Low Fresh Gas Flow
Oxygen and Agent Considerations

James H. Philip, M.E.(E.), M.D.

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Technology Block 2004

10/06/04 James Philip MD  Low flow & closed circuit safety & danger
10/06/04 James Philip MD  Errors with clinical monitoring
10/13/04 David Lubarsky MD  AIMS (Anes Info Mgt Systems)
10/13/04 David Lubarsky MD  AIMS inferences
10/20/04 James Philip MD  Physiology and physics of fluid flow
10/20/04 Neil Ray & J Philip  Patient Warming and other consid’s
Low Fresh Gas Flow
Oxygen and Agent Considerations

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Anesthesiologist and
Director of Technology Assessment
Brigham and Women's Hospital
Associate Professor of Anaesthesia
Harvard Medical School
Boston MA

Everything profitable I ever invented is owned by Brigham and Woman’s Hospital
(Edwards Vigilance CCO, Baxter-Bard InfusOR Pump, Cardinal-IVAC-Alaris Signature Pump
Perkin-Elmer Life Watch™ CO2 Monitor)
Low Fresh Gas Flow
Oxygen and Agent Considerations

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I have a financial interest in Gas Man® and Med Man Simulations, Inc.
I have performed funded research on Desflurane and Sevoflurane
I am a frequent speaker for Baxter and Abbott
Safety Impact of Low Fresh Gas Flow

You will learn that low fresh gas flow can predispose to certain hazards and that these can be averted through knowledge and skills in clinical practice.

After attending this program, you will understand that:
1 Flows are low in some hospitals
2 Toxic substances don’t build up in low flow or closed circuits
3 Hypoxia can happen but we must not let it
4 Circuit gas composition approaches the composition of the net flow of gases into the circuit
5 The net flow of gases into the circuit includes patient uptake of oxygen and anesthetic
Flows are low at BWH

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>FGF (LPM)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before education</td>
<td>2.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Immediate after</td>
<td>1.8*</td>
<td>1.0</td>
</tr>
<tr>
<td>Later (6 months)</td>
<td>1.9*</td>
<td>1.1</td>
</tr>
<tr>
<td>Fractional Reduction</td>
<td>21%</td>
<td></td>
</tr>
</tbody>
</table>

Recent meeting have taught me

We are spending > $400,000 per year on vapors

BWH would like us to reduce costs
Robert Goldszer, Asst. CMO is shepherd

We must do one or more of the following:
Lower Fresh Gas Flow
Switch from Desflurane and Sevoflurane
Switch to Isoflurane
Switch to other inexpensive drugs
<table>
<thead>
<tr>
<th>Flow Technique Nomenclature (EU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Flow</td>
</tr>
<tr>
<td>Low Flow</td>
</tr>
<tr>
<td>Minimal Flow</td>
</tr>
<tr>
<td>Metabolic (closed)</td>
</tr>
<tr>
<td>Metabolic (closed)</td>
</tr>
<tr>
<td>Uptake (titration)</td>
</tr>
</tbody>
</table>
Why Low Flow?

- Low waste
- Low expense
- Safe
- Effective
- Planet-friendly
- Warm patient
- Moist CO$_2$ absorbent
Cost of three inhalants as a function of FGF

(Using Gas Man)
Low FGF

More rebreathing
Inspired more dependent on Expired
Inspired less dependent on Fresh Gas

Oxygen
Agent
Nitrous Oxide

View the Breathing Circuit
The Circle-Absorber System
The Circle-Absorber System

- Sampled
- Expired
- CO$_2$ Absorbant
- 200 mL/min
- Fresh
- Inspired
- Rebreathed
- Gas Flows

- Exhaust
- Sampled
- 200 mL/min
The Circle-Absorber System

Gas Flows

Inspired

Expired

CO₂ Absorbant

Rebreathed

Sampled 200 mL/min

Fresh

Exhaust

Sampled

200 mL/min
The Circle-Absorber System

Gas Flows

Sampled
200 mL/min

Expired

Exhaust

Rebreathed

Inspired

Fresh

CO₂ Absorbant
The Circle-Absorber System

- Sampled
- Exhaust
- Expired
- Gas Flows
- CO$_2$ Absorbant
- Fresh
- Inspired
- Rebreathed

