Kinetics and Monitoring of Inhaled Anesthetics

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In the past but not at present, I performed funded research on Sevoflurane, Desflurane, Isoflurane. I created Gas Man® but have no financial interest in it. Gas Man® and Med Man Simulations, Inc. are a nonprofit corporation.
Learner Goals and Objectives

Anesthetic Path from Vaporizer to Brain is
  Del (D) -> CKT (I) -> Alv (A, E) -> art (a) -> Brain (VRG)

Tension rather than Concentration describes anesthetic behavior
  Kety, 1950 article in Anesthesiology. All should read it.

ATC (Alveolar Tension Curve) The Inspired to Alveolar relationship

Monitor I and E agent with an agent analyzer
  Monitor past, present. Plan and create future with graphic display

Use Gas Man computer simulation to explore concepts and practice
Focus on the

Alveolar Tension Curve
Alveolar Tension Curve

Alveolar response to an Inspired Step

\[ \text{The time course of alveolar tension} = P_A \]
\[ \text{in response to a step change in inspired tension} = P_I \]

\[ P_I \rightarrow P_A \]
Path of Anesthetic Tension from Vaporizer to Brain
Flows facilitate or impede the passage
Open (Non-Rebreathing) Circuit provides controlled Inspired Step
Axes and Labels

A / I

minutes (time)
Inspired Step

Alveolar response to a step change in inspired agent
Inspired Tension

Alveolar Tension

exponential curve

Pure Lung wash-in Without Uptake into Blood

A / I

0.0

1.0

0

1

2

3

minutes (time)
Time constant, \( \tau \) is the time required to achieve 63% of the final value.*

\[ \tau = 0.5 \text{ min} \]

* Derive in long course
**Time Constant**

Time constant, \( \tau \) (\( \tau = 0.5 \text{ min} \))

- **Inspired Tension**
- **Alveolar Tension**

*Time required to fill the compartment if there were no mixing*

*Derive in long course*
Alveolar Tension

Inspired Tension

Pure Lung wash-in Without Uptake into Blood

A / I

Alveolar Tension

is the same for:

Cardiac Output = zero (CO = 0) or

Zerothane, Drug with solubility = zero (λ = 0)

Xe, which has a very low solubility ~ 0

This is mixing a new gas into a container with old gas
Now, add uptake into blood

Uptake into blood produces an Alveolar Tension Plateau
A / I

Inspired Tension

Alveolar Tension

Pure Lung wash-in
Without Uptake into Blood

minutes (time)
Plateau is produced by Anesthetic Removal by Blood.
Alveolar Tension Plateau

A / I

Inspired

Delivery

Removal

Alveolar Plateau

minutes (time)
Alveolar Tension Plateau

Inspired

Delivery = $V_A$

Removal = $CO \cdot \lambda$

0.0

0

1

2

3

minutes (time)
Several Drug Plateaus

Xe or Zerothane

Alveolar Plateaus

N₂O  Des
Sevo
Iso
Enf
Hal

Infinthiane

0.0  1.0
0  1  2  3 minutes (time)
Alveolar Plateau Heights and solubilities

<table>
<thead>
<tr>
<th></th>
<th>Zerothane</th>
<th>Infinithane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ht</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>λ</td>
<td>1.3</td>
<td>Inf.</td>
</tr>
</tbody>
</table>

Height and Solubility

- **Infinithane**
  - Ht: 0.00
  - λ: Inf.

- **Zerothane**
  - Ht: 1.00
  - λ: 0.00

- **Sevo**
  - Ht: 0.54
  - λ: 0.67

- **N2O**
  - Ht: 0.66
  - λ: 0.42

- **Hal**
  - Ht: 0.24
  - λ: 2.4

- **Enf**
  - Ht: 0.38
  - λ: 1.3

- **Iso**
  - Ht: 0.24
  - λ: 2.4

A / I vs. time (minutes)
Venous Return brings anesthetic back to alveoli
Tail of the Alveolar Tension Curve
Venous Return converts Plateau

Plateau produced by
Removal by Blood
Venous Return converts Plateau into Tail
Alveolar Tension Curve sections named

- Inspired
- Knee
- Plateau
- Initial Rise
- Tail

A / l vs. minutes (time)
Arterial = Alveolar (ignore shunt)
VRG follows arterial blood with $\tau = 3 - 5$ min

VRG = Brain, etc.
Next, Real drugs and real curves
Real drugs and real curves

Yasuda & Eger, 1991
What is the same among these curves?

