The Anesthesia Gas Machine

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  - Dräger Divan, Julian, Fabius GS, AV-E and AV-2; Datex-Ohmeda 7000, 7100, 7800, 7900
  - SmartVent, S/5 ADU, Kion

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  • Negative pressure leak check, Minimum test under life-threatening conditions, Electronic checklists, FDA anesthesia gas machine checklist 1993, Modified Anesthesia Gas Machine Checklist
• Medicolegal
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• Cleaning and sterilization
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  • Care of specific equipment

ANESTHESIA GAS MACHINE> NEW GAS MACHINES
• Dräger Medical Inc. (Telford, Pennsylvania)
  • Narkomed 6400 and 6000, Narkomed Fabius GS, Narkomed GS, Julian, Narkomed MRI, Narkomed Mobile, Narkomed 2C, Narkomed 4
• Datex-Ohmeda (Madison Wisconsin)
  • S/5 ADU (also known as S/5 or AS/3 ADU), Aestiva, Aestiva/5 MRI, Modulus SE, Excel 210, Excel 110
• Siemens
  • Kion
ANESTHESIA GAS MACHINE> NEW GAS MACHINES> NEW CAPABILITIES, NEW ISSUES> ADVANCED VENTILATION, INTEGRATED MONITORING, LOW FLOWS, TRAINING, ELECTRONIC CHECKLIST

- Purchasing new gas machines
  - Education and training (Advanced ventilation, Computer and monitor integration, Low flows, Laryngeal mask airway and mechanical ventilation, Electronic Checkout)
- Operating costs
- Installation of new machines

ANESTHESIA GAS MACHINE> TEST YOURSELF

Supply system: Gases & electricity

Gas sources

Pipeline
The hospital medical gas pipeline source is the primary source for the anesthesia gas machine. Oxygen is produced by fractional distillation of liquid air. It is stored as a liquid at -150 to -175 degrees C in a large flask (because the liquid occupies 1/860 of the space the gas would occupy). Safety systems and regulators send oxygen to the hospital pipeline at approximately 50 psi; the "normal working pressure" of the anesthesia gas machine.

Nitrous oxide is stored as a liquid, at ambient temperature, in large tanks (745 psi- H tank) connected to a manifold which regulates the pipeline pressure to approximately 50 psi.

Pipeline inlets (near the yoke blocks for cylinders) are connected with DISS (diameter index safety system) non-interchangeable connections. The check valve, located down stream from the pipeline inlet, prevents reverse flow of gases (from machine to pipeline, or to atmosphere), which allows use of the gas machine when pipeline gas sources are unavailable.

Cylinder source

Standards
Standards for cylinders are written by the U.S. Department of Transportation (DOT), the Compressed Gas Association, the National Fire Protection Association, and the American Society of Mechanical Engineers. US DOT regulations have the force of law, as do Food and Drug Administration (FDA) regulations on the quality and purity of the medical gas contents.

Capacity, color, markings of cylinders
(from CGA Pamphlet P-2)
**Cylinder component parts**

**Cylinder valve** - most fragile part, so protect during transport. Consists of

- body
- port (where the gas exits)
- stem (shaft)
- handle or hand wheel (to open the valve)
- safety relief device
- conical depression (opposite the port, it accepts the tip of the screw which secures the cylinder in the yoke)
- PISS pins (Pin Index Safety System)

The **safety relief device** is composed of at least one of

- frangible disc (bursts under extreme pressure),
- fusible plug (*Wood's metal*, which has a low melting point), or
- safety relief valve (opens at extreme pressure).

The **hanger yoke**:  
1. orients cylinders,  
2. provides unidirectional flow, and  
3. ensures gas-tight seal.

The **check valve** in the cylinder yoke functions to:  
1. minimize trans-filling,  
2. allow change of cylinders during use, and  
3. minimize leaks to atmosphere if a yoke is empty.

**Storage, handling and installation**

- Use only aluminum cylinders in an MRI suite.
- Use only one washer, or PISS system will be defeated.
- Do not oil valve.
- Protect the valve when transporting.
- *Never* stand upright without support.
To install

1. Check & remove labels
2. Hold valve away from face, and "crack" valve
3. Place in hanger yoke
4. Observe for appropriate pressure and lack of audible leak.

- Leave cylinders on machine closed.
- Don't leave empty cylinder on machine.

For more detail, see Safety rules for handling compressed gases

Medical gases

Nitrous oxide is manufactured by thermal decomposition of (NH4)2NO3. It is non flammable but supports combustion (same as oxygen). Oxygen is produced by fractional distillation of liquid air. Impurities are permitted in medical gases as long as they do not exceed small amounts of known contaminates.

Use

Reserve tanks are present on the gas machine for emergency use. Marked & color-coded. (Beware if you practice overseas- there are US and global color standards, which differ.) PISS (pin-index safety system) prevents misconnection of a cylinder to the wrong yoke. Keep cylinders closed except when checking, or while in use. The **cylinder pressure regulator** converts high, variable cylinder pressure to a constant pressure of approximately 45 psi downstream of the regulator. This is intentionally slightly less than pipeline pressure, to prevent silent depletion of cylinder contents if a cylinder is inadvertently left open after checking its pressure. Cylinder pressure **gauge** indicates pressure in the higher-pressure cylinder only (if two are opened simultaneously).

Electrical power supply

Main electrical power is supplied to the gas machine through a single power cord which can become dislodged. Because of this possibility, as well as the possibility of loss of main electrical power, new gas machines must be equipped with battery backup sufficient for 30 minutes of limited operation. What functions remain powered during this period is device-specific, so one must familiarize oneself with the characteristics of each model. For example, if you disconnect electrical power from the S/5 ADU, it loses monitors (right screen), but gas delivery and ventilation continue during the period when you are relying on battery backup.

Convenience receptacles are usually found on the back of the machine so that monitors or other equipment can be plugged in. These convenience receptacles are protected by circuit breakers (usually) or fuses.

It is a mistake to plug devices into these convenience receptacles which turn electrical power into heat (air or water warming blankets, intravenous fluid warmers) for two reasons. First, these devices draw a lot of amperage (relative to other electrical devices), so they are more likely to cause a circuit breaker to open. Second, the circuit breakers are in non-standard locations (so check for their location before your first case). In the Modulus SE they can only be reset by reaching from the front of the machine over the vaporizers(!). If a circuit breaker opens, all
devices (monitors, perhaps the mechanical ventilator) which receive their power there may cease to function. If you are not familiar with the circuit breaker location, valuable time may be lost while a search is conducted.

**Failures and faults**

**Loss of main electrical power**

Devices (or techniques) which **do not rely** on wall outlet electrical power include:

- spontaneous or manually assisted ventilation
- mechanical flowmeters
- scavenging
- laryngoscope, flashlights
- intravenous bolus or infusion
- battery operated peripheral nerve stimulators or intravenous infusion pumps
- monitoring using the anesthetist's five senses
- variable bypass vaporizers (Tec 4, Vapor 19)

Devices which **require** wall outlet electrical power include:

- mechanical ventilators
- electronic monitors
- room and surgical field illumination
- digital flowmeter displays for electronic flowmeters
- cardiopulmonary bypass pump/oxygenators
- air warming blankets
- gas/vapor blenders (Suprane Tec 6) or vaporizers with electronic controls (Aladin cassettes in the S/5 ADU)

Generally, hospitals have emergency generators that will supply operating room electrical outlets in the event power is lost. But these backup generators are not completely reliable. Troianos (*Anesthesiology* 1995;82:298-302) reports on a 90 minute interruption in power during cardiopulmonary bypass, complicated by almost immediate failure of the hospital generators. One unanticipated hazard was injuries to personnel as they went to fetch lights and equipment.

In older gas machines, loss of room illumination, mechanical ventilators and electronic monitors were the principal problems. In general, new gas machines have battery backup sufficient for 30 minutes of operation—also, however, without patient monitors or mechanical ventilation. New flowmeters that are entirely electronic (Julian) require a backup pneumatic/mechanical flowmeter (“Safety O2” flowmeter). Mechanical flowmeters with digital display of flows have a backup glass flow tube which indicates total fresh gas flow (S/5 ADU, Fabius GS). New gas machines with mechanical needle valve flowmeters and variable bypass vaporizers (ie Fabius GS) have an advantage in that delivery of gases and agent can continue indefinitely—but how long do you want to continue
surgery by flashlight, and anesthesia monitored by the five senses? The Narkomed 6000 and Julian provide gas and vapor delivery and all monitors (oxygen, volume and pressure, gas monitoring) for 30 minutes if main electrical power is lost.

It remains critical to understand and anticipate how each particular anesthesia gas machine type functions (what parts and for how long) when main electrical power is lost. The best place to find this information is in the operator’s manual.

**Failure of pipeline oxygen supply**

**Pipeline sources are not trouble free:** contamination (particles, bacteria, viral, moisture), inadequate pressure, excessive pressures, and accidental crossover (switch between oxygen and some other gas such as nitrous oxide or nitrogen) are all reported. These are not theoretical problems. Intraoperative hypoxemia related to pipeline gas contamination continues to be reported in the US ([Anesth Analg](1997;84:225-7), [Anesth Analg](2000;91:242-3)).

For a crossover, one must

1. turn on backup oxygen cylinder, and
2. disconnect oxygen pipeline supply hose from the wall.

Gas will flow from whichever source is at a higher pressure- the pipeline (at 50 psi, containing for example, nitrous oxide) or the emergency tank supply of oxygen (supplied to the machine at 45 psi). So you must disconnect the pipeline supply.

In contrast, if oxygen pressure is lost entirely, a low oxygen supply alarm will sound, and the fail safe system will activate (see next section). Similar to a crossover, first you must open the backup oxygen cylinder fully.

Anesthetists are not in the habit of doing this- usually we need to open the cylinder 2 or 3 turns for checking its pressure. It must be opened fully when using it as the oxygen source, or it may not empty completely. Second, although it is not strictly necessary, I advocate disconnecting the pipeline supply if it fails for two reasons:

1. The oxygen supply system has failed. Until notified that it is functional and free of impurities, why use it? If the pressure is restored, but with inappropriate (non-oxygen) contents, the pipeline (wrong) gas will flow if its pressure exceeds the regulated cylinder pressure (45 psi).
2. It is mandatory to disconnect the pipeline in case of a crossover. Is it wise to memorize two different strategies for two similar problems, when disconnecting from the pipeline supply is a safe response for both situations?

It is recommended to ventilate manually when pipeline oxygen is unavailable in machines which use oxygen in whole or part as the driving gas that compresses the ventilator bellows. Maintaining mechanical ventilation in the absence of pipeline oxygen can use an entire E cylinder of oxygen (approximately 600 L) in an hour or less ([Anesth Analg](2002;95:148-50)).

This admonition applies to almost all gas machines. The exceptions are piston ventilators, which do not use driving gas or bellows at all (Narkomed 6000, Fabius GS). They only require electrical power and fresh gas flow. A
second exception would be the S/5 ADU, which can sense the loss of oxygen and switch to piped air as the driving gas, which would also tend to preserve the cylinder oxygen for the fresh gas flow.

Diagram of the left hand display of the Datex-Ohmeda AS3 ADU. Click on the thumbnail, or on the underlined text, to see the larger version (77 KB).

Users should exercise caution with regard to the displayed "calculated oxygen" concentration on the Datex-Ohmeda AS/3 ADU gas machine. The "Calc. 0₂ %", optionally displayed in the mid-lower left of the primary machine status screen, is based on the flowmeter settings only-unlike the oxygen analysis results displayed in the lower center area. The danger arises in a crossover situation where the pipeline oxygen supply is replaced with another gas (for example, nitrogen). In this emergency, two sections of the same display will offer conflicting information. Because it is based on flowmeter settings, the "Calc. 0₂ %" will indicate the set oxygen concentration. The oxygen analyzer display will simultaneously alarm, accurately showing a dangerous hypoxic mixture. Although the manual clearly warns of this problem, the design may confuse providers in this rare emergency situation, and delay their response

### Processing: Fail-safe, Flowmeters, Hypoxic guard

#### Fail-safe system

What happens if you lose oxygen pipeline pressure?

The fail safe device ensures that whenever oxygen pressure is reduced and until flow ceases, the set oxygen concentration shall not decrease at the common gas outlet. In addition, the loss of oxygen pressure results in alarms, audible and visible, at 30 psi pipeline pressure.

