ANESTHESIA DELIVERY SYSTEMS (ADS)

Ventilators

**Fabius compensates for Circuit Compliance**

But, only for the compliance measured during pre-use system check
Adding tubing will add compliance – Fabius will not adapt
Record circuit compliance if adding length during case is possible
Compliance is likely linear with length
Compliance will have little or no impact during spontaneous breathing

**Fabius will not compensate for Lung Compliance or Changes in lung compliance**

**SmartVent will compensate for changing circuit and lung compliance**

SmartVent has exhaled tidal volume feedback
If circuit or patient compliance changes,
exhaled volume changes
next inspired tidal volume is adjusted to compensate for this

**Compliance will not impact spontaneous breathing much.**

Airway pressure will not differ much from zero
Thus, with no change in pressure, there will be no change in volume

Three Ventilator types at BWH

**Uncompensated Bellows Movement Control**
Gas Compression and tubing expansion decrease actual tidal volume
Fresh gas flow (during each inspiration) adds to actual tidal volume
Ohmeda Modulus 2 Plus and CD

**Fresh Gas Flow decoupled**
Piston pushes defined volume into lungs
Fresh gas is stored in reservoir bag during inspiration
Piston takes first from reservoir bag, then from Exhaled gas
Feature of Draeger Fabius and Apollo

**Exhaled tidal volume feedback control**
Bellows moves approximately set tidal volume
Exhaled volume is measured with a Variable Orifice Flow Sensor
Next and subsequent inspired bellows movement changes
Bellows volume changes based on previous exhaled tidal volumes
Feature in SmartVent® in Ohmeda Modulus SE and Ohmeda Aestiva
SmartVent® will compensate for changing circuit and lung compliance
SmartVent has exhaled tidal volume feedback
If circuit or patient compliance changes,
exhaled volume changes for one breath
next inspired tidal volume is adjusted to compensate for this
full compensation within 6 breaths
WYSIWYG What You Set Is What You Get

Four Gas Flow Sensor Technologies at BWH

Turbine Flow Sensor
Turbine (fan) spins, light is interrupted by the blades
Second light sensor-receiver pair senses direction
Turbine must be on expiratory limb
Turbine Clip must have arrow point in director of expired flow

Hot Wire Anemometer Flow Sensor
Wire is heated. Flow of gases cools it
Desflurane has high specific heat and cools sensor more
Des comp means Desflurane compensation on
Draeger Fabius.
Under left side of top surface of Absorber+ assembly
Subject to physical damage leading to leak and bad measurements

Differential Pressure Across Variable Orifice Flow Sensor
Variable orifice allows accuracy over flow range from infant to giant
Variable orifice is a mylar flap valve which opens wider with flow.
Nonlinearity characteristic of orifice is coded into a microchip in each sensor.
One water droplet disables pressure reading and flow calculation
Keep this sensor dry
Keep pressure sample ports pointing up
Any blockage of tubing between orifice and transducer will disable flow
SmartVent is in Ohmeda Modulus SE and Aestiva

Ultrasonic Flow Sensor
Present in Draeger MRI anes machine
Sound waves bounce off expired gas flow

Two Gas Sensor Technologies at BWH

Circuit Oxygen Sensor is common and present on most Anes Machines
All the same time with three names
Polarographic, Galvanic, Clark Cells are Circuit Oxygen Sensors
Cell is too slow to measure more than just inspired or expired gas
Cell is placed where Fresh and Exhaled gases are mixed to form Inspired
You must calibrate Circuit Oxygen Sensor at least once daily
Calibration is part of pre-use check
Expose sensor to air and press Calibration Button
Button differs from machine to machine
Principle is the same for all Circuit Oxygen Sensors
Cell may not be present in Apollo Anes Machines
Calibrate Circuit Oxygen Sensor at 21%, check at 100%
21% Oxygen Cal is mandatory and important for patient care
100% Oxygen is a useful test of the Cell’s performance
If cell is correct at 21% and> 10% off at 100%, request new O2 Cell