Inspired Gas Flows

Sampled 200 mL/min
The Circle-Absorber System

Sampled
Exhaust

Expired

CO₂ Absorbant

Rebreathed

Inspired

Gas Flows

Fresh

200 mL/min
The Circle-Absorber System

**Gas Flows**
- **Exhaust**
- **Expired**
- **Rebreathed**

**Fresh**
- **Inspired**
- **Sampled 200 mL/min**

**CO₂ Absorbant**

**Sampled CO₂ Absorbant**

200 mL/min
The Circle-Absorber System

- Sampled
- Expired
- CO$_2$ Absorbant
- 200 mL/min
- Fresh
- Inspired
- Gas Flows
- Rebreathed Oxygen
- Sampled 200 mL/min

Inspired Fresh Gas Flows

Expired

CO$_2$ Absorbant
The Circle-Absorber System

**Gas Flows**

- Sampled 200 mL/min
- Expired
- Inspired
- Fresh

**Gas Flows**

- CO$_2$ Absorbant
- Rebreathed Agent

**Inspired Fresh Exhaust**
The Circle-Absorber System

Gas Flows

Expired

Inspired

Sampled
200 mL/min

CO₂ Absorbant

No Rebreathed CO₂

Fresh

Exhaust

200 mL/min

Inspired

Expired

Exhaust

Expired

No Rebreathed CO₂

CO₂ Absorbant

Sampled

200 mL/min

Fresh

Inspired
The Circle-Absorber System

Gas Flows

Sampled 200 mL/min

Expired

Inspired

Fresh

CO₂

Ab- sorb- ant

Rebreathed Oxygen Agent
The Circle-Absorber System

Gas Flows

Inspired

Expired

Sampled 200 mL/min

Exhaust

CO₂ Absorbant

Rebreathed Oxygen Agent

Fresh
The Circle-Absorber System

Gas Flows

Sampled
200 mL/min

Expired

Inspired

CO₂ Absorbant

Exhaust

Fresh

Inspired

Sampled
200 mL/min
Low Flow Oxygen Considerations
Hypoxia can happen

But we must avoid it.

Always.

No matter what!
Question

Standard anesthesia machine
Everything works (CO$_2$ absorbent,..)
FGF = 1 L/min Air
No other flows
Patient is awake and breathing
Will the patient live or die?
Assume Oxygen consumption = 0.21 L/min
Answer
Past {Live : Die answers = 98:1}
Subject is me
Two Residents, two pulse oximeters
Beware of leak around needle valves
Sometimes nitrous oxide sneaks into circuit
I cancelled first attempt (I felt “funny”)  
Second attempt, I disconnected nitrous oxide
Begin with 80% oxygen in circuit
Experiment ended when Sat = 80%

$F_1O_2$ reached 8%
Experiment ended when Sat = 80%

F₁O₂ reached 8%
F₁O₂ approached 0%

Linear fall implies
Zero order, constant uptake, process

Exponential fall implies
First order, proportional uptake, process
Quick recovery
(my steady hand held the camera)
Compute expected gas concentrations

Conservation of mass applies but is not necessary to compute equilibrium conditions.

No matter what the starting concentrations of gases in the circuit, the circuit concentration will head toward and eventually reach the concentration of the net flow of gases into the breathing circuit.

The concentration of gases in the circuit will change toward the net inflow concentration.

Key word is “net”
Net = what goes in (FGF) minus what goes out (uptake)
Net Flows

1) FGF is comprised of individual flows of
   oxygen
   nitrous oxide
   air
   vapor

2) Patient removal is comprised of
   oxygen consumption
   nitrous oxide uptake
   nitrogen uptake
   vapor uptake
Net flows in Clinical Practice

FGF Oxygen - patient uptake (200 mL/min) = $O_2$ in

FGF Nitrogen - patient uptake (0 mL/min) = $N_2$ in

FGF Nitrous oxide - uptake (100 mL/min) = $N_2O$ in
# Low Flow Air (1 L/min)