Fail-safe systems don’t prevent hypoxic mixtures. For example, as long as there is pressure in the oxygen line, nothing in the fail safe system prevents you from turning on a gas mixture of 100% nitrous oxide (however, this should be prevented by the hypoxic guard system) or 100% helium (which wouldn’t be prevented by the hypoxic guard since the hypoxic guard only connects oxygen and nitrous oxide flowmeters).

Datex-Ohmeda terms their fail safe a "pressure sensor shut off valve"- at 20 psi oxygen, the flow of all other gases are shut off. Also, Ohmeda uses a second-stage O2 pressure regulator (ensures constant oxygen flowmeter input until supply pressure is less than 12-16 psi).

Dräger’s "oxygen failure protection device" (OFPD) threshold is proportional, unlike Ohmeda’s which is off-or-on. The oxygen ratio monitor controller (ORM [newer] or ORMC, both by Dräger) shuts off nitrous oxide when oxygen pressure is less than 10 psi.

The newest Dräger machine, the Fabius GS, uses a Sensitive Oxygen Ratio Controller (S-ORC). It’s fail-safe component shuts off nitrous oxide if the oxygen flow is less than 200 mL/min, or if the oxygen fresh gas valve is
closed. Audible and visible alarms sound if pipeline pressure is less than 1.38 ± 0.27 bar (20 ±4 psi). In case of complete oxygen pipeline failure, the machine will supply pipeline air so that some oxygen and agent can still be supplied to the patient.

**What should you do if you lose oxygen pipeline pressure?**

Just like a crossover,

1. Open the emergency oxygen cylinder fully (not just the three or four quick turns used for checking)
2. Disconnect the pipeline connection at the wall

- Why? Something is wrong with the oxygen pipeline.
- What if the supply problem evolves into a non-oxygen gas in the oxygen pipeline? If so, it will flow (pipeline pressure 50 psi) rather than your oxygen cylinder source (down-regulated to 45 psi).
  - If you are lucky, the oxygen alarm will sound to warn you of the change (you do set your alarms, don't you?).
  - If for some reason the oxygen analyzer does not warn of the crossover, the pulse oximeter will- but only after the oxygen has been washed out by ventilation from the patient's functional residual capacity and vessel-rich group.
- So disconnect the pipeline connection at the wall if oxygen pipeline pressure is lost. It's also easier to remember one strategy which works for any problem with the pipeline, than to remember that sometimes you must, and sometimes it is optional, to disconnect. And use that oxygen analyzer always!

3. Ventilate by hand rather than with the mechanical ventilator (which uses cylinder oxygen for the driving gas if the pipeline is unavailable)

**Flowmeters**

**Glass flowmeters**

Diagram of a glass flowmeter. Click on the thumbnail, or on the underlined text, to see the larger version (51 KB).

Thorpe tube is an older term for flowmeters. The components are- needle valve, indicator float, knobs, valve stops. Flow increases when the knob is turned counterclockwise (same as vaporizers). At low flows, the annular-shaped orifice around the float is (relatively) tubular so (according to Poiseuille’s Law) flow is governed by viscosity. At high flows (indicated on the wider top part of the float tube), the annular opening is more like an orifice, and density governs flows.

Regular mechanical needle valves and glass flowtubes are utilized in the Excel, Modulus, Aestiva; and Narkomed 2, 3, 4, and 6000.
**Electronic flowmeters**

S/5 ADU electronic flowmeters are on the lower-left of the left hand display, Datex-Ohmeda S/5 ADU. Click on the thumbnail, or on the underlined text, to see the larger version (77 KB).

Fabius GS flowmeters and Common gas outlet flowmeter (left). Click on the thumbnail, or on the underlined text, to see the larger version (29 KB).

Gas machines with electronic flowmeters have no glass tubes, and the flow rate is indicated with a bar graph on a monitor screen. There is a needle valve (so flow can be generated even without electric power) in the S/5 ADU and Fabius GS. Flows are captured electronically as follows: flow from the needle valve is conducted to a small chamber of known volume and held there momentarily by a solenoid valve until the transduced pressure within the chamber reaches a preset limit. This gives a known mass of gas. This cycle is repeated sufficiently often for the desired flow rate to occur, and the number of times the solenoid opens is sensed and can be related to flow. Thus, electronic flowmeters allow automated anesthesia record-keepers to chart fresh gas flows. They are also five to ten times as accurate at metering gas flow than glass flowtubes.

Julian electronic flowmeters. Click on the thumbnail, or on the underlined text, to see the larger version (92 KB).

Setting fresh gas flow on the Kion and Julian machines is different. The flowmeters are all electronic. The controls and numeric display are on the lower-left of the control screen. The display is numeric, with an optional bar-graph display. The user sets

- FIO2 percent desired
- Total fresh gas flow L/min
- What carrier gas is desired (nitrous oxide, air)

**Using flowmeters**

Choosing an appropriate fresh gas flow rate is covered below in Delivery: Using breathing circuits and ventilators.

Flowmeters on some (particularly older) machines have a minimum oxygen flow of 200-300 mL/min. Some (especially newer) machines have minimum oxygen flows as low as 50 mL. Supply pressure 50 psi (Dräger); Ohmeda 14 psi (for oxygen), approximately 26 psi (nitrous oxide).

Safety features - The oxygen flow control knob is touch-coded. If a gas has two tubes, they are connected in series. All gas flows first through fine, then through coarse flowtubes, controlled by a single flow-control knob. The alternative, (very much) older, less safe arrangement is two tubes in parallel with two knobs. It is customary in the US for the oxygen flow tube to be on the right of the others, on the left in the UK. In either case, oxygen always enters the common manifold downstream of other gases.

Care of flowmeters includes ensuring that:

- floats spin freely,
qualified service personnel regularly maintain gas machines,

- an oxygen analyzer used always (of course, the readings are erroneous during the use of a nasal cannula),

- one never adjusts a flowmeter without looking at it,

- one includes flowmeters in visual monitoring sweeps, and

- one turns flowmeters off before opening cylinders, connecting pipelines, or turning machine "on".

**Auxiliary oxygen, common gas outlet, and scavenging flowmeters**

**Auxiliary oxygen flowmeters** are an optional accessory currently offered on many models of gas machines. They are useful for attaching a nasal cannula or other supplemental oxygen delivery devices. They are advantageous because the breathing circuit and gas delivery hose (between the common gas outlet and breathing circuit) remain intact while supplemental oxygen is delivered to a spontaneously breathing patient. Thus, if the anesthetist desires to switch from a nasal cannula to the circle breathing system during a case, he or she can accomplish this instantaneously, and without the possibility of forgetting to reconfigure the breathing circuit properly. Another advantage is that an oxygen source is readily available for the Ambu bag if the patient needs to be ventilated manually for any reason during a case (for example, breathing circuit failure). One disadvantage is that the auxiliary flowmeter becomes unavailable if the pipeline supply has lost pressure or has been contaminated; this is because the auxiliary flowmeter is supplied by the same wall outlet and hose connection that supplies the main oxygen flowmeter. If users do not realize this, then time could be wasted while they attempt to utilize this potential oxygen source.

**Common gas outlet flowmeters** are used as a backup on some gas machines that electronically capture and display flows on a computer screen (Fabius GS, S/5 ADU). They are optional but strongly recommended, as they are the only indication of oxygen flow if the computer display fails, or in a power failure situation after battery backup is exhausted.

**Scavenging flowmeters:** Many new machines use open scavenging interfaces. An indication that suction is adequate is mandatory with these systems in order to avoid exposure to waste anesthesia gases (see below Disposal: Scavenging and Waste gases). Unfortunately, the suction indicator may be occult (within the back cabinet behind the E cylinders in the Julian) or not included with the basic package, only as an optional accessory (S/5 ADU).

**Processing- Hypoxic Guard System**

Proportioning Systems are the board exam terminology for the hypoxic guard system. These systems link nitrous oxide and oxygen flows (mechanically, pneumatically, or electronically) to prevent final inspired oxygen concentration less than 0.25.

Photograph of the Link-25 system. Click on the thumbnail, or on the underlined text, to see the larger version (63 KB).
**Ohmeda Link 25:** A chain links nitrous oxide and oxygen flow control knobs, allows either to be adjusted independently, yet automatically intercedes to maintain a **minimum 1:3 ratio** of oxygen to nitrous oxide. Also, Ohmeda supplies nitrous oxide to its flow control valve at 26 psi, via a second-stage pressure regulator. Therefore, the system has pneumatic and mechanical components in its control of gas mixture. See *Anesth Analg* 2001;92:913-4 for a report of failure of the chain-link mechanism.

The hypoxic guard system includes desflurane on the S/5 ADU. However, when using air and desflurane on the S/5 (as well as on older machines) it is possible to deliver less than 21% oxygen. The hypoxic guard system does not prevent this (again, it only links oxygen and nitrous oxide). Of course, the oxygen concentration monitor (in the gas analysis module of the monitor) as well as the ADU itself (the left screen) should alarm under these conditions. The left (gas machine) side will alert the user to the fact that they have created a hypoxic mixture.

**Dräger ORMC** is a pneumatic interlock designed to keep fresh gas flow (FGF) at least 25 ± 3% oxygen, by limiting nitrous oxide flow (unlike the Link-25, which increases oxygen flow as nitrous oxide flow is turned on). The ORMC also rings alarms (it has an electronic component) which are inactivated in *All gases* mode (a switch found on older machines).

**Dräger S-ORC** (newest hypoxic guard system as found on Fabius GS) guarantees a minimum FIO2 of 23%.

**Key points**

- remember the alternate term proportioning system, and
- hypoxic guard systems **CAN** permit hypoxic breathing mixtures **IF:**
  1. wrong supply gas in oxygen pipeline or cylinder,
  2. defective pneumatic or mechanical components,
  3. leaks exist downstream of flow control valves, or
  4. if third inert gas (such as helium) is used.

**Processing: Vaporizers**

**Physical principles**

**Vapor pressure** Molecules escape from a volatile liquid to the vapor phase, creating a "saturated vapor pressure" at equilibrium. **Vapor pressure (VP) increases with temperature.** VP is independent of atmospheric pressure, it depends only on the physical characteristics of the liquid, and its temperature.

**Latent heat of vaporization** is the number of calories needed to convert 1 g of liquid to vapor, without temperature change in the remaining liquid. Thus, the temperature of the remaining liquid will drop as vaporization proceeds, lowering VP, unless this is prevented.

**Specific heat** is the number of calories needed to increase the temperature of 1 g of a substance by 1 degree C. Manufacturers select materials for vaporizer construction with high specific heats to minimize temperature changes associated with vaporization.
Thermal conductivity - a measure of how fast a substance transmits heat. High thermal conductivity is desirable in vaporizer construction.

**Classification**

Dräger Vapor 19.1, Vapor 2000, Penlon Sigma, Datex-Ohmeda S/5 ADU Aladin vaporizers, and Datex-Ohmeda Tec 4, 5 are classified as

**Variable bypass**

Fresh gas flow from the flowmeters enters the inlet of any vaporizer which is on. The concentration control dial setting splits this stream into bypass gas (which does not enter the vaporizing chamber), and carrier gas (also called chamber flow, which flows over the liquid agent).

**Flow over**

Carrier gas flows over the surface of the liquid volatile agent in the vaporizing chamber, as opposed to bubbling up through it (as in the copper kettle and Vernitrol)

**Temperature compensated**

Equipped with automatic devices that ensure steady vaporizer output over a wide range of ambient temperatures

**Agent-specific**

Only calibrated for a single gas, usually with keyed fillers that decrease the likelihood of filling the vaporizer with the wrong agent

**Out of circuit**

Out of the breathing circuit, as opposed to (much) older models such as the Ohio #8 (Boyle's bottle) which were inserted within the circle system.

