Anesthesia Machines, History and Current Evolution

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Evolution

Is NOT morphing…
Requires BOTH
   Variation
   Selection
There is no great blue heron

Aristotle: The setting of definitions is the beginning of wisdom

Species do not exist, except as a construct.

What exists is a population of individuals:

Everytime one dies or hatches, the meaning of “great blue heron” changes
And so it is

Even with anesthesia machines...
Population Anes Machine
Population Anes Machine
First component: Gas Delivery

Gas Delivery

Tanks

Tanks

Color coded

different sizes

different volumes, same pressures
Pipeline

Different paths for different gases

Oxygen
  Can be from bank of tanks
  Can be from liquid

Nitrous
  Tanks are liquid!

Air
  Compressed or Tanks
On site compression

Let me sell you some liquid air...
Flowmeters and controllers

Once you have gas, want to deliver it and measure it

Flow controllers
- Needle valve
- Proportional valve
Electromagnetic Valve
Thorpe tube

Gas enters at the bottom and elevates the indicator.

The indicator floats where gravity equals the upward force caused by gas flow.

The tube is tapered so the annular opening increases with height.

The indicator float is calibrated for specific gas.

Density and viscosity differ.
Hot Wire Flow meter

A thin platinum wire, electrically heated to constant temperature 150°C. As gas passes through the meter, the wire cools off, requiring extra electrical energy to maintain its temperature. The extra electrical energy is a measure of gas flow.
Vaporizers

Open drop
Boyle’s bottle (various)
Copper Kettle
Variable bypass, temperature (and flow) compensated
Electronic injection
Advantages/disadvantages
Yankauer mask
Boyle’s Bottle, Goldman Vap
Copper Kettle
Vapor pressure of volatile agents at 20 degrees C (mmHg)

Sevoflurane: 157
Desflurane: 669
Isoflurane: 238
Enflurane: 172
Halothane: 243
N2O: 38,770
Vaporizer Math

If 100 ml of gas enters Copper Kettle containing Iso, How much leaves?
More than entered...
Iso...238/760=.313, so 31% vapor will exit
If 100 ml enters, then how much is added to make 31%?
OMG Math!

\( \frac{P_{vap}}{P_{atm}} = \frac{x}{(F_{O2} + x)} \)

\( P_{atm} \times x = (P_{vap} \times F_{O2}) + (P_{vap} \times x) \)

\( P_{atm} \times x - P_{vap} \times x = P_{vap} \times F_{O2} \)

\( x \times (P_{atm} - P_{vap}) = P_{vap} \times F_{O2} \)

\( x = \frac{P_{vap} \times F_{O2}}{P_{atm} - P_{vap}} \)

For 100 ml of O\(_2\) flow, 45 ml iso vapor

45/145 = .31
So...

To deliver one percent Iso....
Mix 45 ml of vapor with 4.5 liters of bypass gas

OR Use the following which “automatically” sets splitting ratio of 0.1 liter to 4.5 liters
Generic Bypass Vaporizer

Flow from the flowmeters enters
The control valve regulates the split
Splitting Ratio = flow though vaporizing chamber/flow through bypass chamber
Saturated gas leaves chamber
Diluted by bypass gas
### Splitting Ratios...20° C

<table>
<thead>
<tr>
<th>Desired anesthetic percentage</th>
<th>Halothane</th>
<th>Enflurane</th>
<th>Isoflurane</th>
<th>Sevoflurane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>46:1</td>
<td>29:1</td>
<td>44:1</td>
<td>25:1</td>
</tr>
<tr>
<td>2%</td>
<td>22:1</td>
<td>14:1</td>
<td>21:1</td>
<td>12:1</td>
</tr>
<tr>
<td>3%</td>
<td>14:1</td>
<td>9:1</td>
<td>14:1</td>
<td>7:1</td>
</tr>
</tbody>
</table>
Temperature compensated
Put it all together...
Denver Question

If I take my vaporizer to Denver (5280 ft elevation), what happens?

n.b. anesthesia is provided NOT by vol%, but by partial pressure!

1% vol/vol = 7.6mmHg at sea level

$P_{\text{atm}}$ in Denver is 615mmHg

So a greater volume %, but same partial pressure...
True for variable bypass vap

Not true for desflurane Tec 6

? For future vaporizers…
Back to Evolution

Hill climbing...
Local optima...
Need variation and selection
Circle System

There are others... who cares?

wasteful of gases & unneeded
How to think of circle system

Figure 111: The COSY II breathing system and its components
Circle System

The usual suspect....

Figure 111: The COSY II breathing system and its components
Labels...

CO2 Abs

Expiratory valve

FGF inflow

Inspiratory valve

Lungs

RV

LV

Anesthesia Machine
Black Box
Shuzan’s Short Staff

Shuzan held out his short staff and said:

“If you call this a short staff, you oppose its reality. If you do not call it a short staff, you ignore the fact. Now what do you wish to call this?”
Ventilators

Bag in a bottle
Piston
Turbine
Air Shields Ventilator

Entirely pneumatic
Bag in a bottle
Ventilator controls

- $T_{insp}$
- $F_{insp}$
- $Paus_{exp}$
Pressure/Volume/Time

A. Volume Control
   - Pressure
   - Flow

B. Volume Control Insp Pause
   - Pressure
   - Peak
   - Plateau

C. Pressure Control
   - Pressure

Expiration

Inspiration

Volume

Peak pressure

Note: constant pressure
**Standard Vent (Bellows)**

**FIGURE 6-22** Ventilator-delivered breath in inspiration with the Datex-Ohmeda 7900 ventilator (GE Healthcare, Waukesha, WI) circuit (simplified schematic). While the bag/ventilator switch (d) is in the “ventilator” position, the ventilator (h) is activated. Gases within the ventilator bellows are pushed into the ventilator circuit, closing the exhalation valve (c). These gases pass antegrade through the CO₂ absorber (e) and combine with the fresh gas flow (FGF). The mixed gases enter the patient circuit through the inspiratory valve (a) to the patient (b). A higher pressure within the patient to machine circuit closes the exhalation valve (c). f, reservoir bag; g, adjustable pressure limiting value.