<table>
<thead>
<tr>
<th>Name</th>
<th>Flow</th>
<th>N₂</th>
<th>O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGF Air</td>
<td>1.0</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Pt</td>
<td>-0.2</td>
<td>-0.0</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

| Net    | 0.8  | 0.8 | 0.0 |

\[ F_{tO_2} = \frac{0.0}{0.8} = 0.0 \]

**Result = Death**

after falling \( F_{tO_2} \), then falling \( S_pO_2 \)
and lots of alarms sounding
### Add 200 mL O₂ to Low Flow Air

<table>
<thead>
<tr>
<th>Name</th>
<th>Flow</th>
<th>N₂</th>
<th>O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGF Air</td>
<td>1.0</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>FGF O₂</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Pt</td>
<td>- 0.2</td>
<td>- 0.0</td>
<td>- 0.2</td>
</tr>
</tbody>
</table>

**Net**

\[
\text{Net} = 1.0 \quad 0.8 \quad 0.2
\]

\[
F_1O_2 = \frac{0.2}{1.0} = 0.2 = \text{air}
\]

**Result = Life**

with stable \( F_1O_2 \), and adequate \( S_pO_2 \)
### High Flow Nitrous Oxide

<table>
<thead>
<tr>
<th>Name</th>
<th>Flow</th>
<th>$\text{N}_2\text{O}$</th>
<th>$\text{O}_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGF</td>
<td>8.0</td>
<td>6.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Pt</td>
<td>- 0.3</td>
<td>- 0.1</td>
<td>- 0.2</td>
</tr>
<tr>
<td>Net</td>
<td>7.7</td>
<td>5.9</td>
<td>1.8</td>
</tr>
</tbody>
</table>

$F_{1\text{O}_2} = \frac{1.8}{7.7} = 0.233 = 23\% \approx 25\%$

**Result:** Life, as expected

**Error usually not noticed or ignored**
<table>
<thead>
<tr>
<th>Name</th>
<th>Flow</th>
<th>N\textsubscript{2}O</th>
<th>O\textsubscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGF</td>
<td>1.0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Pt</td>
<td>-0.3</td>
<td>-0.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

Net          0.7         0.4  0.3

\[ F_{1}O_{2} = \frac{0.3}{0.7} = 0.43 = 43\% \neq 50\% \]

Result = Life
Concern with \( F_{1}O_{2} \) monitor
Low Flow Nitrous Oxide

<table>
<thead>
<tr>
<th>Name</th>
<th>Flow</th>
<th>$N_2O$</th>
<th>$O_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGF</td>
<td>0.8</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Pt</td>
<td>-0.3</td>
<td>-0.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

Net

<table>
<thead>
<tr>
<th>Flow</th>
<th>$N_2O$</th>
<th>$O_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.0</td>
</tr>
</tbody>
</table>

$F_{iO_2} = 0.0 / 0.5 = 0.0$

Result = Death

after falling $F_{iO_2}$, rising $F_{iN_2O}$, then finally, falling $S_pO_2$
Correct for Uptake with Low Flow Nitrous Oxide

<table>
<thead>
<tr>
<th>Name</th>
<th>Flow</th>
<th>N₂O</th>
<th>O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGF</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Pt</td>
<td>-0.3</td>
<td>-0.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

Net          0.3         0.2 0.1

\[ \text{F}_{i}\text{O}_2 = \frac{0.1}{0.3} = 0.33 \]

Result = Life with stable \( \text{F}_{i}\text{O}_2 \), stable \( \text{F}_{i}\text{N}_2\text{O} \), and adequate \( S_p\text{O}_2 \)

all this with still lower FGF = 0.6 L/min
## Correct for Uptake with Low Flow Nitrous Oxide

<table>
<thead>
<tr>
<th>Name</th>
<th>Flow</th>
<th>N\textsubscript{2}O</th>
<th>O\textsubscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGF</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Pt</td>
<td>-0.3</td>
<td>-0.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

### Net

\[
\text{Net} = 0.3 \quad 0.2 \quad 0.1
\]

\[
\text{F}_{1}\text{O}_2 = \frac{0.1}{0.3} = 0.33
\]

\[
50/50 = \text{N}_2\text{O} / \text{O}_2 \text{ Flow rates}
\]

\[
67/33 = \text{N}_2\text{O} / \text{O}_2 \text{ Concentrations}
\]

