Uptake and Distribution

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The diagram!
Definitions

Low flow (Miller) ... low-flow (less than half minute ventilation) anesthetic delivery.

Low flow anesthesia (Nunn): FGF of 1 l/m

Minimal flow anesthesia: FGF of 500 ml/min

Closed Circuit anesthesia: No gas or vapor leaving the circuit
Variables

Agent
Lambda b/g (of agent)
MAC (of agent)
Weight of patient
Cardiac Output, Q=
O$_2$ consumption, VO$_2$=
Time
WTF, What The Formula?

\[ U_t = 2\lambda_{b/g} FQ \sqrt{t} \]

\[ U_{dt} = \frac{\lambda_{b/g} FQ}{\sqrt{t}} \]
Definitions:

\[ U_t = 2FQ\sqrt{t} \]
\[ U_{dt} = \frac{\lambda_{b/g}FQ}{\sqrt{t}} \]

U=Uptake
F=fraction inspired, ie 1% agent=0.01
Q=Cardiac output
\[ \lambda_{b/g} \] =blood gas solubility
\[ t \] =time
What does this mean?

In words, the uptake at time \( t \) is equal to a constant \( x \) square root of time.

The rate of uptake at time \( t \) is
Assumptions

Q is constant
fMAC is constant
VO2 is constant
Ventilation is “adequate”
What Uptake looks like
What Uptake rate looks like

Uptake rate (ml/min) vs Time
Agent Solubility

“Equilibrium”
Doubling Ventilation

Note effect greater for more soluble agents

Figure 21-5 The FA/Fi ratio rises more rapidly if ventilation is increased, in this case doubled. Solubility modifies this impact of ventilation: the effect on the anesthetizing partial pressure is greatest with the most soluble anesthetic (methoxyflurane) and least with the least soluble anesthetic (desflurane). (Derived from simulations using GAS MAN from Philip JH: GAS MAN Computer Program. Chestnut Hill, MA, Med Man Simulations, Inc., 2002.)
Doubling Cardiac Output

Again, note effect of solubility

Figure 21-7: If unopposed by a concomitant increase in ventilation, an increase in cardiac output will decrease alveolar anesthetic concentration by augmenting uptake. The resulting alveolar anesthetic change is proportionately greatest (i.e., as a fraction of the "normal" curve; the "doubled" curve is least) with the most soluble anesthetic. (Derived from simulations using GAS MAN from Philip JH: GAS MAN Computer Program. Chestnut Hill, MA, Med Man Simulations, Inc., 2002.)
### Table 21-1: Partition Coefficients at 37°C

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Desflurane</td>
<td>0.45</td>
<td>1.3</td>
<td>1.4</td>
<td>1.0</td>
<td>2.0</td>
<td>27</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>0.47</td>
<td>1.1</td>
<td>0.8</td>
<td>—</td>
<td>1.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>0.65</td>
<td>1.7</td>
<td>1.8</td>
<td>1.2</td>
<td>3.1</td>
<td>48</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>1.4</td>
<td>1.6</td>
<td>1.8</td>
<td>1.2</td>
<td>2.9</td>
<td>45</td>
</tr>
<tr>
<td>Enflurane</td>
<td>1.8</td>
<td>1.4</td>
<td>2.1</td>
<td>—</td>
<td>1.7</td>
<td>36</td>
</tr>
<tr>
<td>Halothane</td>
<td>2.5</td>
<td>1.9</td>
<td>2.1</td>
<td>1.2</td>
<td>3.4</td>
<td>51</td>
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<tr>
<td>Diethyl ether</td>
<td>12</td>
<td>2.0</td>
<td>1.9</td>
<td>0.9</td>
<td>1.3</td>
<td>5</td>
</tr>
<tr>
<td>Methoxyflurane</td>
<td>15</td>
<td>1.4</td>
<td>2.0</td>
<td>0.9</td>
<td>1.6</td>
<td>38</td>
</tr>
</tbody>
</table>

Data from references 1 through 8.
Limitations…

In the real world…

Q is not constant

We don’t want to keep F constant
Given those limitations...

Let’s break down the formula...

\[ U_t = 2\lambda_{b/g} FQ \sqrt{t} \]

\[ U_{dt} = \frac{\lambda_{b/g} FQ}{\sqrt{t}} \]
For those from calc I

\[ D = \frac{1}{2}at^2 \]
\[ V = \frac{D}{dt} = at \]

Our formula for uptake follows same pattern
Uptake = \(2F\lambda_{b/g}Q\sqrt{t}\)

Uptake = \(2\times (f_{MAC}-(Nit/100))\times MAC\times \lambda_{bg}\times 2\times (kg^{0.75})\times D^2^{0.5}\)

But first (second) a little explanation…

Nitrous displaces MAC such that 50% Nitrous = 1/2MAC

1 MAC = 50% move, so use fMAC, fraction MAC

MAC, \(\lambda\) are “constants”

Cardiac output (in dl/min) est as 2 times \(kg^{3/4}\)

D2 is “time”
Link to excel on dropbox

Use name manager
Why bother?