The copper kettle and Vernitrol are measured-flow, bubble-through, non-temperature compensated, multiple agent, and out of circuit.
Vaporizer Models

<table>
<thead>
<tr>
<th>Classification</th>
<th>Datex-Ohmeda Tec 4, Tec 5, SevoTec, and Aladin (AS/3 ADU); Dräger Vapor 19.n, Vapor 2000</th>
<th>Copper Kettle, Vernitrol</th>
<th>Datex-Ohmeda Tec 6 (Desflurane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Splitting ratio (carrier gas flow)</td>
<td>Variable-bypass (vaporizer determines carrier gas split)</td>
<td>Measured-flow (operator determines carrier gas split)</td>
<td>Dual-circuit (carrier gas is not split)</td>
</tr>
<tr>
<td>Method of vaporization</td>
<td>Flow-over (including the Aladin for desflurane, which does not require added heat like the Tec 6)</td>
<td>Bubble-through</td>
<td>Gas/vapor blender (heat produces vapor, which is injected into fresh gas flow)</td>
</tr>
<tr>
<td>Temperature compensation</td>
<td>Automatic temperature compensation mechanism</td>
<td>Manual (i.e., by changes in carrier gas flow)</td>
<td>Electrically heated to a constant temperature (39°C; thermostatically controlled)</td>
</tr>
<tr>
<td>Calibration</td>
<td>Calibrated, agent-specific</td>
<td>None; multiple-agent</td>
<td>Calibrated, agent-specific</td>
</tr>
<tr>
<td>Position</td>
<td>Out of circuit</td>
<td>Out of circuit</td>
<td>Out of circuit</td>
</tr>
<tr>
<td>Capacity</td>
<td>Tec 4: 125 mL&lt;br&gt;Tec 5: 300 mL&lt;br&gt;Vapor 19.n: 200 mL&lt;br&gt;Aladin: 250 mL</td>
<td>200-600 mL (no longer manufactured)</td>
<td>390 mL</td>
</tr>
</tbody>
</table>

Vaporizer interlock

The vaporizer interlock ensures that
- Only one vaporizer is turned on
- Gas enters only the one which is on
- Trace vapor output is minimized when the vaporizer is off
- Vaporizers are locked into the gas circuit, thus ensuring they are seated correctly.

Operating principles of variable bypass vaporizers

Total fresh gas flow (FGF) enters and splits into carrier gas (much less than 20%, which becomes enriched-saturated, actually- with vapor) and bypass gas (more than 80%). These two flows rejoin at the vaporizer outlet. The splitting ratio of these two flows depends on the ratio of resistances to their flow, which is controlled by the concentration control dial, and the automatic temperature compensation valve.
Effect of flow rate: The output of all current variable-bypass vaporizers is relatively constant over the range of fresh gas flows from approximately 250 mL/min to 15 L/min, due to extensive wick and baffle system that effectively increases surface area of vaporizing chamber. All sevoflurane vaporizers are less accurate (due to the low vapor pressure of the agent) at high fresh gas flows (> 10 L/min) and high vaporizer concentration settings typical after induction, where they deliver less than the dial setting (Anesth Analg 2000;91:834-6 notes that this tendency is accentuated if the vaporizer is nearly empty). Clinically this is relatively unimportant, since we titrate to effect (end tidal agent concentration) using overpressure.

Effect of ambient temperature: The output of modern vaporizers is linear from 20-35 degrees C, due to
1. Automatic temperature compensating devices that increase carrier gas flow as liquid volatile agent temperature decreases
2. Wicks in direct contact with vaporizing chamber walls
3. Constructed of metals with high specific heat and thermal conductivity

Effect of intermittent back pressure transmitted from breathing circuit: The pumping effect is due to positive pressure ventilation or use of the oxygen flush valve. It can increase vaporizer output. Modern vaporizers are relatively immune (older vaporizers are certainly not immune) due to check valves between the vaporizer outlet and the common gas outlet, smaller vaporizing chambers, or tortuous inlet chambers. Any of these design features prevent gas which has left the vaporizers from re-entering it. The check valves are why a negative pressure leak check is recommended by the FDA checklist (step 5), since it works for all machines. The S/5 ADU has check valves in the vaporizer control mechanisms.

How to fill vaporizers

For either funnel or keyed filler types, fill the vaporizer only to the top etched line within the sight glass. Do not hold the bottle up on a keyed filler until it stops bubbling (this will overfill the chamber, particularly if the concentration control dial "on", or if leaks are present). The only current vaporizer which can be filled while it is operating is the Tec 6 (Desflurane).

How much liquid agent does a vaporizer use per hour?

Ehrenwerth and Eisenkraft (1993) give the formula:
3 x Fresh gas flow (FGF) (L/min) x volume % = mL liquid used per hour

Or one can determine the volume (mL) of saturated vapor needed to provide 1% (ie 4000 x 0.01 = 40 mL); then use Avogadro's hypothesis, the molecular weight, the liquid density, and molar volume (22.4 L at 20 degrees C) to determine how many mL of liquid become 40 mL vapor per minute. Typically, 1 mL of liquid volatile agent yields about 200 mL vapor. This is why tipping is so hazardous- it discharges liquid agent into the control
mechanisms, or distal to the outlet. And minute amounts of liquid agent discharged distal to the vaporizer outlet result in a large bolus of saturated vapor delivered to the patient instantaneously.

Hazards and safety features of contemporary vaporizers

Hazards

- Incorrect agent
- Tipping
  - If tipped more than 45 degrees from the vertical, liquid agent can obstruct valves.
  - Treatment: flush for 20-30 minutes at high flow rates with high concentration set on dial. Please note that this is the recommended treatment for the Tec 4 vaporizer. The correct approach for other models differs, so their individual operating manuals must be consulted.
- Simultaneous inhaled agent administration
  - If removing the central vaporizer from a group of three on an Ohmeda Modulus machine, move the remaining two so that they are adjacent. On models which were manufactured prior to 1995, removing the center vaporizer of three defeats the interlock, and allows the outer two vaporizers to be turned on simultaneously.
- Reliance on breath by breath gas analysis rather than preventive maintenance
  - Problem: failure of temperature compensation device may result in a rapid onset, high output failure of the vaporizer
  - Failure of renewable components such as seals and O-rings may have the same effect
- Overfilling
  - May be prevented by following the manufacturer’s guidelines for filling: fill only to the top etched line on the liquid level indicator glass, and fill only when the vaporizer is off. Anaesthesia 2002;57:288
- Leaks
  - Leaks are relatively common, often due to malposition of vaporizers on the back bar (Anaesthesia 2002;57:299-300), or loss of gaskets, and these leaks may not be detected with the standard checklist unless the negative pressure check is performed.
  - Tec 6 vaporizers can also leak liquid while being filled, if the desflurane bottle is missing the white rubber O-ring near its tip. This can be mistaken for a defective vaporizer (Anesth Analg 2003;96:1534-5)
- Electronic failure
  - As vaporizers incorporate electronics, they are susceptible to electronic failure. Two case reports in 2000 detail ADU vaporizers failing due to "fresh gas unit failure", and from copious emesis soaking the machine (Anaesthesia 2000;55:1214-5, Anaesthesia 2000;55:1215).
Safety features

Important safety features include:

- Keyed fillers
- Low filling port
- Secured vaporizers (less ability to move them about minimizes tipping)
- Interlocks
- Concentration dial increases output in all when rotated counterclockwise (as seen from above)

Current models

Variable bypass vaporizers

[Tec 4 vaporizers](#) Click on the thumbnail, or on the underlined text, to see the larger version (120 KB).

[Tec 5 vaporizers](#) Click on the thumbnail, or on the underlined text, to see the larger version (146 KB).

**Ohmeda Tec 4, 5** With the center vaporizer removed (if three are mounted side by side), one can activate both outer vaporizers simultaneously (in machines manufactured after 1995, this fault is corrected). Vaporizer outlet has check valve.

[Sevotec 5 vaporizer](#) (right). Click on the thumbnail, or on the underlined text, to see the larger version (25 KB).

The Sevotec 5 is used in a similar fashion to the other Tec 5 vaporizers. Note that in December 1997 the product labeling was changed to allow fresh gas flow as low as 1 L/min (for not greater than 2 MAC-hours).

[Penlon Sigma Delta sevoflurane vaporizer](#) (right). Click on the thumbnail, or on the underlined text, to see the larger version (15 KB).

[Penlon Sigma vaporizer](#) Click on the thumbnail, or on the underlined text, to see the larger version (36 KB).

Penlon Sigma is similar to the Tec vaporizers, and can be found on either type (Ohmeda, Dräger) of machine. The Penlon Sigma Delta sevoflurane vaporizer fits a SelectaTec interlock bar for Dräger machines.

[Vapor 19.3 vaporizer](#) Click on the thumbnail, or on the underlined text, to see the larger version (144 KB).
Dräger Vapor 19.1 is similar to Ohmeda Tec 4, 5: all are variable bypass types. The interlock on Dräger machines continues to function if any vaporizers are removed, but one must attach a short-circuit block to prevent leaks if any vaporizer is removed. There is no outlet check valve- the tortuous inlet arrangement protects from the pumping effect. The Dräger site has a description of the Vapor 19, with operating principles and clinical guidelines.

The Vapor 2000 is one of two tippable vaporizers (ADU Aladin cassettes are the other). The dial must first be rotated to a "T" setting ("transport" or "tip") which is beyond zero (clockwise). Datex-Ohmeda Aladin vaporizer Cassettes containing each volatile liquid anesthetic are inserted into a port containing the central electronic control mechanism, which recognizes the contents of the cassette and dispenses agent into the stream of fresh gas flow. Because each cassette is only a liquid sump without control mechanisms, they can be tipped in any orientation without danger, and they are maintenance free. The cassette and the control mechanisms are checked as part of the electronic equipment checklist daily. The Aladin will not deliver volatile agent without mains power or battery backup, and adequate oxygen (or air) pressure. The output of older vaporizers varies slightly with changes in fresh gas mixture, whereas the Aladin compensates for this automatically. The S/5 ADU features a low agent alarm for desflurane, the hypoxic guard system takes the desflurane concentration into account along with nitrous oxide, and the desflurane cassette works without added heat. The cassettes are extremely light, and may be removed with one hand. For a study of this vaporizer's performance, see Anesth Analg 2001;93:391-5.

Gas/vapor blenders

Tec 6 Suprane™ (desflurane) vaporizer: Because of the volatility of this agent, it requires new systems to contain, transfer, and vaporize it. The saturated vapor pressure at room temperature (20 degrees C) is 664 torr- 87% of one atmosphere. This means that desflurane is nearly boiling at room temperature. The vaporizer is a gas/vapor blender, not a variable bypass type.
Classification (from Anesth Analg 1993;76:1338-41): electrically heated, dual circuit gas/vapor blender, constant-temperature, agent specific, and out-of-circuit. Function: Heats agent to 39 degrees C, which produces a vapor pressure of around 1550 mm Hg. Electronic controls inject pure vapor into the fresh gas flow from the flowmeters, controlled by the concentration control dial, and a transducer (which senses the fresh gas flow rate, and adjusts the vapor output accordingly). Requires electrical power (it shuts off in power failures!), and has alarms; two unusual aspects compared to other contemporary vaporizers. In use it is similar to variable bypass vaporizers: it fits in the interlocks, and is mounted on the back bar in a similar way. It is accurate at low flows (ie considerably less than 1 L/min total FGF). It may be filled during use. A mark on a liquid crystal display indicates when the liquid level is one bottle low (250 mL). The user must replace a battery which powers the alarms periodically. There is an alarm for low liquid level. The unit requires a warm-up period. Datex-Ohmeda has moving pictures on their site to help in troubleshooting the Tec 6.

Checkout procedure for the Tec 6

1. Press and hold the mute button until all lights and alarms activated.
2. Turn on to at least 1% and unplug the electrical connection. A "No Output" alarm should ring within seconds. This tests battery power for the alarms. This step is crucial in relation to the quick emergence characteristics of this agent- any interruption in its supply must be noted and responded to at once.

Injectors

The Siemens vaporizer (for the Kion; click on "Anaesthesia Systems", then Kion on the left) is a concentration-calibrated injector. By its nature, it needs no thermal compensation, since it does not vaporize agent.

A calibrated throttle valve is opened or closed by the user. The more it is closed, the greater the pressure exerted by the fresh gas flow on the surface of the liquid anesthetic. This pressure tends to force liquid to atomize at the injector nozzle. The number of molecules of liquid injected is proportional to the resistance to gas flow at the throttle valve (controlled by the concentration-control dial). The liquid droplets vaporize in the flowing fresh gas stream. Thus, since the liquid is not vaporizing (at least within the vaporizer), no thermal compensation is required.