Common observation
### Closed Circuit - Don’t add excess gas

<table>
<thead>
<tr>
<th>Name</th>
<th>Flow</th>
<th>( \text{N}_2\text{O} )</th>
<th>( \text{N}_2 )</th>
<th>( \text{O}_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGF</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Pt</td>
<td>-0.2</td>
<td>-0.0</td>
<td>-0.0</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

---

\[ F_{1\text{O}_2} = 0.0 / 0.0 = 0 / 0 = \text{indeterminate} \]

**Result = No change in circuit conc.**

Stable \( F_{1\text{O}_2} \), stable \( F_{1\text{N}_2\text{O}} \), stable \( F_{1\text{N}_2} \), and stable \( S_{p\text{O}_2} \)

all this with closed circuit FGF = 0.2 L/min
Consider rebreathed agent

Inspired gas with vaporizer Agent conc. enters the system. The rebreathed gas with expired Agent conc. is mixed with fresh gas and CO₂ absorber. The mixture is exhausted, and a sample is taken at 200 mL/min for measurement.
Expired Agent Concentration is important
Expired gas rebreathing

Dilutes Inspired Concentration toward Expired Concentration

So, the lower the expired concentration the greater the dilution it causes, the higher my vaporizer must be set, and the harder it is to use low FGF.

Low solubility has the advantage of high Expired Concentration

We see this by viewing the Alveolar Curve
Alveolar Curve - note Height and $\lambda$

<table>
<thead>
<tr>
<th>Name</th>
<th>$\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>0.00</td>
</tr>
<tr>
<td>Des</td>
<td>0.42</td>
</tr>
<tr>
<td>Sev</td>
<td>0.67</td>
</tr>
<tr>
<td>Iso</td>
<td>1.3</td>
</tr>
<tr>
<td>Hal</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Alveolar Curve
Alveolar Tension
Fraction Concentration

divided by
Inspired [same]
Alveolar Curve - note Height and $\lambda$

- Name: Zero, Des, Sev, Iso, Hal
- $\lambda$: 0.00, 0.42, 0.67, 1.3, 2.4

Blood/Gas Solubility

Alveolar Curve
Alveolar Tension
Fraction Concentration

divided by

Inspired [same]

Minutes of administration

0 30

Inf $\infty$
Alveolar Curve - note Height and $\lambda$

<table>
<thead>
<tr>
<th>Name</th>
<th>$\lambda$</th>
</tr>
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<tbody>
<tr>
<td>Zero</td>
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<tr>
<td>Hal</td>
<td>2.4</td>
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</tbody>
</table>

$$\frac{A}{I} = \frac{1}{1 + \frac{CO \cdot \lambda \cdot F(t)}{V_A}}$$

Alveolar Curve
Alveolar Tension Fraction
Concentration

Divided by

Inspired [same]
### Alveolar Curve - note Height and $\lambda$

<table>
<thead>
<tr>
<th>Name</th>
<th>$\lambda$</th>
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<tbody>
<tr>
<td>Zero</td>
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<td>1.3</td>
</tr>
<tr>
<td>Hal</td>
<td>2.4</td>
</tr>
</tbody>
</table>

**Alveolar Curve**

**Alveolar Tension Fraction**

**Concentration divided by Inspired [same]**

\[
\frac{A}{I} = \frac{1}{1 + \frac{C_O}{V_A} \cdot \frac{\lambda \cdot F(t)}{V_A}}
\]
Alveolar Deficiency - Initial

- Alveolar Deficiency
- A/I
- Zero
- Des
- Sev
- Iso
- Hal
- 34% Des
- 46% Sev
- 62% Iso
- 76% Hal
- 100% Inf

Minutes of administration
Alveolar Deficiency - Late

Minutes of administration

A/I

1.0

Zero

Des

Sev

Iso

Hal

A/I

0.88

0.83

0.71

0.56

12%

17%

29%

44%

Alveolar Deficiency

300 Minutes of administration
Low solubility facilitates low FGF

Allows low FGF.
Expired gas concentration is high,
Expired admixture is not a problem,
Inspired follows the vaporizer, and
Expired follows inspired.
Low Flow Practice