**FIGURE 6-23** Ventilator-delivered breath in exhalation with the Datex-Ohmeda 7900 ventilator (GE Healthcare, Waukesha, WI) circuit (simplified schematic). While the bag/ventilator switch (d) is in the “ventilator” position, the ventilator (h) is activated. Exhaled patient gases (b) close the inspiratory valve (a) and open the exhalation valve (c). Because the inspiration valve is closed, the fresh gas flow (FGF) is diverted retrograde through the CO₂ absorber (e). Mixed gases from the FGF and exhaled gases reinfate the ventilator bellows. Excess gas volume is eliminated through a low-pressure pop-off valve within the ventilator assembly to the gas scavenger system. f, reservoir bag; g, adjustable pressure limiting value. (From *Explore the anesthesia system*, 1996, Ohmeda [now GE Healthcare, Waukesha, WI], pp 6-45.)
Drager Piston Vent

**FIGURE 6-27** Ventilator-delivered breath in inspiration with the Apollo and Fabius ventilator (Dräger Medical, Telford, PA) circuits (simplified schematic). While the ventilator switch is on, the ventilator piston (b) is activated. In addition, the adjustable pressure-limiting (APL) valve (g) is deactivated, and the APL.
Ventilator Modes

Feedback loops
Pressure control
Volume control
PEEP

Standard way, just impede exhalation (pressure limit valve)

Different using turbine vent, turbine keeps spinning at a lower rate to maintain the PEEP pressure
Specifics to each machine

Flow uncoupling
Flow compensation
Future directions
Fresh Gas Decoupling

Without Fresh Gas Decoupling or compensation, in a circle system, the fresh gas flow would be added to the tidal volume

Example:
Vt set at 600, FGF 1 l/m

I:E ratio 1:2
RR 10/min
Therefore 6 seconds/breath, 2 seconds insp, 4 seconds expiration

1 l/min = 1000 ml/min = 1000 ml / 60 sec = 17 ml/sec
Therefore 34 ml are added to each inspiration
Vt set at 600, FGF 6 l/minute

I:E ratio 1:2
RR 10/min
Therefore 6 seconds/breath, 2 sec insp, 4 sec exp
6 l/min = 6000 ml/min = 6000 ml/60 sec = 100 ml/sec
Therefore 200 ml are added to each insp
Vt may increase to 800 ml
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Aisys method

Measure the flow, derive tidal volume
If tidal volume decreases, increase pressure/volume delivered
If tidal volume increases, decrease pressure/volume delivered
Repeat....
GE flow sensor

- Lower Flow
- Higher Flow
- Reverse Flow

- Transducer Diaphragm
- Differential Pressure Transducer
- Flow Sensor Connector
- Flow Sensor Lines
- Flow Sensor Tube
- Flow Sensor Flap

Gas Flow
**Standard Vent plus sensors**

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Draeger Method

When the ventilator is driving gas to the pt, route the fresh gas flow during inhalation into the rebreathing bag/scavenging

Therefore a leak in the rebreathing bag will yield a circuit leak

Total volume of system is increased, increasing the time constant
Drager Piston Vent

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Engineered to keep the gas moving, decreasing the time needed to mix in fresh gas
Relation between Fresh Gas Flows, Rebreathing, Fi, and Fe

Old anes machines had mechanical/analog methods to maintain $F_iO_2 > 25\%$

Drager OMRC, used pressure gradient between oxygen and nitrous to keep $F_iO_2$ up

Ohmeda used link 25 to mechanically tie flows together

Current models use computers and controlled flowmeters
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% = 0.01 x 4000 = 40 ml/min delivered.
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/minute is from exhaled gases
So it has a lower concentration of gases (O₂, agent)
CO₂ is removed (one hopes)
Air (at 1 l/m) is hypoxic...
Only contains 210 ml O₂
Leaves only 10 ml of O₂ to mix with old gas...
Problems with computer control...1

Air France 477 Airbus 330
pitot tube iced over
lack of inputs
improper response by crew
Problems with computer control 2....

Boeing 737 Max MCAS system

single point of failure

sensor thinks AOA is too high, forces nose down
General issues/specific issues

Overall issues with computerization, feedback loops

Single point of failure (737 max), human reliance on computers (AirFrance 477)

Safety design features (separate knob, tactile coding) bypassed

Change in software $\rightarrow$ change in functions without apparent/obvious change
Future of Anesthesia Systems

Good

Computer control can offload work

Bad

false inputs $\rightarrow$ false outputs
lack of user experience handling workload/situations
Guess what…

Anesthesia machines (& humans) can “morph”

Memetic evolution

Reprogramming. Old hardware, new software, anes machines can behave in new ways…
Have a plan...

Know how to go to manual...
Look at the patient...
Major problem, universal solution?
Ambu bag + TIVA
Questions?

jfszocik@gmail.com
references

6. Virtual Anesthesia Machine Project. Project Director: Sem Lampotang, Ph.D., Simulation Engineer: Dave Lizdas, BSME Clinical Advisers: Nikolaus Gravenstein, MD, UF College of Medicine Faculty and Members of the International VAM Network. https://vam.anest.ufl.edu/ Soon to be outdated due to Adobe Flash limitations…