A desflurane vaporizer for the Kion is not available.
Delivery: Breathing circuits

Breathing circuit classification

The function of any breathing circuit is to deliver oxygen and anesthetic gases, and eliminate carbon dioxide (the latter either by washout with adequate fresh gas flow (FGF) or by soda lime absorption).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Reservoir (breathing bag)</th>
<th>Rebreathing</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>No</td>
<td>No</td>
<td>Open drop</td>
</tr>
<tr>
<td>Semi-open</td>
<td>Yes</td>
<td>No</td>
<td>Nonrebreathing circuit, or Circle at high FGF (&gt; VE)</td>
</tr>
<tr>
<td>Semi-closed</td>
<td>Yes</td>
<td>Yes, partial</td>
<td>Circle at low FGF (&lt; VE)</td>
</tr>
<tr>
<td>Closed</td>
<td>Yes</td>
<td>Yes, complete</td>
<td>Circle (with pop-off valve [APL] closed)</td>
</tr>
</tbody>
</table>

The Circle system can be either

1. closed (fresh gas inflow exactly equal to patient uptake, complete rebreathing after carbon dioxide absorbed, and pop-off closed)
2. semi-closed (some rebreathing occurs, FGF and pop-off settings at intermediate values), or
3. semi-open (no rebreathing, high fresh gas flow [higher than minute ventilation])

Open systems have no valves, no tubing: for example open drop ether, or a nasal cannula. In either, the patient has access to atmospheric gases.

Non-rebreathing (Mapleson) breathing circuits

All non-rebreathing (NRB) circuits lack unidirectional valves and soda lime carbon dioxide absorption: thus, the amount of rebreathing is highly dependent on fresh gas flow (FGF) in all. Work of breathing is low in all (no unidirectional valves or soda lime granules to create resistance).
How do NRB’s work? During expiration, fresh gas flow (FGF) pushes exhaled gas down the expiratory limb, where it collects in the reservoir (breathing) bag and opens the expiratory valve (pop-off or APL). The next inspiration draws on the gas in the expiratory limb. The expiratory limb will have less carbon dioxide (less rebreathing) if FGF inflow is high, tidal volume (VT) is low, and the duration of the expiratory pause is long (a long expiratory pause is desirable as exhaled gas will be flushed more thoroughly). All NRB circuits are convenient, lightweight, easily scavenged. One objection is that the circuit must be reconfigured between cases, with the possibility of error.

Minimum FGF In practice, most anesthetists will provide a minimum 5 L/min for children on up to adults to prevent rebreathing (or 2-3 x minute ventilation [VE], whichever is greater).

The Bain circuit is a "coaxial" Mapleson D- the same components, but the fresh gas flow tubing is directed within the inspiratory limb, with fresh gas entering the circuit near the mask. Fresh gas flow requirements are similar to other NRB circuits. The Bain has been shown to add more heat and humidity to inhaled gases than other Mapleson circuits.

The Pethick Test for the Bain Circuit

A unique hazard of the use of the Bain circuit is occult disconnection or kinking of the inner, fresh gas delivery hose. If this occurs, the entire corrugated limb becomes dead space. This results in respiratory acidosis which is unresponsive to increased minute ventilation. To perform the Pethick test, use the following steps:

1. Occlude the patient's end of the circuit (at the elbow).
2. Close the APL valve.
3. Fill the circuit, using the oxygen flush valve.
4. Release the occlusion at the elbow and flush. A Venturi effect flattens the reservoir bag if the inner tube is patent.

Dorsch & Dorsch (Understanding Anesthesia Equipment 4th ed. Williams & Wilkins: Baltimore. 1999:950-1.) give a second test. If fresh gas flow is established, and the inner tube is occluded, the flowmeter bobbins should dip (due to back pressure) if the inner tube is patent.

Circle Breathing Circuit

The circle is the most popular breathing system in the US. It cleanses carbon dioxide from the patient’s exhalations chemically, which allows rebreathing of all other exhaled gases (a unique breathing arrangement in medicine, but used extensively in other environments ie space, submarine).
reservoir bag, carbon dioxide absorbent canister and granules. **Resistance** of circle systems is less than 3 cm H2O (less than the resistance imposed by the endotracheal tube). **Dead space** is increased (by all respiratory apparatus). \( V_{o/r} = 0.33 \) normally, 0.46 if intubated and 0.65 if mask case. **Mechanical dead space** ends at the point where inspired and expired gas streams diverge (the Y-connector).

Diagram of the King circuit (top) compared to the Bain. Click on the thumbnail, or on the underlined text, to see the larger version (28 KB).

A "Universal F" or "Mera F" circuit (King™ circuit) is a coaxial circle system, with the inspiratory limb contained within the expiratory. Like a Bain, it is less bulky, and may offer more heat and humidification of the inspired gases. Like the Bain, occult disconnection or kinking of the inner limb causes a huge increase in dead space and respiratory acidosis (Anesth Analg 2001;93:973-4). This respiratory acidosis does not respond to increased minute ventilation either- if exhaled gases are not forced through the absorbent granules, no amount of ventilation will cleanse carbon dioxide from the patient's exhalations. The tests for inner tube patency which can be used for a Bain circuit are not readily adaptable to the circle system connected to a King circuit.

**Circle system advantages and disadvantages**

Circle advantages:

- constant inspired concentrations
- conserve respiratory heat and humidity
- useful for all ages (may use down to 10 kg, about one year of age, or less with a pediatric disposable circuit)
- useful for closed system or low-flow
- low resistance (less than tracheal tube, but more than a NRB circuit)

Circle disadvantages:

- increased dead space
- malfunctions of unidirectional valves

**Carbon dioxide absorption**

**General characteristics**

Function- makes rebreathing possible, thus conserving gases and volatile agents, decreasing OR pollution, and avoiding hazards of carbon dioxide rebreathing. **Soda lime- Activator** is NaOH or KOH. Silica and kieselguhr
added as hardeners. Indicators for Sodasorb™ (such as ethyl violet) are colorless when fresh, and purple when exhausted, because of pH changes in the granules.

Soda lime is absolutely incompatible with trichloroethylene (causes production of dichloroacetylene, a cranial neurotoxin and phosgene, a potent pulmonary irritant). Sevoflurane is unstable in soda lime, producing Compound A (lethal at 130-340 ppm, or renal injury at 25-50 ppm in rats; but incidence of toxic [hepatic or renal] or lethal effects in millions of humans are comparable to desflurane). Compound A concentrations of 25-50 ppm are easily achievable in normal clinical practice. Sevoflurane is not recommended at total fresh gas flows less than 1 L/min for more than 2 MAC-Hours. Carbon monoxide is produced by (desflurane >= enflurane > isoflurane) >> (halothane = sevoflurane). Worse in dry absorbent, or with baralyme as compared to soda lime. So turn oxygen off at end of case, change absorbent regularly, change if FGF left on over the weekend or overnight, and use low flows (this will tend to keep granules moist).

Amsorb The strong bases (activators NaOH, KOH) have been convincingly implicated in the carbon monoxide problem with the ethyl-methyl ethers, and the generation of Compound A by sevoflurane. Eliminating the activators produces an absorbent which has similar physical characteristics and carbon dioxide absorption efficiency (perhaps- this is controversial), as compared to soda lime. Amsorb (Armstrong Medical Ltd., Coleraine Northern Ireland) was planned for introduction to the US market in 2000 by Abbott, but it is not yet widely available. Lithium hydroxide is also an effective carbon dioxide absorbent.

Read more:
- Anesthesiology 1999 Nov;91:1342-8
- Anesth Analg 2001;93:221-5
- Anesthesiology 2002;96:173-82
- Anesthesiology 2001;95:1205-12

New "house brand" absorbents have been created to help deal with the problems of modern volatile anesthetic (desflurane, sevoflurane) breakdown. North American Dräger makes an absorbent with decreased amounts of NaOH, and no KOH - Drägersorb 800 Plus. Datex-Ohmeda makes Medisorb, which has similar composition. The canisters which fit on the S/5 ADU are filled with Medisorb.

Baralyme- activator Ba(OH)2 octahydrate; no hardeners, slightly less efficient. Colorless or pink changing to blue-gray with exhaustion.

For all:
- Size a compromise between absorptive capacity and resistance to airflow
- Resistance of full canister is < 1 cm H2O at 60 L/min flow through the canister
- Inhaled dust is caustic and irritant
May see exhaustion without color change, due to channeling or inactivation of indicator along the canister walls by UV light. So check color at the end of the case, and change on a regular basis (there are few recommended intervals published because the way soda lime is used varies so greatly from room to room). Do not assume that lack of color change means that the granules are intact (see Anesthesiology 2000 Apr;92:1196-8.)

**Composition**

Numbers are approximations which may not sum to 100%. Data assembled from Anesth Analg 2001;93:221-5, Anesthesiology 2001;95:1205-12, and Anesth Analg 2000;91:220-4.

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<th>(PRIVATE) Component</th>
<th>Soda lime</th>
<th>Baralyme</th>
<th>Medisorb 800+</th>
<th>Dragerorb</th>
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<td>Yes</td>
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</tr>
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</table>

**Chemical reactions**

**Soda lime**

1. \( \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \)
2. \( \text{H}_2\text{CO}_3 + 2 \text{NaOH (or KOH)} \rightarrow \text{Na}_2\text{CO}_3 (\text{or K}_2\text{CO}_3) + 2 \text{H}_2\text{O} + \text{Energy} \)

3. \( \text{Na}_2\text{CO}_3 (\text{or K}_2\text{CO}_3) + \text{Ca(OH)}_2 \rightarrow \text{CaCO}_3 + 2 \text{NaOH (or KOH)} \)

#1 is called the first neutralization reaction. In #3 the second neutralization reaction and the regeneration of activator take place. \( \text{CaCO}_3 \) is an insoluble precipitate.

**Barium hydroxide lime (Baralyne™)**

1. \( \text{Ba(OH)}_2\cdot8\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{BaCO}_3 + 9\text{H}_2\text{O} + \text{Energy} \)

2. \( 9\text{H}_2\text{O} + 9\text{CO}_2 \rightarrow 9\text{H}_2\text{CO}_3 \)
   (Then by direct reactions and by \( \text{NaOH, KOH} \) if present)

3. \( 9\text{H}_2\text{CO}_3 + 9\text{Ca(OH)}_2 \rightarrow \text{CaCO}_3 + 18\text{H}_2\text{O} + \text{Energy} \)

\( \text{CaCO}_3 \) is an insoluble precipitate.

**To change canisters**

{PRIVATE "TYPE=PICT;ALT=To change canisters"}Steps for changing canisters. Click on the thumbnail, or on the underlined text, to see the larger version (23 KB).

1. Wear gloves
2. Loosen clamp
3. Remove & discard top canister
4. Promote the bottom canister to the top and put the fresh canister on the bottom
5. Check for circuit leaks
6. Always remove wrap before inserting canister
7. Don’t change mid-case; convert to semi-open circuit by increasing FGF to > 5 L/min

**Clinical signs of exhaustion**

- Rise (later a fall) in heart rate and blood pressure
- Hyperpnea
- Respiratory acidosis
- Dysrhythmia
- Signs of SNS activation
  - Flushed
  - Cardiac irregularities
  - Sweating
- Increased bleeding at surgical site
- Increased end tidal carbon dioxide
- **NOT** dark or cherry-red blood!
Ventilators

Classification

- **Power source** is either compressed gas, electricity or both (contemporary bellows ventilators require both; piston ventilators do not require driving gas).

- **Drive mechanism** - modern vents classified as double-circuit, pneumatically driven.
  - Double-circuit means that a pneumatic force compresses a bellows, which empties its contents (gas from flowmeters and vaporizer) into the patient.
  - Driving gas is oxygen, air, or a venturi mix of O₂ and air (Dräger).
  - Piston ventilators (Narkomed 6000, Fabius GS) do not require driving gas

- **Cycling mechanism** - time cycled, control mode. Newer ventilators feature pressure control and SIMV modes.
  - Modern ventilators use solid state electronics for timing. In volume control mode, driving gas flow ceases when the set tidal volume is delivered to the breathing circuit (not necessarily the patient- the two quantities may differ due to compliance losses or leaks!) or when a certain pressure is reached (peak pressure varies). In pressure control mode, the target pressure is established and maintained for a certain time (allowing delivered tidal volume to vary).

Bellows classification

To remember the classification: "ascend" and "descend" have "e" in them - so look at them during expiration. Ascending bellows ("standing") ascend during expiration (modern type - preferred by many) and descending bellows ("hanging") descend during expiration. **Ventilator relief valve** gives 2 - 3 cm water pressure positive end-expiratory pressure (PEEP) (true for almost all mechanical ventilators- exceptions are the new Dräger Divan ventilator, which has a horizontal piston, and the Julian hanging bellows). The ventilator relief valve (spill valve) allows scavenging ONLY during expiratory phase.