A / I

Des
Sev
Iso
Hal

$\frac{P_A}{P_I}$

Minutes of administration
Initial rise follows the same Zerothane curve

- **Zero**
- **Des**
- **Sev**
- **Iso**
- **Hal**

Variable: \( \frac{P_A}{P_I} \)

Minutes of administration: 0 to 30
What is the difference between these curves?
Plateau Height is the only kinetic difference!
And, plateau height is determined by $\lambda$
Blood / Gas Solubility

Dominates Inhalation Kinetics

Determines how closely

Expired Tension approaches

Inspired Tension

in the first few minutes after you change inspired
Emergence from a long 1 MAC anesthetic

Yasuda & Eger, 1991. Analysis by JHP.
Clinical Care – precise control of anesthetic depth

Every time you make a change, up or down, the same thing happens
- Initial change, plateau

Good clinicians use the shape of this curve to contour the course of inspired, expired, and brain tension to produce the anesthetic they desire

It is the tail of the curve that lets your patient drift too deep or too light after the plateau turns into a knee and ongoing tail
Sevoflurane, 6 hrs on, then off

Leeson S, Roberson RS, Philip JH. Hypoventilation after Inhaled Anesthesia Results in Reanesthetization. Anesth & Analg, August 2014
Clinical Control
Measurements and Adjustments

Inspired = Inspired
End-Tidal ~ Alveolar [10% dead space error]
Alveolar ~ arterial [5% shunt error]

Beware
Inspired ≠ Delivered [FGF mixing error]*
Brain ≠ End-Tidal [Brain time constant]

* Another lecture
Agent Monitor

ET Value now will be in the brain in about 3 minutes

ET Trend Graph value 3 minutes ago is in the brain now
GE Solar 8000
6 minute window shows this
Note BIS and ET Desflurane trends
Draeger Apollo
VCI with optimized control of I and E

Draeger Apollo 30 min trend
Longer Graphic Trend shows whole case

Sevoflurane VIMA with optimized control of I and E

GE Solar 90 min
Desflurane Ramp Apollo

JHP photo of JHP case
Desflurane ramp up
HR & BP ramp down, slightly

JHP photo 4-28-05
Cook Co Hosp case
Bolus down and up (GE Solar 6 min)
Bolus up, bolus down (GE Remote View 1 hr)
Bolus down before wake up (GE Solar 6 min)
Computer simulation can explain what we observe during clinical anesthesia and can help us to plan and create effective clinical techniques.
Gas Man download directions

Our Medical Education Programs

Online collections of presentations and documents from the Department's teaching programs
For the weekly schedule of Educational presentations and events, see:

- Anesthesia Educational Calendar
  
Current online training highlights:

- Core Didactics Series Website
- PIMS (Perioperative Information Management System) Documentation
- Online Omnicell Training
- BWH US–Guided Central Venous Catheter Placement Training Program
- GasMan: Links and Installation Information
Thank you
Residents Can Complete Gas Man Homework and Demonstrate Core Competency in Inhalation Kinetics

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Introduction:
Core competency in inhalation anesthesia is important for Anesthesiology Residents. Recently, Eger and Shafer published a Tutorial that demonstrated that the Gas Man® Computer Simulation Program1 can teach complex topics in inhalation anesthesia kinetics. Their example was context-sensitive decrement times2. In order to understand whether Anesthesia Residents could demonstrate Core Competency in Inhalation Kinetics, Gas Man homework was assigned to residents on the BWH Ambulatory Anesthesia service between September and December 2005.

Methods:
An e-mail stating the homework assignment was sent to each resident at the beginning of their 1-month rotation. The assignment was to simulate administering 1 MAC (alveolar) anesthesia for 1.5 hours, simulate emergence, and measure wake up time (time for Brain to reach 0.33 MAC). This was to be performed with Isoflurane (I), Sevoflurane (S) and Desflurane (D) using a standard semi-closed breathing circuit. The educational goals were: 1) maintenance of anesthesia at constant depth, 2) wake up with high fresh gas flow and normal ventilation, and 3) ability to use the Gas Man® program.

Results:
Twenty-five (25) of 26 residents completed the homework. Of these, 22 of 25 demonstrated they mastered all 3 goals. Three (3) residents failed to grasp 1 goal: administering anesthesia at constant depth. Instead, they gave constant inspired concentration resulting in increasing depth. All 25 responders used the Gas Man® program successfully. Wake up (VRG = 0.33 MAC) times (Mean ± SD [min]) reported by residents were 1 = 10.7 ± 1.8, S = 7.9 ± 2.2, D = 5.8 ± 1.0 minutes. These did not differ from the instructor’s times of 1 = 10.9, S = 7.7, D = 5.4 minutes.

Summary:
Residents can demonstrate core competency in inhalation kinetics by using the Gas Man® computer simulation. Those residents who did not initially grasp the didactic concepts were identified, given additional instruction, and then demonstrated competency.

Disclosure:
Gas Man is a registered trademark of James H. Philip. Med Man Simulations is a non-profit corporation and is in the process of applying for tax-exempt status under Internal Revenue Code 501(c)(3).

References:
1. Philip JH. GAS MAN® - Understanding anesthesia uptake and distribution. Med Man Simulations Inc., Chestnut Hill, 2004. [Dr. Philip has a financial interest but draws no profit or income from Gas Man®]