Desflurane Example:
Make inspired tension rise slowly by using low fresh gas flow
Save money
More convenient than adjusting vaporizer several times
Adjust Vaporizer - increase slowly
Use high FGF for tight control

FGF = 5 L/min air or oxygen
Vaporizer set to 3, 4, 5, 6, 7, 8, 9 %

Inspired rises over 5 - 7 minutes
Expired rises over 5 - 7 minutes
Clinical Low Flow Technique - Desflurane

Simple
Very Inexpensive

FGF = 1 L/min air or oxygen
Vaporizer set to 18%

Inspired rises over 5 - 7 minutes
Expired rises over 5 - 7 minutes
Clinical Low Flow Technique - Desflurane

Simple

Very Inexpensive

FGF = 1 L/min air or oxygen

Vaporizer set to 18%

Then,

Decrease vaporizer &/or FGF when
Inspired = 7% or so, and
Expired = 6%

Patient is deep enough!
Gas Man Examples

FGF Comparison

High FGF
5 L/min $O_2$
Progressively increase vaporizer setting

$7.80 for $0.75 in body

Low FGF
1 L $O_2$ /min
Air + $O_2$
Set vaporizer to 18%
Watch, wait,
Readjust when circumstances merit

$2.90 for $0.75 in body
Clinical Example
1 L/min Air + Oxygen for induction
Vaporizer to Maximum
Desflurane

5 min
Datex-Ohmeda AS/3/5 much better
Inspired and Expired rise smoothly. This controls the rate of Desflurane rise.
This avoids the sympathetic activity that might otherwise be seen

$\text{CO}_2$

Desflurane
GEMS IT (Marquette) SAM Module

Fabius GS Anes Mach with at 1 LPM
Replacing circuit gas loss with oxygen
Clinical Technique with Desflurane

Avoid Tachycardia and Hypertension
increase inspired and expired slowly
5 minutes (1 L/min does this!)

Avoid coughing on induction -
IV induction and secure airway with ET tube or LMA

Avoid coughing on emergence -
Wake up fast
High FGF
Normal Ventilation
Extubate as early as practical
No “re-anesthetization”
Desflurane works well with LMA

Similar profiles for maintenance

Similar profiles for emergence except
Desflurane a bit faster for emergence

Similar profiles for recovery except
Desflurane a bit faster for measures of early recovery
Desflurane much better for return to activities
Full activity next day Des 28/31 vs Sevo 15/29


With very low FGF, it is good to return sampled gas to the breathing circuit.
With high FGF, sampled gas is usually evacuated.
Evacuating sampled gas wastes 200 mL/min
Sample gas exhaust (Datex Monitor)
can be returned to the breathing circuit when using low flow
Reusable sample return devices are better.
Permanent sample gas return is best.
CO2 Absorbent will “do its job” when you use low flows
CO2 Absorbent will also stay wet when you use low flows
CO2 Absorbent will also stay wet when you use low flows.

Avoids Sevo breakdown, forming Compound A, Heat, Fires. Des forming CO.
Closed Circuit

is the limit
when FGF is reduced
to just meet the body’s needs.

Nothing is wasted
because nothing leaves the circuit
but, flow = 200 mL/min oxygen

Anything more is
“minimal flow” or “low flow”
Closed Circuit

140 - 250 mL/min O₂ for maintenance
Keep bellows away from the top
Constant Concentrations
Constant Concentrations
get Constant Vital Signs
Do not press O2, Flush to fill Bellows
Do not press O₂ Flush to fill Bellows
Liquid to Vapor

Volume relationship
What happens when I inject 1 mL liquid agent?
Vapor / Liquid Volume Ratio