Sampled Gas Sensor is present on all Anes Machines
Sampled Gas Tubing connects from Y to multi-gas monitor
Multi-gas monitor measures CO2, N2O, Agent, possibly O2
Multi-gas monitors are fast and measure Insp and Exp concentrations
CO2 portion is fast enough to display CO2 wave morphology
Some Sampled Gas Monitors show wave of O2 (Datex Ultima, Apollo)
Some Sampled Gas Monitors do not show wave of O2 (RGM, SAM)
Sampled Gas oxygen is likely more accurate than Circuit Cell Oxygen

Sampled Gas Monitor does not need user Calibration
Sample Gas Monitor automatically samples room air and Zeros or Calibrates
Auto Cal O2 = 21%, CO2 = 0 mmHg, Agent = 0%, N2O = 0%
This is called Sidestream since it takes a sample from side of expired gas stream
Mainstream refers to CO2 sensor which is placed in the expired flow stream
Sampled Gas Monitor is calibrated every 3 or 6 months
If Gas Monitor seems inaccurate, request BMET calibrate it for you
Page BMET (Bio Medical Equipment Technician) On Call Pager 11055

All Sampled Gas Monitors at BWH
All Gas Sensor connections need to be tight
Loose Gas Sample Line will give incorrect gas readings
Loose Gas Sample Line will allow room air to be entrained
Monitor will read mixture of patient gas and room air
Dilution applies to Inspired and Expired readings
Oxygen dilutes toward 21%, CO2, Agent, N2O dilute toward 0.
Clinician ETpCO2 = approximately 40 mmHg. This is a good test.
CO2, N2O, Agent use NDIR (Non-Dispersive Infra Red) absorption sensor
Oxygen uses Electronic Paramagnetic O2 sensor

Positive Pressure Ventilation further confuses the incorrect gas readings
During the positive pressure phase of inspiration, leak dynamics change
Patient gas is pushed along Gas Sample Line and out the leak
The input connector of the Gas Monitor is swamped with patient gas
The gas monitor gets a better sample of patient gas
The CO2 waveform develops a higher plateau
The timing of the higher plateau depends on the length of the Sample Gas Line
Readings confuse even the best of clinicians
Remedy Tighten Sample Gas Line Connections at Y, Filter, Stopcock, Aquanaut,
Sample Gas - what is done with it after it is analyzed
Two Options - Sample Gas Return (SGR) or Sample Gas to WAGD
Sample gas is the gas sampled from the Y in the breathing circuit
Sample Gas and be recycled or disposed of
Recycled means Sample Gas Return to exp limb of breathing circuit (SGR)
\Disposed means collecting it and sending it to the WAGD system
WAGD stands for Waste Anesthetic Gas Disposal, AKA scavenger

Older Ohmeda Modulus 2+ and SE have SGR connected to CO2 absorber
A specific port is on Absorber but functionally in Expired Ckt Limb
Connection is labeled “Expiratory Airway Pressure”
Ohmeda Aestiva and Draeger Fabius need circuit adapters for SGR
SGR connector is black or silver color and connected to CO2 Absorber Exp limb
Sample Gas to WAGD is available on all machines

Leak Tests are confused by Sampled Gas and Sampled Gas Return

Pre-Use check seeks leaks from breathing circuit
Sample Gas and Sample Gas Return or Disposal confuse tests

During Leak Test, be careful with Sample Gas and Sample Gas Return
One bad and Two good options
Bad – Connect one but not both of Sample and Return
   Connect Sample = 200 mL/min leak
   Connect Return = 200 mL/min anti-leak or volume gain
Good - Disconnect Sample Gas and Sample Gas Return
Good - Connect both Sample Gas and Sample Gas Return
   This also checks gas monitor for leaks
Sample Gas Return from Gas Monitor (SGR) can confuse leak tests