The hanging design was chosen for the Julian for compactness and ease of sterilization of the entire breathing circuit. The Julian hanging bellows housing, unlike older designs, lacks an internal weight, and senses when the bellows do not return to the full "down" position. These factors, plus integration of disconnect alarms based on chemical (capnograph), and mechanical (pressure, volume, and flow sensors) detection, make piston or hanging bellows designs safe. The placement of the hanging bellows below the writing surface makes visual detection of disconnects difficult; also it is less easy to determine if the patient is breathing spontaneously in addition to the rate set on the mechanical ventilator. The user must rely more on the pressure and capnography waveforms as opposed to the bellows. Water may gather in the bellows (lessening tidal volume and creating an infection risk), but this tendency should be opposed by the heated absorber head.
Choosing ventilator modes and settings

Besides increased accuracy (due to compliance and leak compensation- see below on this page), the biggest improvement in current ventilators is their flexibility in modes of ventilation. Offering pressure controlled ventilation (PCV) allows more efficient and safe ventilation of certain types of patients. The improvement in accuracy afforded by modern ventilators means that switching of circuits (for example, to a non-rebreather for small children) is not as necessary. (This is safer because potential misconnects are avoided, and quicker besides.) The next direction the manufacturers will take is offering modes (such as pressure support) that will support spontaneous ventilation, seen in anesthesia with much greater frequency due to the advent of the laryngeal mask airway.

**Controlled Mandatory Volume (CMV)**

All ventilators offer controlled mandatory volume (CMV) ventilation. In this mode, the volume is kept constant, and it is delivered at a constant flow. The peak inspiratory pressure is allowed to vary, and it does, according to the patient’s compliance and airway resistance. Rate and volume are adjusted for reasonable end-tidal carbon dioxide and peak inspiratory pressure.

**Settings for CMV in an adult**

- VT 10 mL/kg
- RR 6-12 breaths per minute (bpm)
- PEEP 0 cm H2O to start (add if trouble oxygenating)

**Pressure control ventilation (PCV)**

Pressure control ventilation (PCV) controls inspiratory pressure, and allows inspired volume to vary (with changes in compliance and airway resistance). The flow generated varies; high at first to produce the set pressure early in inspiration, and less later in inspiration to maintain this pressure through the inspiratory time. Target pressure and rate are adjusted to a reasonable end-tidal carbon dioxide, and tidal volume is monitored. The result is increased tidal volume at a lower PIP, in many instances where peak inspiratory pressure (PIP) had been high when employing CMV (for example laparoscopy).

How is it possible to get greater tidal volumes at a lower PIP? The answer is that flow of gas is greater early in inspiration (see waveforms above). Overall this may result in greater delivered volume with the same (or lower) pressure.

**Indications**

If there is a danger of high PIP, use PCV to limit pressure within the airway and lungs.

- laryngeal mask airway
• emphysema
• neonates/infants

If compliance is low, use PCV to obtain a higher tidal volume.
• pregnancy
• laparoscopic surgery (pneumoperitoneum)
• morbid obesity
• ARDS

**Settings for PCV in an adult**
• Pressure Limit ~20 cm H2O
• RR 6-12 breaths per minute (bpm)
• PEEP 0 cm H2O to start (add if trouble oxygenating)

**Modes for spontaneous ventilation**
With the advent of the LMA, spontaneous (unassisted) breathing is much more common during general anesthesia. But it is difficult to maintain a light enough plane of anesthesia to permit spontaneous ventilation, while retaining sufficient depth for surgery to proceed. Too deep, and respiratory acidosis will occur; too light, and bucking and awareness are risks. Ventilation modes which could support a spontaneously breathing patient would be useful to provide normocapnia without bucking. Modes which might be useful include synchronized intermittent mandatory ventilation (SIMV), pressure support ventilation (PSV), continuous positive airway pressure (CPAP), and airway pressure release ventilation (APRV).

Of these modes, SIMV is currently available only on the S/5 ADU and the Narkomed 6000. Pressure control ventilation (PCV) may be used with an LMA as well (Anesthesiology 2000;92:1621-3). It is available on the Datex-Ohmeda 7900 SmartVent, S/5 ADU, and the Dräger 6000, and Fabius GS.

**Typical ventilator alarms**
• High pressure
• Pressure below threshold for 15 to 30 seconds (apnea or disconnect)
• Continuing high pressure
• Subatmospheric pressure
• Low tidal or minute volume
• High respiratory rate
• Reverse flow (may indicate incompetence of expiratory unidirectional valve in the breathing circuit)

**Apnea/disconnect alarms** may be based on
1. Chemical monitoring (lack of end tidal carbon dioxide), or
2. Mechanical monitoring
   • Failure to reach normal inspiratory peak pressure, or
• Failure to sense return of tidal **volume** on a spirometer, or
• Failure of standing bellows to fill during mechanical ventilator exhalation, or
• Failure of manual breathing bag to fill during mechanical ventilation (machines with fresh gas decoupling- the Julian, Fabius GS, Narkomed 6000), or
• Other- lack of breath sounds, etc.

3. **Electronic**

   Failure of the hanging bellows to fill completely (the *garage door* electronic eye sensor on the Julian)

### New features of modern ventilators

**Piston ventilators**

Piston ventilators use an electric motor to compress gas in the breathing circuit, creating the motive force for mechanical ventilator inspiration to proceed. Thus they use no driving gas, and may be used without depleting the oxygen cylinder in case of oxygen pipeline failure.

![NM 6000 piston bellows](PRIVATE "TYPE=PICT;ALT=NM 6000 piston bellows") NM 6000 piston bellows. Click on the thumbnail, or on the underlined text, to see the larger version (44 KB).

In the Narkomed 6000, the bellows are occult, being placed horizontally under the writing surface. Although they can be viewed by lifting the writing surface, their to-and-fro movement is not normally visible during mechanical ventilation. The anesthetist relies on pressure and capnography waveforms to guard against disconnects or other problems.

![Piston ventilator window Fabius GS](PRIVATE "TYPE=PICT;ALT=Piston ventilator window Fabius GS") Piston ventilator window Fabius GS. Click on the thumbnail, or on the underlined text, to see the larger version (35 KB).

The Fabius GS has a piston ventilator similar to the Divan, but the bellows travel vertically, and their movement is continuously visible through a window to the left of the flowmeter bank.

The piston ventilator has positive and negative pressure relief valves built in. If the pressure within the piston reaches $75 \pm 5$ cm H$_2$O, the positive pressure relief valve opens. If the pressure within the piston declines to $-8$ cm H$_2$O, the negative pressure relief valve opens, and room air is drawn into the piston, protecting the patient from NEEP (negative end-expiratory pressure).

There are several advantages to the Divan piston ventilator system (NM 6000 & Fabius GS):

- Quiet
- No PEEP (2-3 cm water are mandatory on standing bellows ventilators due to the design of the ventilator spill valve)
- Greater precision in delivered tidal volume due to compliance and leak compensation, fresh gas decoupling, and the rigid piston design.
  - There are less compliance losses with a piston as compared to a flexible standing bellows compressed by driving gas.
• Measuring compliance and leaks with a transducer near the piston eliminates a bulky, costly sensor close to the patient's airway (such as the D-Lite sensor on the S/5 ADU).

• Electricity is the driving force for the piston, so if oxygen pipeline pressure fails and one must rely on oxygen from the emergency cylinder, mechanical ventilation may continue (without exhausting the cylinder oxygen simply to drive the bellows).

The disadvantages of the piston design include:

• Loss of the familiar visible behavior of a standing bellows during disconnects, or when the patient is breathing over and above the ventilator settings.

• Quiet (less easy to hear regular cycling)

• The piston ventilator design cannot easily accommodate nonrebreathing circuits (although the same can be validly argued in regards to traditional absorber heads like the Ohmeda GMS, or newer ascending bellows ventilators like the S/5 ADU).

• Potential for NEEP

**Flexibility**

The appearance of pressure control ventilation is a major advantage, allowing patients to be ventilated efficiently who were very difficult with control (CMV) mode, such as patients with ARDS or morbid obesity. PCV also allows safety in ventilating patients in whom excessive pressure must be strictly avoided; such as neonates and infants, and emphysematous patients. The future appearance of modes capable of supporting the patient with spontaneous respirations will extend our capabilities further.

**Accuracy at lower tidal volumes**

Factors contributing to a discrepancy between set and delivered tidal volumes are especially acute in pediatrics and include

• large compression volume of the circle system relative to the infant's lung volume

• leaks around uncuffed endotracheal tubes

• effects of fresh gas flow on delivered tidal volume

• mechanical difficulty of setting a small tidal volume using an adult bellows assembly

Because of the greatly increased accuracy in tidal volume delivery achieved through compliance and leak testing and compensation, modern ventilators have an unprecedented tidal volume range. They are able to ventilate smaller patients much more accurately than any previous anesthesia ventilator could. This will undoubtedly lessen the need for non-rebreathing (Mapleson & Bain) circuits, and make care safer, since anesthetists will no longer have to disassemble and reconfigure to a non-rebreathing circuit for a child in the middle of several adult cases. However, it is mandatory to substitute a pediatric circuit for tidal volumes less than 200 mL (*Anesthesiology* 2001;94:543-4) with the NM 6000 and the Fabius GS. Smaller filters, a pediatric D-Lite sensor, and less-compliant circle breathing systems must be used on the S/5 ADU as well.
Compliance and leak testing

The accuracy comes with a price. An electronic leak and compliance test must be repeated every time the circuit is changed, particularly if changing to a circuit with a different configuration (adult circle to pediatric circle, or adult to long circuit). This test is part of the electronic morning checklist.

![Aestiva flow sensor](PRIVATE "TYPE=PICT;ALT=Aestiva flow sensor") Photograph of the Aestiva flow sensor. Click on the thumbnail, or on the underlined text, to see the larger version (25 KB).

The placement of the sensor used to compensate tidal volumes for compliance losses and leaks has some interesting consequences. The Aestiva flow sensors are placed between disposable corrugated breathing circuit limbs and the absorber head. Here they are able to compensate tidal volumes for fresh gas flow, compliance losses and leaks internal to the machine and absorber head, but not in the breathing hoses.

![D-Lite sensor](PRIVATE "TYPE=PICT;ALT=D-Lite sensor") Photograph of the D-Lite sensor. Click on the thumbnail, or on the underlined text, to see the larger version (46 KB).

The Datex-Ohmeda D-Lite sensor is placed just distal to the Y-piece. In this position, it can compensate for all leaks and compliance losses out to the Y piece (thus including the breathing circuit hoses). However, at this point it adds appreciable and perhaps objectionable bulk and weight close to the patient's face. This may make mask ventilation a bit more cumbersome. Further, a sensor closer to the patient is exposed to more exhaled moisture, but the impact can be lessened with a heat and moisture exchanger between patient and sensor. Unfortunately, this adds further bulk and weight.

The Narkomed 6000 tests compliance and leaks of all components to the Y-piece via a pressure transducer within the internal circuitry near the bellows. Here the sensor is relatively protected from moisture.

Fresh gas decoupling versus compensation

A final factor adding to modern ventilator accuracy is that they compensate delivered tidal volume for the fresh gas flow. In traditional ventilators, which are not fresh gas decoupled, the delivered tidal volume is the sum of the volume delivered from the ventilator and the fresh gas volume. Thus, delivered tidal volume may change as FGF is changed. For example, consider a patient with a FGF of 4 L/min, a respiratory rate of 10, inspiratory:expiratory ratio of 1:2, and a tidal volume of 700 mL. During each minute, the ventilator spends 20 seconds in inspiratory time and 40 seconds in expiratory time (1:2 ratio). During this 20 seconds, the fresh gas flow is 1,320 mL (4000 mL/min FGF times 1/3). So each of the 10 breaths of 700 mL is augmented by 132 mL of fresh gas flowing while
the breath is being delivered, so the total delivered tidal volume is 832 mL/breath. This 19% increase is reasonably unimportant.

But what happens if we decrease to lower fresh gas flow? Assume the same parameters, but a FGF of 1,000 mL/min. During each minute, the ventilator spends 20 seconds in inspiratory time and 40 seconds in expiratory time (1:2 ratio). During this 20 seconds, the fresh gas flow is 330 mL (1000 mL/min FGF times 1/3). So each of the 10 breaths of 700 mL is augmented by 33 mL of fresh gas flowing while the breath is being delivered, so the total delivered tidal volume is 733 mL/breath. This means that changing FGF from 4,000 mL/min to 1,000 mL/min, without changing ventilator settings, has resulted in a 14% decrease in delivered tidal volume (832 to 733 mL). It would not be surprising if the end tidal carbon dioxide rose as a result.

