Reusable surgical linens

**RECYCLE**
- Recycle clean plastic and paper

**RETHINK**
- Anesthetic gas reclamation

**RESEARCH**
- Life cycle analyses of materials, cost comparison of technologies and development of “green” devices
Modifications to the anesthesia machine

Figure 1. The Dräger Apollo main display with the 3 possible Low Flow Wizard recommendations demonstrated.
The future of **GREEN** anesthetics

**RECYCLED ANESTHETICS**

**Dynamic Gas Scavenging System (Vanderbilt University Medical Center)**
- collects and reuses 99% of anesthetic gases without chemically altering them in the process.

**Deltasorb (Blue-Zone Technologies)**
- captures the inhalation anesthetics before they enter the atmosphere through a filtration process, drugs are extracted and used to produce bulk anesthetic drugs.

John Pappas - Mazetti
Thanks
Discussion

We are all students and teachers. I often ask myself, “What did I come here to learn, and what did I come to teach?”
We are all students and teachers. I often ask myself, “What did I come here to learn, and what did I come to teach?”

What are the pockets of resistance in the work that I do?
I just learned about the "procedures" button on the aisyx machine. If you need to disconnect the circuit and want to turn off the gas it'll restart in a min.
Survey

- I run FGFs < 1 during maintenance phase
- I run FGFs < 1-2
- I use 100% FiO2 concentration during maintenance
- I use the pause gas flow button
- APP /Program - mentimeter
Adapted from Charlesworth M. How green is your gas? Anaesthesia News 2009; 267: 22-23.

One study says isoflurane is the most environmentally friendly.

<table>
<thead>
<tr>
<th>Agent</th>
<th>MAC in 100% O₂</th>
<th>GWP100</th>
<th>Environmental factor, EF (GWPxMAC)</th>
<th>Relative EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isoflurane</td>
<td>1.3</td>
<td>350</td>
<td>455</td>
<td>1</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>2.2</td>
<td>575</td>
<td>1265</td>
<td>2.8</td>
</tr>
<tr>
<td>Desflurane</td>
<td>6.0</td>
<td>1526</td>
<td>9156</td>
<td>20.1</td>
</tr>
</tbody>
</table>
Low flow anaesthesia

Lockwood GG, White DC. Measuring the costs of inhaled anaesthetics. *BJA* 2001; **87**: 559-63.

- NARKUP
- Hip#, 50kg, SV, CO 4.5, MV 4.5, FRC 1500ml

<table>
<thead>
<tr>
<th>Cons</th>
<th>Induct Time (min)</th>
<th>LOS (min)</th>
<th>Flow induct (l/min)</th>
<th>Flow Surg (l/min)</th>
<th>Sevo Used (mls)</th>
<th>Cost (£.p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17</td>
<td>80</td>
<td>12/4%</td>
<td>5/2%</td>
<td>109</td>
<td>53.63</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>80</td>
<td>6/4%</td>
<td>3/2%</td>
<td>56</td>
<td>27.55</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>6/2%</td>
<td>0.6/2%</td>
<td>13</td>
<td>6.40</td>
</tr>
</tbody>
</table>
So $\text{N}_2\text{O}$ is most pollutant, BUT

- Greenhouse gases: 6%
- Nitrous oxide: 20%
- Anthropogenic $\text{N}_2\text{O}$: 4%
- Specific manufacture: 90%

Medical $\text{N}_2\text{O}$: ... equivalent to approximately
- 1% atmospheric nitrous
- 0.07% global warming
Multimodal pain management strategy is beneficial in reducing perioperative opioid consumption and pain scores. Pharmacologically targeting multiple unique pain receptor pathways is the standard of care for the surgical patient. “Enhanced Recovery After Surgery (ERAS)” pathways and arthroplasty protocols employ multimodal pain regimens:

- One common factor is the use of pre-operative acetaminophen
Background
IV Acetaminophen

- IV formulation approved by the FDA in 2010; currently in widespread use
- Cost substantially greater than oral formulation (patient charged $180 for IV vs $0.80 for oral)
- No definitive advantage of IV acetaminophen over oral acetaminophen
Oral Acetaminophen

- Can reduce immediate post-operative pain scores by 50% in a wide variety of surgeries (2012 Cochrane review)
- The number needed to treat with 500 mg oral acetaminophen in order to reduce post-operative pain scores by 50% is 3.5
- 51 double-blinded, placebo-matched randomized controlled trials did not show any adverse events associated with oral acetaminophen
Expected Benefits

- Encourage the use of a multimodal pain strategy by targeting one intervention consistently
- Decreased pain scores and perioperative opioid use
- Decreased hospital costs/patient charges by decreasing the use of IV acetaminophen when oral acetaminophen is of equal efficacy
References

- Toms L, McQuay HJ, Derry S, Moore RA. Single dose oral paracetamol (acetaminophen) for postoperative pain in adults.
Hutchins DCJ, White S. Coming round to recycling. BMJ 2009; 338: 609

- 2300kg of anaesthetic waste/theatre/year
- 40% of anaesthetic theatre waste is potentially recyclable
- 4% of sharps bin waste was appropriate
A visual tour of the world's CO2 emissions

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