Charcoal Anesthetic Agent Absorbers

Charcoal Absorbers can remove volatile agents from effluent gas
Charcoal is “activated” in factory by heating to eliminated hydrocarbons
Charcoal absorber can be placed where Scavenger is attached
Charcoal absorbs Iso, Sevo, Des, and other vapors
Charcoal does not absorb Nitrous Oxide
Don’t use Nitrous Oxide where there is no proper WAGD System
WAGD is the standard acronym for Waste Anesthetic Gas Disposal
Outlying Anesthetizing Locations need innovative scavenging
No wall Waste Anesthetic Gas Disposal (WAGD) System
Charcoal absorber on scavenger connection accomplishes this
These Anes Machines are not fitted with Nitrous Oxide
Rooms without WAGD System also lack wall Nitrous Oxide
Wide bore hose connects between Circuit and Charcoal Absorber

Charcoal Absorbers absorb 50 g anesthetic
Volume = 50 g / 1.5 g/mL = 33 mL liquid anesthetic
Anes Tech will weigh Charcoal Absorber after each anesthetic
Anes Tech will discard Charcoal Absorber that has gained 50 g

Charcoal Absorbers absorb almost same amount that vaporizer delivered
All agent from vaporizer goes to Patient or out Scavenger to Absorber
At end of case, agent in patient goes out Scavenger to Absorber
Therefore, Charcoal Absorber collects all that leaves the vaporizer
directly via excess FGF or indirectly via Patient
Amount absorbed is a bit less by amount patient retains on discharge from OR

Altitude affects Gases and Vaporizers

Partial pressure of anesthetic is what anesthetizes the patient
Partial pressure of oxygen is what oxygenates the patient
Concentration of gases describes fractional composition
Concentration times local barometric pressure = partial pressure
This applies to all gases

Barometric pressure decreases with altitude
Barometric pressure decreases approximately 20 mmHg / 1000 ft
Fractional barometric pressure makes calculations simple
Sea Level = 1.00, Denver = 5000 ft = 0.87 Atm, Vail base = 800 ft = .79 Atm
Vail Peak = 11,570 ft = .71 Atm

Concentration-Delivery Vaporizers under-anesthetize at altitude
Desflurane via Tec 6 Vaporizer provides the dial set concentration
Concentration is fractional composition
Desflurane partial pressure is reduced proportional to barometric pressure

Nitrous oxide concentration under-anesthetizes at altitude
Nitrous oxide flow / FGF = Delivered Nitrous Oxide concentration
Nitrous oxide partial pressure is reduced proportional to barometric pressure
Oxygen concentration is not as effective at altitude
Oxygen flow / FGF = Delivered Oxygen concentration
Oxygen partial pressure is reduced proportional to barometric pressure
For 21% Atm, the following concentrations are needed
Sea Level need 21%, Denver (5000 ft) need 24%, Vail base (8000 ft) need 27%

Partial Pressure Delivery Vaporizers perfectly anesthetize (Sevo, etc)
Modern Vaporizers for the volatile liquids Iso, Sevo, Halo are all similar
Dial is set and produces a splitting ratio.
Flowmeter gas splits between vaporization chamber and bypass
The actually splitting is applied at the outflow of the vaporization chamber
Thus, saturated vapor pressure (mmHg) is fractionally divided by the split
Output is constant partial pressure at any altitude
These vaporizers correctly anesthetize at altitude

Approximate Partial Pressure Delivery Vaporizers (Tec 3) slight overdose
Older vaporizers for Halothane, Enflurane, and Isoflurane were different
Split was at entrance to Vaporization Chamber rather than at exit from chamber
Outflow fraction from vaporization chamber increased slightly with altitude
These vaporizers slightly over anesthetized at altitude
Some textbooks and papers still cite this incorrect obsolete design
ABA may currently use correct or incorrect analysis

Oxygen Ratio Control differs among machines

Ohmeda Modulus 2+, Modulus SE, Aestiva) use Chain Link and turn knob
Hidden Chain links O2 and N2O needle valves and prevent Fresh Gas < 25% O2
If rotate N2O or O2 to produce Fresh Gas < 25% oxygen then other knob turns
Nitrous turned up or oxygen turned down drags the other needle valve
No hidden or undisclosed functionality; The knob has rotated
Icon/Picture of a chain linking the knobs is on the machine