Sev 182  Iso 195  Enf 196  Des 207  Agent mL Vapor mL Liquid 226

200
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP

\[ V = 1 \text{ mL Liq} \]
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP

\[ V = 1 \text{ mL Liq} \times \frac{22.4 \text{ L Vap}}{\text{mole}} \]
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP

\[ V = \frac{1 \text{ mL Liq}}{\text{ mole}} \times \frac{22.4 \text{ L Vap}}{\text{ mole}} \times \frac{\text{ mole}}{\text{ GMW g}} \]
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP

\[
V = \frac{22.4 \text{ L Vap}}{\text{mole}} \cdot \frac{\text{mole}}{\text{GMW g}} \cdot \frac{\text{d g}}{1 \text{ mL Liq}}
\]
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP

\[
V = 1 \text{ mL Liq} \times \frac{22.4 \text{ L Vap}}{\text{mole}} \times \frac{\text{mole}}{\text{GMW g}} \times \frac{\text{d g}}{\text{mL Liq}} \times \frac{1000 \text{ mL}}{\text{L}}
\]
Dimensional analysis for liq -> vap

Given:  Molar Volume = 22.4 L at STP

\[
V = \frac{1 \text{ mL Liq}}{\text{mole}} \times \frac{22.4 \text{ L Vap}}{\text{mole}} \times \frac{\text{mole}}{\text{g GMW}} \times \frac{\text{d g}}{\text{mL Liq}} \times \frac{1000 \text{ mL}}{\text{L}}
\]
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP

\[ V = \frac{1 \text{ mL Liq}}{\text{mL Liq}} \times \frac{22.4 \text{ L Vap}}{\text{mole}} \times \frac{\text{mole}}{\text{d g GMW g}} \times \frac{\text{d g}}{\text{mL Liq}} \times \frac{1000 \text{ mL}}{\text{L}} \]
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Given: Molar Volume = 22.4 L at STP

\[
V = \frac{1 \text{ mL Liq}}{1 \text{ mole}} \times \frac{22.4 \text{ L Vap}}{1 \text{ mole}} \times \frac{1 \text{ g GMW}}{1 \text{ mole}} \times \frac{1 \text{ g}}{1000 \text{ mL Liq}} \times \frac{1000 \text{ mL}}{1 \text{ L}}
\]
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP

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V = \frac{1 \text{ mL Liq}}{\text{mole}} \times \frac{22.4 \text{ L Vap}}{\text{mole}} \times \frac{\text{d g}}{\text{mL Liq}} \times \frac{1000 \text{ mL}}{\text{L}}
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### Dimensional analysis for liq -> vap

**Given:** Molar Volume = 22.4 L at STP

<table>
<thead>
<tr>
<th>V =</th>
<th>1 mL Liq</th>
<th>(\frac{22.4 \text{ L Vap}}{\text{mole}})</th>
<th>(\frac{\text{mole}}{\text{GMW g}})</th>
<th>(\frac{\text{d g}}{\text{mL Liq}})</th>
<th>(\frac{1000 \text{ mL}}{\text{L}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>V =</td>
<td>1.0</td>
<td>22.4</td>
<td>d</td>
<td>1000</td>
<td>mL Vap</td>
</tr>
</tbody>
</table>

\[ V = \frac{1 \text{ mL Liq} \times \frac{22.4 \text{ L Vap}}{\text{mole}} \times \frac{\text{mole}}{\text{GMW g}} \times \frac{\text{d g}}{\text{mL Liq}} \times \frac{1000 \text{ mL}}{\text{L}}}{\text{GMW}} = \text{mL Vap} \]
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP

\[
V = \frac{1 \text{ mL Liq}}{1.0} \times \frac{22.4 \text{ L Vap}}{\text{mole}} \times \frac{\text{mole}}{\text{g GMW}} \times \frac{\text{d g}}{\text{mL Liq}} \times \frac{1000 \text{ mL}}{\text{L}}
\]

\[
V = \frac{1.0 	imes 22.4 \times 1000 \text{ d}}{\text{GMW}} \text{ mL Vap}
\]
Dimensional analysis for liq -> vap

Given: Molar Volume = 22.4 L at STP

\[ V = \frac{1 \text{ mL Liq}}{1.0} \times \frac{22.4 \text{ L Vap}}{\text{mole}} \times \frac{\text{mole}}{\text{g GMW}} \times \frac{\text{d g}}{1000 \text{ mL Liq}} \times \frac{1000 \text{ mL}}{\text{L}} \]

\[ V = \frac{1.0}{22.4} \times \frac{22.4}{1.0} \times \frac{1.0}{1000} \times \frac{d}{GMW} = \frac{22,400 \text{ d}}{GMW} \]
Temperature correction for liq -> vap