The situation is more acute with a traditional anesthesia ventilator in children. Assume a 20 kg patient with a FGF of 4 L/min, a respiratory rate of 20, inspiratory:expiratory ratio of 1:2, and a tidal volume of 200 mL. During each minute, the ventilator spends 20 seconds in inspiratory time and 40 seconds in expiratory time (1:2 ratio). During this 20 seconds, the fresh gas flow is 1,320 mL (4000 mL/min FGF times 1/3). So each of the 20 breaths of 200 mL is augmented by 66 mL of fresh gas flowing while the breath is being delivered, so the total delivered tidal volume is 266 mL/breath. This is a 33% increase above what is set on the ventilator.

There are two approaches to dealing with the problem. The Dräger Julian, Narkomed 6000 and Fabius GS use fresh gas decoupling. The fresh gas is not added to the delivered tidal volume. Thus, fresh gas decoupling helps ensure that the set and delivered tidal volumes are equal. This is most clearly visualized by visiting the Virtual Fabius GS Simulation. The action of the piston closes a one-way (check) valve, diverting FGF to the manual breathing bag during the inspiratory cycle. The visual appearance is unusual:

- the manual breathing bag, normally quiescent during mechanical ventilation, moves with each breath
- the manual breathing bag movement is opposite to the movement seen in a mechanical ventilator

bellows- the manual breathing bag inflates during inspiration (due to fresh gas flow), and deflates during expiration as the contents empty into the absorbent and move on towards the patient.

With fresh gas decoupling, if there is a disconnect, the manual breathing bag rapidly deflates, since the piston retraction draws gas from it.

The second approach is fresh gas compensation, which is utilized in the Aestiva, and S/5 ADU. The volume and flow sensors provide feedback which allows the ventilator to adjust the delivered tidal volume so that it matches the set tidal volume, in spite of the total fresh gas flow, or in case of changes in fresh gas flow.
Suitability for low flows

Low fresh gas flow is desirable to reduce pollution and cost of volatile agents and nitrous oxide, preserve tracheal heat and moisture, prevent soda lime granules from drying, and preserve patient body temperature. Factors which enhance the safety and efficiency of low flows in modern ventilators include:

- Compliance and leak testing, automatic leak detection
- Fresh gas compensation or decoupling
- Warmed absorber heads (Julian, NM 6000)
- Low volume absorber heads
  - allows faster equilibration of dialed and delivered agent concentration
    - Julian mL 1500 mL canister
    - NM 6000 1500 mL canister
    - Fabius GS 1500 mL (2800 mL + bag for entire breathing system)
    - Aestiva 2700 mL in canisters alone
    - S/5 ADU 750 mL canister
  - As you can see, a traditional sized absorber head like the Aestiva, which is similar to the familiar Ohmeda GMS absorber head, is roughly twice the volume of any of the newer designs.
- Low fresh gas flows allowed by gas machine- most no longer have mandatory minimum oxygen flows of 200-300 mL/min (the exception is Julian with a minimum flow of 500 mL/min)
- Electronic detection of bellows not filling (Julian)
- Low flow wizard- an electronic monitor that gives indications when fresh gas flow is excessive or too low by monitoring gas volume passing through the scavenger (NM 6000)

Current models

Dräger Divan ventilator

The Dräger Divan ventilator is a modern ventilator, offering features such as: pressure control mode, SIMV, correction for compliance losses, and integrated electronic PEEP. Unlike the S/5, newer Dräger absorber heads warm the gases in the breathing circuit. Also unique is that fresh gas flow does not add to delivered tidal volume ("fresh gas decoupling"- see New features above on this page). The Divan is limited to a pressure of 70 cm water-so like the Ohmeda 7000, it cannot ventilate patients in CMV mode beyond this pressure (although, again, it is
possible and even perhaps preferable to ventilate the ARDS patient with pressure control mode). It is installed on the Narkomed 6000. The Fabius GS has a piston ventilator as well, but the piston is mounted vertically to the left of the flowmeters and visible through a window.

Unlike most other anesthesia ventilators, there are no visible bellows on the NM6000 Divan ventilator. It is unique among current models in having a horizontal piston which is hidden within the writing surface of the gas machine. To provide a visible indication of lung inflation, fresh gas is diverted to the manual breathing bag, which inflates during mechanical ventilator inspiration, and deflates during expiration. A disconnect will cause the manual breathing bag to gradually lose volume (in addition to activating other apnea alarms). A pressure transducer within the ventilator measures compliance losses and leaks in the total breathing circuit (absorber head and corrugated limbs).

Read about Divan operating parameters.
Read about the NM 6000-Divan system.

**Dräger Julian ventilator**

The Julian ventilator is electronically controlled, gas-driven, hanging bellows ventilator which may be used in Manual/Spontaneous, CMV, or pressure control modes. With a small absorber volume and heated head, it is well-suited for low flow anesthesia. Parameters include:

- VT 50-1400 mL
- Freq 6-60 bpm
- I:E ratio 2:1 to 1:4
- PEEP to 20 cm H2O
- Adjustable Peak flow, plateau time, insp flow (max 75 L/min)
- Pressure limit 70 cm H2O

**Dräger Fabius GS ventilator**

The Fabius GS ventilator controls and piston window (left of flowmeters). Click on the thumbnail, or on the underlined text, to see the larger version (36 KB).
The Fabius GS ventilator is an electronically controlled, electrically driven piston ventilator. It consumes no drive gas. The piston is continuously visible. One button is unassigned on the controls, for the next mode to be developed. Operating parameters include

- VT 20-1400 mL
- Freq 4-60 bpm
- I:E ratio 4:1 to 1:4
- Inspiratory Pause 0-50%
- PEEP to 20 cm H2O
- Adjustable Peak flow, plateau time, insp flow (max 75 L/min)
- Pressure limit 15-70 cm H2O
- Inspiratory pressure (pressure control mode) 5-60 cm H2O
- Inspiratory flow (pressure control mode) 10-75 L/min

Dräger AV-E and AV-2

Classification: pneumatically and electrically powered, double circuit, pneumatically driven, ascending bellows, time cycled, electronically controlled, VT-preset vent. Incorporates Pressure Limit Controller (PLC) which allows maximum peak inspiratory pressure (PIP) adjustment from 10-110 cm water. Inspiratory flow control must be set properly (like the Ohmeda 7800), so that driving gas flow does not create an inspiratory pause. Standard on Narkomed 2A, 2B, 2C, 3, 4, and Narkomed (not Fabius) GS. See instructions for using the AV2+ in volume or pressure mode at the Dräger web site.

Ohmeda 7000

Same classification as Dräger AV-E except it is minute-volume preset (unique among current ventilators). VT cannot be set directly, it is calculated from settings of VE and respiratory rate (VE = RR x VT). Inspiratory flow stops when set VT worth of driving gas has been delivered to the driving circuit side of the bellows chamber or if pressure greater than 65 cm water is attained. Thus, a patient requiring peak inspiratory pressure > 65 cm water cannot be mechanically ventilated with this ventilator. Though this ventilator is still commercially available, there is little reason to purchase it, in view of the useful features on newer designs. Read Datex-Ohmeda's description and specifications.

Ohmeda 7100


Same as the Smart Vent 7900 (see below), except that the optional pressure control mode is not as strong as the 7900. Features tidal volume compensation. Read Datex-Ohmeda’s description.

Ohmeda 7800

Ohmeda 7800 controls. Click on the thumbnail, or on the underlined text, to see the larger version (34 KB).

This ventilator or the 7900 Smart-Vent™ are standard on newer Excel or Modulus machines. Same classification as Dräger AV2 ventilator; Vt preset. Tidal volume, respiratory rate, inspiratory flow and pressure limit controls are present.

**Ohmeda 7900 "SmartVent"**

Ohmeda 7900 controls. Click on the thumbnail, or on the underlined text, to see the larger version (34 KB).

Same classification as Dräger AV ventilator, Vt preset. Microprocessor control delivers set Vt, in spite of changes in fresh gas flow, small leaks, and absorber or bellows compliance losses proximal to the sensors. These flow sensors are placed between corrugated plastic breathing circuit and the absorber head, in both limbs. These are connected to pressure transducers in the ventilator. Compliance losses in the breathing circuit corrugated hoses are not corrected, but these are a relatively small portion of compliance losses.

The first "modern" ventilator- it offers such desirable features as integrated electronic PEEP control, and pressure-controlled ventilation (PCV) mode. It has been reported that the sensors can be quite sensitive to humidity, causing ventilator inaccuracy or outright failure. The problem may be more likely when active airway humidifiers are used- read more at:

- **Anesth Analg** 1998;86:231-2
- **Anesth Analg** 1999;88:234
- **Anesth Analg** 2002;96:766-8

Read Datex-Ohmeda’s description and specifications

Controls are similar to the 7800. Users should be vigilant for cracked tubing in the flow sensors, which are located where the breathing circuit corrugated hoses attach to the absorber head. Leaks here have been reported to cause inability to ventilate, either mechanically or manually. When these failures occur, the ventilator may indicate alarm messages like “VT” or “Apnea”, rather than “Check sensor”. Flow sensor tubing must be vertical, must be changed regularly, and sensors must be in the proper side (inspiratory or expiratory). Although the sensor plugs are keyed by size and shape, if both sensors come off the absorber head when the circuit is changed they can be inadvertently replaced on the wrong side.

**Datex-Ohmeda S/5 ADU ventilator**

Photograph of the S/5 ADU ventilator controls. The left arrow shows the Bag/Auto and APL valve location. The right arrow shows the location of the thumbwheel and
Ohmeda’s newest ventilator has a suite of useful and unique features not previously seen in ventilators meant for use during anesthesia. **Single switch activation** (setting the Bag Vent switch to "Auto") is all that is needed to start mechanical ventilation. Entering the patient’s weight will suggest appropriate ventilator settings. Delivered VT is adjusted to **compensate for changes in fresh gas flow, and total (absorber head and corrugated limbs) breathing circuit compliance losses** through the D-Lite sensor at the elbow.

The ventilator can utilize either oxygen or air as a driving gas, and will switch automatically from one to the other if pipeline pressure is lost. Volume-control, **pressure control**, and **synchronized intermittent mandatory ventilation** (SIMV) modes are offered, along with **integrated electronic PEEP**. Overpressure release valve at 80 cm water (in spontaneous or mechanical ventilation) means that patients requiring higher peak inspiratory pressure cannot be ventilated in volume control mode (but they may be ventilated successfully in pressure control mode). The pressure control mode should be very useful to increase delivered tidal volume when lung compliance is low (laparoscopic procedures, obesity, pregnancy) or when high peak inspiratory pressures must be avoided (pediatric patients, laryngeal mask ventilation, emphysema). SIMV is unique to this machine (and the Divan) among anesthesia ventilators, and may prove useful during emergence. **Flow-volume (resistance) or pressure-volume (compliance) loops** may be displayed breath-by-breath.

**Siemens Kion ventilator**

The Kion ventilator operates in Manual, Volume control, and Pressure control modes. Pressure support is implemented on some machines. Very few Kion machines have yet been sold in the US.

**Using Breathing Circuits and Ventilators**

**Humidification**

Dry gas supplied by the gas machine may cause clinically significant dessication of mucus and an impaired mucociliary elevator. This may contribute to retention of secretions, blocking of conducting airways, atelectasis, bacterial colonization, and pneumonia.
Absolute humidity is the maximum mass of water vapor which can be carried by a given volume of air (mg/L). This quantity is strongly determined by temperature (warm air can carry much more moisture). Relative humidity (RH) is the amount present in a sample, as compared to the absolute humidity possible at the sample temperature (expressed as a %).

Some examples:
- 0 mg/L are supplied by the machine,
- 9 mg/L is found in normal room air at 20 degrees C and 50% relative humidity,
- 44 mg/L is found in tracheal air at the carina, at 37 degrees C and 100% relative humidity.