Draeger Narkomed, Fabius, Apollo use N2O Flow restriction
Flow Sensor measures O2 and N2O needle valve flows
If setting would produce Fresh Gas < 25% O2, pressure to N2O is diminished
Decreased pressure causes decreased flow of N2O
If you later increase O2 flow, N2O flow increases by itself
N2O turned up or O2 turned down deceases pressure to N2O needle valve
Hidden, undisclosed functionality is present; Knob is constant, flow is reduced
You can but should not administer hypoxic gas mixture to patient
Anes Machine controls FGF (delivered) O2 concentration > 25%
You control Inspired O2 Concentration
Anes Machine allows Inspired Concentration as low as 0%
Inspired gas is a mixture of Fresh (Delivered) Gas and Expired Gas
This mixture can be lethal
Low FGF and lack of understanding are a dangerous combination
Beware, Beware, Beware

Miscellaneous
Aestiva Absorber hides Oxygen Sensor and Water Dump Button
Datex-Ohmeda Aestiva Anesthesia Machines are mostly in L&D
An Aestiva/5 with Heliox, Oxygen, and N2O is in ENT OR #6
An Aestiva is usually in INR
Absorber houses SmartVent flow sensors
Door on front of Absorber assembly opens and hides:
Oxygen sensor, to be removed and placed in air during daily calibration
Water Dump button (with faucet as icon) to be pressed between cases
Pressing this between cases will reduce or eliminate water buildup

Negative Pressure Leak Test (NPLT) is sometimes required
NPLT detects a leak in Anes Machine Low Pressure System
Low Pressure System is from Pressure Regulator to Common Gas Outlet (CGO)
Concept – “low pressure” because the pressure drops at the needle valve
NPLT is required on ADSs with a 1-way valve between Vaporizer and CGO
NPLT (Negative Pressure Leak Test) is performed as follows
Switch off Anes Machine to achieve 0 FGF.
Flow = 50 mL/min is almost perfect.
Take negative pressure bulb from bottom drawer of Anes Machine
Test negative pressure bulb: occlude CGO connector with finger; squeeze bulb
If bulb fills, bulb has a leak. Replace it.
Connect negative pressure bulb to CGO (Common Gas Outlet, FGF source)
With a vaporizer on, squeeze bulb three times to apply neg. pressure to CGO
If bulb fills, there is a leak
Leak is in needle valve, flow meter, vaporizer, pipe, vaporizer fitting
Test each vaporizer this way
Several Common leak sources:
Vaporizer Filler Port open, Flow Tube broken, Vaporizer mis-seated on back bar
Draeger Fabius Alarms can be confusing – Some of them work as follows

Ventilation alarms depend on pressure ventilator achieves and pressure thresholds
Vent Monitor wants threshold to be 4 cmH2 below present peak ventilation pressure
If Vent pressure is too high or too low compared with this, alarm sounds
Pressure Threshold Low Advisory means you should raise the threshold
This will make monitor more sensitive to leak or decreased pressure
Apnea Pressure means pressure did not cross the threshold
You may be ventilating adequately but monitor only knows Pressure &Threshold
How to correct this warning or advisory
1) Check patient IS BEING VENTILATED AS YOU PLANNED
2) Reset thresholds to current situation of ventilator settings and patient physiology -
2) Press SETUP button; Press AUTO SET. You are done.

Usual source of alarm is Changed Tidal Volume Setting; This changed Pres.