Given: Molar Volume = 22.4 L at STP

\[ V = \frac{1 \text{ mL Liq}}{1.0} \times \frac{22.4 \text{ L Vap}}{22.4 \text{ mole}} \times \frac{\text{ mole}}{\text{ mole}} \times \frac{d \text{ g}}{\text{ g}} \times \frac{1000 \text{ mL Liq}}{1 \text{ mL Liq}} = 22,400 \frac{d}{\text{ GMW}} \text{ mL Vap} \]

\[ V = 1.0 \times 22.4 \times 1000 \frac{d}{\text{ GMW}} = 22,400 \frac{d}{\text{ GMW}} \]

\[ V_T = V_{0C} \times \frac{273.15}{273.15 + T} \]
Temperature correction for liq -> vap

Given: Molar Volume = 22.4 L at STP

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\[ V = \frac{1.0 \times 22.4 \times 1000}{\text{ GMW}} \]

\[ V = 22,400 \frac{\text{ d}}{\text{ GMW}} \]

\[ V_T = V_{0^\circ C} \times \frac{273.15}{273.15 + T} \]

\[ V_{20^\circ C} = V_{0^\circ C} \times 1.073 \]
Dimensional analysis for liq -> vap

\[ V_{0C} = \frac{22,400}{d \text{ GMW}} \]
Dimensional analysis for liq -> vap yields:

\[ V_{0\,\text{C}} = \frac{22,400 \, d}{\text{GMW}} \]

<table>
<thead>
<tr>
<th></th>
<th>GMW</th>
<th>d</th>
<th>0 C</th>
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</thead>
<tbody>
<tr>
<td>Sevoflurane</td>
<td>200.1</td>
<td>1.52</td>
<td>170</td>
</tr>
<tr>
<td>Desflurane</td>
<td>168.0</td>
<td>1.46</td>
<td>195</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>184.4</td>
<td>1.50</td>
<td>182</td>
</tr>
<tr>
<td>Halothane</td>
<td>197.4</td>
<td>1.87</td>
<td>212</td>
</tr>
<tr>
<td>Enflurane</td>
<td>184.4</td>
<td>1.52</td>
<td>184</td>
</tr>
</tbody>
</table>
Dimensional analysis for liq -> vap yields:

\[ V_{0C} = \frac{22,400}{GMW} d \]

<table>
<thead>
<tr>
<th></th>
<th>GMW</th>
<th>d</th>
<th>0°C</th>
<th>20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sevoflurane</td>
<td>200.1</td>
<td>1.52</td>
<td>170</td>
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</tr>
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<td>168.0</td>
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<td>195</td>
<td>208</td>
</tr>
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<td>Isoflurane</td>
<td>184.4</td>
<td>1.50</td>
<td>182</td>
<td>195</td>
</tr>
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<td>Halothane</td>
<td>197.4</td>
<td>1.87</td>
<td>212</td>
<td>227</td>
</tr>
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<td>Enflurane</td>
<td>184.4</td>
<td>1.52</td>
<td>184</td>
<td>198</td>
</tr>
</tbody>
</table>
Real Injections

Real Circuits

Why inject in the inspired limb?

Otherwise too slow for clinical care
1.0 mL injections of liquid Isoflurane in a Closed Circuit

Liquid Injections:  I = Inspired limb,  E = Expired Limb
1 mL Desflurane injected inspired limb
Syringe must always point up

So only vapor is lost
Syringe must always point up

So only vapor is lost

Otherwise, liquid is lost, 208 times as fast.
Syringe must always point up

So only vapor is lost

Otherwise, liquid is lost, 208 times as fast

Vaporization?
Desflurane does not disappear

Evaporates slowly
Absorbing Heat of Vaporization as it goes
Fast from the floor
Slow from the table top
Fast in the breathing circuit
Baxter packs bottle in a plastic cover anyway
just in case the bottle breaks
We will test this today at 5,700 feet where
Vapor pressure = Atmospheric pressure
How much anesthetic?
Initial Vapor Uptake