It is ideal to provide gases at body temperature and 100% RH to the patient's airway. For cases lasting longer than 1 hour, humidification measures are often employed including:
- Moisten corrugated breathing circuit hoses (not very practical; also the effect lessens with time)
- Use the circle with absorbent granules and low flows
  - This can provide 100% RH at room temperature at the lowest flows (such as closed circuit with FGF of less than 1 L/min)
- Heat and moisture exchanger (Pall™, Engstrom Emma™, “artificial nose”)
- Heated airway humidifiers

The Heat and moisture exchanger has large thermal capacity, hygroscopic, and (sometimes) bacterial filtration. It can do no more than return the patient’s exhaled water- it can’t add heat or moisture- and it is less efficient with longer cases or higher flows. But it’s easy to use, inexpensive, silent, won’t overheat or overhydrate the patient. The heated airway humidifiers provide perfect conditions- 100% RH at body temperature. Types: Cascade, flow-over (Fisher-Paykell™, Marquest™), heated wet wick (Anamed™). Problems: overhydration, overheating (burns), require higher flows (flow-over type), melted circuits, aspiration.

**How is the "best" fresh gas flow (FGF) determined?**

The fresh gas flow used determines not just FiO₂, but also the speed with which you can change the composition of gases in the breathing circuit.
- 4 L/min is common- a legacy from days when a safety margin was needed for flowmeters & vaporizers which were much less accurate.
- A circle at 1-1.5 times Vₚ is essentially a nonrebreather (5-8 L/min for an adult). FGF should be this high during preoxygenation and induction (allows washin) and emergence (washout).
- Low flows (0.5-2 L/min total FGF) should be used during maintenance to conserve tracheal heat and humidity, and economize on volatile agents.
  - Don’t use less than 1 L/min FGF with sevoflurane for more than 2 MAC-Hours. The package insert (revised late 1997) advises against it, as lower flows accelerate compound A formation.
  - For further information, see the Association for Low Flow Anaesthesia.
Also be sure to look at [LowFlow.net](http://LowFlow.net). Don't miss the very interesting "Conversation with a Student" written by Dr Eger (in the Theatre section) which concerns misconceptions about low flow. There is also a great collection of articles in the Abstracts section.

**Low flows**

Low flows are used to decrease the usage, cost, and pollution of volatiles. A 50% reduction in FGF translates to a 50% savings, without placing the patient at risk or lessening the quality of their care. Tracheal heat and humidity, and patient core body temperature are preserved better than at higher flows.

Since the fresh gas flowing during the inspiratory phase of each breath augments delivered tidal volume (VT), changing FGF changes delivered tidal volume, unless fresh gas decoupling or compensation are employed. A decrease to low flows on older machines will decrease delivered VT to decrease, and end tidal carbon dioxide to increase to an extent.

The composition of gases in the breathing circuit may change as lower flows are employed, since a greater fraction of the gas inspired by the patient will be rebreathed.

- **Oxygen**- inspired oxygen may decline to less than the amount set on the flowmeter, especially as oxygen flowmeter settings approach the metabolic requirement for oxygen (250-300 mL/min in an adult). Inspired oxygen declines because of uptake, and dilution of oxygen distal to the common gas outlet by leaks, exhaled nitrogen, carbon dioxide, and water vapor.
- **Agent**- inspired agent may be much less than that dialed on the vaporizer when low flows are employed, also due to leaks, uptake and dilution.

Large discrepancies between dialed and inspired agent concentration can be unsettling, raising apprehensions about vaporizer or breathing circuit malfunction. An analogy may help to clarify why this is an expected result of low flows. Imagine you are entering an automobile in the winter. You turn the heater on at maximum heat level and fan speed. After the car is warmed to a comfortable temperature, heat must still be supplied since it is always dribbling out (the car is not airtight). To keep the car at equilibrium, you may either flow a moderate to high fan speed, but decrease the heat mix to nearly room temperature air, or you may leave the heat mix level high, and slowly blow in a small amount of very hot air. It makes no difference- in either case the car stays at the desired temperature.

Similarly, we begin cases with higher flows. Since there is little rebreathing at 4 L/min FGF and above, the dialed and inspired agent concentration is very similar. We induce with overpressure until the patient is saturated (reflected in an end-tidal agent concentration near MAC). Then we may either leave the flows high with a moderate agent concentration near MAC, or turn the flows to low flow. But if we use low flows, we must still provide the same number of molecules of agent in order to replace that lost due to dilution, leaks, and uptake. So we must turn the vaporizer dial well beyond what we might have to at higher flows.
Advantages of low flows

- Economy
- Decreased operating room & environmental pollution
- Estimation of agent uptake and oxygen consumption
  - At some point low flows become closed circuit: the APL valve is closed and only enough gases and agent are supplied to keep the bellows or bag volume constant. One can then infer uptake from changes in volume and composition of the gases in the breathing circuit.
- Buffering of changes in inspired concentration
- Conservation of heat and humidity
- Less danger of barotrauma

Disadvantages of low flows

- More attention required
- Inability to quickly alter inspired concentrations
  - If you must lighten or deepen the agent level quickly, switch for a moment to higher flows
- Danger of hypercarbia
  - Granules are used at a faster rate with low flows because of the higher degree of rebreathing
- Greater knowledge required (if closed circuit employed)
- Accumulation of undesired gases in the circuit (if closed circuit employed)
  - Carbon monoxide, acetone, methane, hydrogen, ethanol, anesthetic agent metabolites, argon, nitrogen

How to denitrogenate ("preoxygenate")

You can *preoxygenate* with a nasal cannula. We need to do more- denitrogenate (cleanse the functional residual capacity of nitrogen) - to help our patients tolerate a potential 2 or 3 minutes of apnea if we have difficulties with intubation.

1. Fresh gas flow 6-8 L/min
2. APL valve open fully
3. Tight mask fit
   - the most significant factor. It cannot be compensated for by increasing time of preoxygenation, because the patient will not be breathing 100% oxygen with a loose fit (*Anesthesiology* 1999;91:603-5).
4. **Every** time you place a mask on a patient's face, look back at the breathing bag (to ensure it is fluctuating with respirations) and the oxygen flowmeter (to ensure it is on). Pay attention to complaints that it "smells funny" - you may have left a vaporizer on. Thus you can avoid the threats to patient safety
Malignant hyperthermia: Implications for equipment

Clinical presentation The cause of the tachycardia, tachypnea, and elevated end-tidal CO2 seen in malignant hyperthermia (MH) must be distinguished from ventilator or unidirectional valve malfunctions (producing respiratory acidosis), as well as hyperthyroidism, cocaine intoxication, pheochromocytoma, and sepsis.

Triggers Succinylcholine and all inhaled agents are the only anesthetic agents that will trigger MH. Safe anesthetics Barbiturates, propofol, etomidate, ketamine, opioids, local anesthetics, catecholamines, nitrous oxide, and all non-depolarizing muscle relaxants are presently considered safe.

Treatment of acute episodes in OR High fresh gas flow (10 L/min), hyperventilation, stop inhaled agents and remove vaporizers, stop succinylcholine, and as time permits change soda lime granules & breathing circuit. The mainstay of treatment is dantrolene 2.5 mg/kg (up to 10 mg/kg). Cooling by any and all means, NaHCO3, treatment of hyperkalemia, and other measures are also important.

Management of known susceptible patients- To prepare the gas machine:

1. Remove or at least drain all vaporizers and tape over the dial.
2. Change breathing circuit disposables and soda lime.
3. Flush by ventilating with high (10 L/min) fresh gas flow for at least 10 minutes (20 min if you cannot remove and replace breathing circuit and granules).
4. Monitor pETCO2 and core temperature in all.
5. Avoid triggers
6. Use rocuronium, particularly if rapid sequence induction is indicated.
   - Sixty (60) sec after rocuronium 0.6-1.2 mg/kg, intubating conditions indistinguishable from succinylcholine can be produced (at the price of a clinical duration of 30-40 min).

Please note that the Kion requires flushing before use on a susceptible patient for 25 minutes- four times as long as required by an Excel 210 (Anesthesiology 2002;96:941-6). Any new equipment has the potential to contain internal components that absorb agent, so each model should be tested before it can be accepted that the standard procedures apply.

You can contact the Malignant Hyperthermia Association of the United States for further information. (The "OnLine Brochures" [button on the left] are very helpful.)

Ventilator and Breathing Circuit: Problems and Hazards

Disconnection

Most common site is Y piece. The most common preventable equipment-related cause of mishaps. Direct your vigilance here by: precordial ALWAYS; if you turn the vent off, keep your finger on the switch; use apnea alarms and don’t silence them.
   - The biggest problem with ventilators is failure to initiate ventilation, or resume it after it is paused.
• Be extremely careful just after initiating ventilation- or whenever ventilation is interrupted: observe and listen to the chest for a few breathing cycles. Never take for granted that flipping the switches will cause ventilation to occur, or that you will always remember to turn the ventilator back on after an Xray.

Monitors for disconnection
• Precordial monitor (the most important because its "alarms" can't be inactivated)
• Capnography
• Other monitors for disconnection
  • Ascending bellows
  • Observe chest excursion and epigastrium
  • Airway Pressure monitors
  • Exhaled Volume monitors

Occlusion/obstruction of breathing circuit
Beside inability to ventilate, obstruction may also lead to barotrauma. Obstruction may be related to:
• Tracheal tube (kinked, biting down, plugged, or cuff balloon herniation). "All that wheezes is not bronchospasm".
• Incorrect insertion of flow-direction-sensitive components (PEEP valves which are added on between the absorber head and corrugated breathing hoses)
• Excess inflow to breathing circuit (flushing during ventilator inspiratory cycle)
• Bellows leaks
• Ventilator relief valve (spill valve) malfunction
• APL valve too tight during mask ventilation or not fully open during preoxygenation.

Misconnection
Much less of a problem since breathing circuit and scavenger tubing sizes have been standardized

Failure of emergency oxygen supply
May be due to failure to check cylinder contents, or driving a ventilator with cylinders when the pipeline is unavailable. This leads to their rapid depletion, perhaps in as little as an hour, since you need approximately a VT of driving gas per breath, substantially more if airway resistance (RAW) is increased.

Infection
Clean the bellows after any patient with diseases which may be spread through airborne droplets, or don’t use the mechanical ventilator, or use bacterial filters, or use disposable soda lime assembly, or use a Bain.

Mechanical ventilator failure
Protocol for mechanical ventilator failure
1. If the ventilator fails, manually ventilate with the circle system.
2. If #1 is not possible, then bag with oxygen (if a portable cylinder is available) or room air.
3. If #2 is not possible, then try to pass suction catheter through the tracheal tube.
4. If #3 is not possible, then visualize the hypopharynx and cords, or reintubate (?).

Don’t delay reestablishing ventilation to diagnose a problem. Proceed expeditiously from one approach to another.

Related information can be found at GasNet. Look under the Point of Care tab for "Management of the Difficult Airway". An excellent well-illustrated guide which contains anatomy, pathology, and the Difficult Airway Algorithm.

**Increased inspired carbon dioxide**

Malfunctioning unidirectional valves can cause serious problems. If the inspiratory valve is incompetent, the patient exhales into both limbs. The capnogram may show a slanted downstroke inspiratory phase (as the patient inhales carbon dioxide-containing gas from the inspiratory limb) and increased end-tidal carbon dioxide (as in the bottom capnogram in the figure). If the expiratory valve is incompetent, increased inhaled and exhaled carbon dioxide levels may appear with a normal appearing capnogram. The cardinal sign in either is an elevated baseline- a non-zero inspired CO2. Failure of granules or valves has been defined as inspired CO2 of 2 (or more) mm Hg (Anesth Analg 2001;93:221-5). Both situations result in respiratory acidosis unresponsive to increased ventilation. If the valves stick closed, all gas flow within the circle system ceases, and one cannot ventilate the patient.

**Differential diagnosis: Machine malfunction? Altered patient physiology?**

Increased carbon dioxide production will not result in increased inspired carbon dioxide. The capacity of the soda lime granules is sufficient to cleanse each breath entirely, even if carbon dioxide production is increased. Further, respiratory acidosis will not cause visibly dark blood, or desaturation on the pulse oximeter.

The causes of increased inspired carbon dioxide are almost exclusively either malfunctioning unidirectional valves, or exhausted absorbent. Increased inspired carbon dioxide has other potential causes but these are rare

- inadvertent administration of carbon dioxide
- low fresh gas flow in a Mapleson system
- improper assembly of Bain system
- excessive dead space [for example rebreathing under drapes]
- leak in inspiratory limb of circle
- capnograph artifact [water in sampling cell, or sampling rate too low]

Treatment must be accurately directed at the cause or it will be ineffective. Many approaches are useless: increasing minute ventilation, seeking signs of malignant hyperthermia, checking for leaks in the circuit, obtaining arterial blood gases, bronchoscopy for mucous plugs, central line insertion, recalibrating or replacing ventilator, capnograph, or entire gas machine.
Diagnosis and treatment

If the granules are *not* exhausted, and the inspiratory and expiratory unidirectional valves are forcing *all* exhaled gas through the granules, there can be *no* increase in inspired carbon dioxide. So, if it is detected:

1. First, **increase fresh gas flow** (FGF) to much greater than minute ventilation.
   
   - A fresh gas flow of 8-10 L/min creates a semi-open system, with essentially no rebreathing, since the amount of fresh gas is sufficient to dilute any exhaled carbon dioxide to very low levels (and send it to the scavenging system).
   