Pre-Use Check Documents are available on each Anes Mach
Every machine has its machine-specific pre-use check list attached to it
Pre-Use Check is usually on chain at right back corner of Anes Machine
Pre-Use Checks vary slightly from model to model
Draeger Fabius is very different and includes automatic ventilator calibration
Documents are available on Anes Dept Web Site
http://etherweb.bwh.harvard.edu/education/resources/technology_resources.php

Abbreviated Pre-Use Check misses a bit
Manual Resuscitator (e.g., Ambu Bag) should be present
One on Anesthesia Machine, One on Red Cart
Fabius - Flow Sensor Calibration is electronic. Do it.
Sample Gas Return and Sample Gas Sensor - OnOn or OffOff
If Sample Gas Return is not On, connect sample gas to Scavenger
CO2 Absorbent mostly white

Please empty water trap in Fabius Ventilator hose
Empty water trap in Fabius Ventilator hose before using Fabius and observe and empty if full during case.
Failure to do this will result in Alarms and Ventilator Failure

First alarm is an incorrect one – “Low Fresh Gas Flow”
Fabius has misinterpreted what is wrong
Piston tried to refill but encountered negative pressure
Negative pressure value is equal to depth of water pool in hose
Negative piston pressure is misinterpreted
Alarm thinks reservoir bag is empty because FGF is low
Low Fresh Gas Flow Alarm sounds
Clinician is confused

Second problem is real - Vent Failure Alarm and Vent Failure
This is from water too deep in the vent hose.

Keeping water trap from overfilling will prevent this problem
Emptying water trap is easy. Pull cover
Please empty water from Aestiva water trap next to oxygen sensor
Drain Button is behind door on CO2 Absorber
Door also hides Oxygen Sensor
Drain between cases and whenever drops are seen in breathing circuit

Use an HME whenever possible
HME = Heat and Moisture Exchangers, AKA artificial nose
At BWH we use HME to keep the breathing circuit dry
Wet breathing circuit degrades ventilator performance
All machines = VTE measurement becomes inaccurate
Draeger –mostly inconvenient, hides lung compliance
Aestiva – Fails to compensate for FGF and Pt changes.
Aestiva – Volume Vent only; no Pressure Vent
Aestiva - Stops ventilating and alarms

Draeger Fabius and Apollo require PRESS ROTARY KNOB TO CONFIRM
Be careful
Green light flashes to remind user to press Rotary Knob to confirm
Ohmeda Smart-Vent allows Confirm with Rotary Knob or Original Select button
Beware, Beware, Beware
This is a challenge to all of us

Backup O2 Tank is present on all Anes Machines
Backup O2 Tank pressure should be > 1000 psi
Full tank pressure is 2000 psi
Pre-use check includes assuring Backup Tank pressure

Leave Backup Tank Valve turned OFF except during testing
If Tank is on, machine leaks and pressing Flush button will drain tank

No Backup N2O tanks are present on Anes Machines at BWH
Use another anesthesia adjunct if wall N2O fails or is not available
Tank N2O is not present especially in locations without WAGD systems

Nominal wall pressure is 55 psi for medical gases
Nominal wall pressure for O2 and N2O are 55 PSI each
Nominal wall pressure for N2 (for drills, etc) is 200 PSI
Nitrogen pressure can be adjusted with a control in each OR

SmartVent needs ADS to be switched off every 12 hours
This zeros the pressure transducers that measure flow

PEEP Valves
Are removable from older machines
Are easy to assemble
Provide PEEP in forward direction; Provide ZEEP in reverse direction
Earlier PEEP valves obstructed in reverse direction
PEEP Valves ADD their PEEP$s$
Circuit Pressure Gauge connects to Inspired Limb (not Absorber)
**Technology Documents are available**
Every machine has its machine-specific pre-use check list attached
Pre-Use Check is usually on chain at right back corner of Anes Machine
Pre-Use Checks vary slightly from model to model
Draeger Fabius is very different and included automatic ventilator calibration
Documents (Microsoft Word) are available:
http://etherweb.bwh.harvard.edu/education/resources/technology_resources.php

**If an Anes Machine or Monitor is not working, call for help**
Anes Tech is first line of defense
BMET (Biomedical Engineering Equipment Tech) is definitive resource
Biomedical Engineering OR Team On Call
Emergency - Page 1-1055
Elective – Call and leave message at 3-1987
Elective – Email BWH Anes Biomed via Outlook

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