Vapor Uptake Initial =
Alv Conc x Blood/Gas Solubility x CO =
F x MAC x Blood/Gas Solubility x CO =

Numbers
Desflurane Vapor Uptake Initial =
0.06 x 0.42 x 5000 mL/min =
1 x 0.06 x 0.42 x 5000 mL/min =
126 mL vapor / minute =
36 mL liquid / hour (for 5 minutes only)
## Other Agents, other Solubilities

**Uptake = Pump Setting (mL/hr)**

<table>
<thead>
<tr>
<th>Agent</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Des</td>
<td>36</td>
<td>9</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Sev</td>
<td>22</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Iso</td>
<td>22</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Enf</td>
<td>49</td>
<td>12</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Hal</td>
<td>26</td>
<td>6</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>5 min</td>
<td>120 min</td>
<td>12 hours</td>
<td></td>
</tr>
<tr>
<td>Agent</td>
<td>&gt;ALV</td>
<td>&gt;VRG</td>
<td>&gt;MUS</td>
<td>&gt;FAT</td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Des</td>
<td>$11</td>
<td>$3</td>
<td>$1</td>
<td>$0</td>
</tr>
<tr>
<td>Sev</td>
<td>$16</td>
<td>$4</td>
<td>$1</td>
<td>$0</td>
</tr>
<tr>
<td>Iso</td>
<td>$10</td>
<td>$2</td>
<td>$1</td>
<td>$0</td>
</tr>
<tr>
<td>Enf</td>
<td>$25</td>
<td>$6</td>
<td>$2</td>
<td>$0</td>
</tr>
<tr>
<td>Hal</td>
<td>$2</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
</tbody>
</table>

Desflurane: $0.29 per mL  Isoflurane: $0.30 per mL
<table>
<thead>
<tr>
<th>Agent</th>
<th>&gt;ALV</th>
<th>&gt;VRG</th>
<th>&gt;MUS</th>
<th>&gt;FAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Des</td>
<td>$10.55</td>
<td>$2.53</td>
<td>$0.63</td>
<td>$0.00</td>
</tr>
<tr>
<td>Sev</td>
<td>$16.11</td>
<td>$3.87</td>
<td>$0.97</td>
<td>$0.00</td>
</tr>
<tr>
<td>Iso</td>
<td>$9.87</td>
<td>$2.37</td>
<td>$0.59</td>
<td>$0.00</td>
</tr>
<tr>
<td>Enf</td>
<td>$24.65</td>
<td>$5.91</td>
<td>$2.37</td>
<td>$0.00</td>
</tr>
<tr>
<td>Hal</td>
<td>$1.77</td>
<td>$0.42</td>
<td>$0.11</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

Desflurane: $0.29 per mL  Isoflurane: $0.30 per mL
Uptake Summary

Uptake = alveolar concentration $\times$ solubility $\times$ CO

Later, uptake is carried away at 1/4 the initial rate.

Liquid agent can be used instead of vapor

Inject liquid in inspiratory circuit limb

A pump can be used for liquid circuit injection

For \{ \text{>Alv, > VRG, >MUS, >FAT} \}, \text{Des} = 36, 9, 2;
\text{Isof} = 22, 5, 1; \text{Sevo} = 22, 5, 1; \text{Hal} = 26, 6, 2 \text{ mL/hr}
How do you know if FGF is sufficient?
Check your gas monitor for Oxygen
for Agent Concentration
Record Vaporizer, Inspired, Expired
Read and think about what you write
Avoid changes in inspired and expired when you want depth constant
Cost reduction is up to you

Hourly Cost US

Low Flow

FGF L/min

Isoflurane

Desflurane

Sevoflurane

Closed Circuit
Cost reduction is up to you

Think carefully about oxygen
Always replace uptake

Hourly Cost US

$0 $10 $20 $30

FGF L/min

0 1 2 3 4 5 6

Low Flow Closed Circuit

Sevoflurane Desflurane Isoflurane
Thank you