Cost
Environment
Win-Win
What is the delta cost?

Case 1: 4 l/m flow of 1.2% iso for 100 min
- \(4 \times 100 \times 1.2 \times 10^{-2} = 4.8\) liters of Iso Vapor
- \(4800\) ml vapor*(1ml liquid/206 ml vapor)
- \(23.3\) ml

At closed circuit level, \(1812\) ml vapor needed, \(1812/4800 = 37.75\%\) efficient
Decreased FGF

Case 2: 2 l/m flow of 1.2\% iso for 100 min
–\(2 \times 100 \times 1.2 \times 10^{-2} = 2.4\) liters of Iso Vapor
– 2400 ml vapor\*(1 ml liquid/206 ml vapor)
– 11.65 ml

At closed circuit level, 1812 ml vapor needed, \(1812/2400 = 75.5\%\) efficient

Not bad!
What else happens?

At low flow (starting at roughly 2 l/m) down to closed circuit…

Pt uptake of agent and Oxygen becomes real important…
Set vs Delivered

If pts minute vent is 6 l/min
And FGF is 1 l/min
Where do the other 5 l/min come from?
Pt ain’t sucking vacuum....

Other 5 l/min is from exhaled gases
So it has a lower concentration of gases (O$_2$, agent)
CO$_2$ is removed (one hopes)
FGF vs MV
Why set concentration is not delivered concentration?

At high flows, set concentration equals delivered

As flows decrease, the gradient increases

Remember concentration is not amount

Think uptake

4 l/min x 1% = .01 x 4000 = 40 ml/min delivered

1 l/min x 4% = .04 x 1000 = 40 ml/min delivered

Uptake can be > 40 ml/min for 1st 10 min
How much are we giving the circuit?

Our fresh gas flows (FGF) x agent concentration in volume % = ml/min
How much is the patient taking up?

Bank account analogy

– Your bank balance is input vs output
– How much you deposit is hours worked x rate/hour
Patient uptake

How much goes in and out?
At what concentration?

Uptake = Alveolar minute ventilation x (Fi – Fe)
Flowchart for how to safely lower flow to minimal

Quickly estimate pt current uptake of agent

- Multiply $F_i_{agent} - F_e_{agent}$ by minute ventilation
- Drop flow to 1 l/m, increase/decrease agent vol% to deliver uptake
- Monitor $F_e$...
  - If decreasing, give more (if vaporizer maxed out, increase flow)
  - If increasing, give less....
- Monitor $F_iO_2$
Saving the Planet?

Relative potency of agents re: Greenhouse gases
Magnitude of the problem
The China Problem…

THE GREEN NEW DEAL WILL DESTROY OUR ECONOMY AND OUR WAY OF LIFE, AND HAVE MINIMAL EFFECT ON GLOBAL CO2 LEVELS

AS LONG AS CHINA, INDIA, AND THE OTHER NATIONS ARE STILL INCREASING THEIR CO2 EMISSIONS.
CO$_2$ equivalents

Des, Sevo, Iso, Hal?, Nitrous
Propofol (water contamination?)
Driving a car
Committing suicide
How to compare?

By mole? By MAC hour? Correct for atmospheric half-life?

<table>
<thead>
<tr>
<th>Compound</th>
<th>Lifetime (yrs)</th>
<th>GWP20</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Sevo</td>
<td>1.2</td>
<td>349</td>
</tr>
<tr>
<td>Iso</td>
<td>3.6</td>
<td>1401</td>
</tr>
<tr>
<td>Des</td>
<td>10</td>
<td>3714</td>
</tr>
<tr>
<td>Nitrous</td>
<td>114</td>
<td>289</td>
</tr>
</tbody>
</table>

…the amount of CO₂ equivalent produced by all the desflurane used worldwide yearly is about one ten-millionth of global yearly CO₂ production or 0.00001%. Mychaskiw G. Anesthesia and global warming: The real hazards of theoretic science
Per Mac Hour, 2l/m FGF

<table>
<thead>
<tr>
<th>Agent</th>
<th>Grams/hour</th>
<th>GWP 20</th>
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</thead>
<tbody>
<tr>
<td>1.2% iso</td>
<td>11.1</td>
<td>1401</td>
</tr>
<tr>
<td>6% Des</td>
<td>50.4</td>
<td>3714</td>
</tr>
</tbody>
</table>

Conclusions

1. Low flow and closed circuit anesthesia can save money and decrease greenhouse gas emissions.

2. Closed circuit is a bit hard and most of the gains are in lowering flow to < 2l/m

3. Desflurane and Nitrous are the worst (in theory)
Questions?

Or for further followup online...

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References

1. Nunn G. Low-flow Anesthesia. Continuing Education in Anaesthesia, Critical Care & Pain. Volume 8 Number 1 2008