   - If the granules are exhausted, inspired CO₂ will return to normal. Change the granules at the end of the case.

2. Second, **inspect the unidirectional valves** (if increased FGF was not effective in reducing increased inspired CO₂).
   
   - If the increased fresh gas flow doesn't solve the problem, the granules can not be at fault.
   
   - The expiratory valve is more prone to trouble because of the higher humidity on that side of the circle.
   
   - Clean or replace the expiratory valve while bagging the patient.

Scavenging and Waste Anesthetic Gases (WAGs)

Disposal: Scavenging Systems

**Purpose of scavenging**

**Definition** Scavenging is the collection and removal of vented anesthetic gases from the OR. Since the amount of anesthetic gas supplied usually far exceeds the amount necessary for the patient, OR pollution is decreased by scavenging. If a fresh gas flow-sized volume enters the breathing circuit each minute, the same flow must leave it, or barotrauma will result. **Scavenger and operating room ventilation** efficiency are the two most important factors in reduction of waste anesthetic gases (WAGs).

**Types**

Scavenging may be active (suction applied) or passive (waste gases proceed passively down corrugated tubing through the exhaust grill of the OR). Active systems require a means to protect the patient’s airway from the application of suction, or buildup of positive pressure. Passive systems require that the patient be protected from positive pressure buildup only.

Another important distinction is that scavenger interfaces may be open (to the atmosphere) or closed (gases within the interface may communicate with the atmosphere only through valves; the more familiar type). The
different types of interface have clinical implications. Open interfaces are found on all Julian, Fabius GS, Narkomed 6000, and S/5 ADU gas machines. Aestiva may have an open or closed interface. Clearly, open interfaces are safer for the patient. From being relatively unknown 10 years ago, they are becoming almost universal on new equipment, so patient (and anesthetists’) safety demands user’s attention to the distinctions.

**Practice guidelines**

JCAHO requires scavenging. AANA published recommendations in 1992, available through the Bookstore at AANA. NIOSH recommendation to OSHA: Workers should not be exposed to an eight hour time-weighted average of >2 ppm halogenated agents (not >0.5 ppm if nitrous oxide is in use) or >25 ppm nitrous oxide. ASA also has a published WAGs guideline and fact sheet.

**Components of the scavenger system**

1. Gas collection assembly, (tubes connected to APL and vent relief valve)
2. Transfer tubing (19 or 30 mm, sometimes yellow color-coded)
3. Scavenging interface
4. Gas disposal tubing (carries gas from interface to disposal assembly)
5. Gas disposal assembly (active or passive - active most common, uses the hospital suction system)

The scavenger interface is the most important component. It protects the breathing circuit from excess positive or negative pressure. Positive-pressure relief is mandatory to vent excess gas in case of occlusion distal to interface. If active disposal system, must have negative pressure relief as well. Reservoir highly desirable with active systems.

Interfaces can be open or closed types. Open interface has no valves, and is open to atmosphere (allows both negative and positive pressure relief). Should be used only with active systems. Keep the suction indicator between the white etched lines. Remember that hissing from an open interface is normal- there is no audible indication of waste gas leaks. Closed interface communicates with atmosphere only through valves. Should adjust vacuum so that reservoir bag neither flat not over-distended.

While safer for the patient (no hazard of positive or negative pressure being applied to the airway as a result of scavenger failure), the risk of occupational exposure for providers ignorant of their proper use is higher with the open interface (Anesth Analg 1992;75:1073). Caveat emptor.
Hazards of scavenging
- Obstruction distal to interface causes barotrauma or excess negative pressure (action: disconnect gas collection tubing from back of popoff valve [APL], or turn off suction at scavenger interface).
- Occupational exposure
- Barotrauma or inability to ventilate

Controlling occupational exposure to waste anesthetic gases

Effectiveness: Unscavenged operating rooms show 10-70 ppm halothane, and 400-3000 ppm N2O. Minimal scavenging brings these levels down to 1 and 60 ppm respectively; adding careful attention to leaks and technique can yield levels as low as 0.005 and 1 ppm.

Avoiding waste gas exposure: Evidence of harm to anesthesia personnel from waste gases is suggestive but unproved (strongest relationship is N2O and reproductive difficulties). There are definite hazards to patients when scavenging systems fail- so consider the scavenger part of the breathing system and check it each day. The smell of gas during a case is abnormal and the cause should be sought. Good technique will also help lessen exposure:
- Good mask fit
- Avoid unscavengeable techniques if possible (insufflation)
- Prevent flow from breathing system into room air (only turn on agent and nitrous oxide after mask is on face, turn them off before suctioning)
- Washout anesthetics (into the breathing circuit) at the end of the anesthetic
- Don’t spill liquid agent
- Use low flows
- Use cuffed tracheal tubes when possible
- Check the machine regularly for leaks
- Disconnect nitrous oxide pipeline connection at wall at the day’s end (beginning?)
- Total intravenous anesthesia

Putting it all together: Machine checklist, Medicolegal, Cleaning & sterilization

Anesthesia gas machine check

*Apparatus of reliable appearance engenders a strong feeling of security which is often not supported by facts. A critical attitude often forestalls unpleasant surprises.* Lucien Morris, in Aldrete Lowe & Virtue Low Flow & Closed System Anesthesia Grune & Stratton 1979.
One of the things that I notice about the practice of anesthesia is the extensive use of protocols and procedures. As I learn more about anesthesia I realize how important protocols and procedures are to ensure patients’ safety. When an emergency arises in anesthesia the anesthetist’s reaction must be swift and accurate. There is no time to begin searching the literature for a discussion about how to handle this crisis. I am impressed with the positive and careful manner in which procedures have been developed to deal with many aspects of anesthesia. As a lawyer I also see that these procedures can protect the anesthetist. Should the anesthetist be required to defend himself or herself, it may be difficult to remember the exact details of an anesthetic given years before. Sometimes, it is helpful to be able to testify that certain matters are always done by following established procedures, even if you cannot remember what happened in a particular case. For example, if you begin your day or each operation checking out your anesthesia machine according to FDA guidelines, then even if you cannot remember what you did on February 1, 1995, you will know you checked the anesthesia machine because that is what you always do.” -Gene A. Blumenreich, JD AANA Journal, The importance of following procedures in anesthesia, April 2000.

**Negative pressure leak check**

Diagram of area proximal to check valve which is not checked with high-pressure methods. Click on the thumbnail, or on the underlined text, to see the larger version (25 KB).

Negative pressure leak test device. Click on the thumbnail, or on the underlined text, to see the larger version (12 KB).

Unidirectional valves (check valves) are present in many machines between the vaporizers and the common gas outlet. Without them (or internal vaporizer design modifications), the cycling of positive pressure in the breathing circuit leads to increases in vaporizer output (the *pumping effect*). A high pressure check of the breathing circuit (Food and Drug Administration [FDA] Checklist 1993 step 11 below or online at [FDA Checklist 1993](#)) will not detect leaks upstream of these valves, since the high pressure in the breathing circuit will only be transmitted upstream to the check valve, and no further. These are vulnerable areas. Glass flowtubes and internal vaporizer seals and rubber O-rings are susceptible to failure. A *universal leak check* that will work on any anesthesia machine is the FDA Checklist Step 5, which relies on negative pressure. Unfortu

**Electronic checklists**

The newer machines (Datex-Ohmeda S/5 ADU, Dräger Julian, NM 6000, Fabius GS) are unique in having a system checkout routine that is electronic and automated. The operator follows instructions to activate flows of gases, occlude the breathing circuit during the leak check, switch from manual to mechanical ventilation, open and close the pop off valve, or manually check various functions (suction, or emergency oxygen cylinder supply). It covers all the steps of the FDA Checklist, but this is apparent only after some study. The system checkout is logged, but may be bypassed in an emergency. Though it takes 3 to 6 minutes, the operator can perform other
tasks simultaneously (such as filling syringes), so it does not appreciably slow morning preparation, unless one had not been accustomed to performing a morning gas machine checklist.

The electronic checklist for the S/5 ADU requires that the D-Lite sensor (gas analysis and volume/flow sensor connection) is disconnected, and the breathing circuit occluded by attaching it to a post. After the electronic checklist is complete, the breathing circuit with D Lite sensor is reassembled. The operator must do a high pressure check of the reassembled breathing circuit before using it on a patient.

Minimum test under life-threatening conditions

While there is no universally accepted machine checklist less than the full FDA Checklist, situations do arise in anesthesia for trauma or emergency cesarean section where there is neither time nor opportunity to fully check the anesthesia gas machine. The following checklist is suggested for these situations. It requires little if any additional time, and can add greatly to safety, and hence, peace of mind.

1. High pressure test of the breathing circuit
   - Ensures there are no leaks distal to common gas outlet

2. Check suction

3. Observe and/or palpate breathing bag during preoxygenation
   - Ensures
   - Adequate flow of oxygen
   - Good mask fit (very important)
   - The patient is breathing
   - The Bag/Vent switch is on "Bag" not "Vent"

With all new machines, the electronic checklist can be bypassed in emergencies. Whether this 30 second process is acceptable must be determined by each clinical practice. It has been suggested that the NM 6000 be left on if trauma or obstetric cases must be done on a moment’s notice (Anesthesiology 2001;95:567-8). The NM 6000 checklist can only be bypassed nine times. The S/5 ADU checklist can be bypassed an indefinite number of times, but it will display a visible, nagging message until the electronic checkout is performed. Since oxygen flow is mechanical in the ADU, the plan in one practice for obstetric emergencies is to leave the gas machine off. When a patient needs emergent general anesthesia, the oxygen flow is established for preoxygenation while the ADU is turned on and the checklist is bypassed. These actions can be accomplished in less than a minute- less time than is needed for preoxygenation to be complete.

FDA anesthesia gas machine checklist (1993)

This checklist is a modified version of the original: Step 10 (Check initial status of breathing system) is followed by Steps 12 (Check ventilator and unidirectional valves), 11 (Perform [high pressure] leak check of breathing system), and then 8 (Adjust and check scavenging system). The primary reason for the modification is to avoid leaving the Bag/Vent switch in "Vent" position after the checklist is complete, which fault is encouraged by the
original checklist order. This modification was agreed upon after local peer review; it is suggested that this should occur anywhere such a modification is contemplated.

**Modified Anesthesia Gas Machine Checklist**

*Introduction* The anesthesia gas machine must be equipped with an ascending bellows ventilator and certain monitors (capnograph, pulse oximeter, oxygen analyzer, spirometer, breathing system pressure monitor with high and low pressure alarms). If not so equipped, the checklist must be modified.

1. **Verify** backup ventilation equipment *is available & functioning.*
   - Contaminated oxygen supply, loss of oxygen supply pressure, and obstruction of the breathing system, though rare, cause the machine to be totally inoperable. So check for that Ambu!

2. **Check** oxygen cylinder supply
   - One cylinder must be at least half full (1000 psi), according to the FDA Checklist (older versions called for 600 psi as the lower limit). This will allow gas machine function for 10-60 minutes, or longer.
   - It is *not* necessary to:
     1. Check any other cylinders beside oxygen
     2. “Bleed” the pressure off the cylinder pressure gauge after checking
   - Leave cylinder closed after checking.
   - *While you’re behind the machine, check* suction, Ambu bag and extra circuit present. Also: gas analysis scavenged, scavenger caps all present, location of circuit breakers, any loose pipeline, electrical, or etc. connections, head strap, tank wrench, and color/date of CO₂ absorbent.

3. **Check** central pipeline supplies.
   - Check for proper connection at wall
   - Check the pipeline pressure gauge- should read approximately 50 psi.
   - It is *not* necessary to unhook pipeline connections at wall.

4. **Check** initial status of low pressure system.
   - Remove oxygen analyzer sensor.
   - Check liquid level and fill vaporizers if necessary.
   - Check vaporizer interlock.

5. **Perform** leak check of low pressure system.
   - Leaks as low as 100 mL/min may lead to critical decrease in the concentration of volatile anesthetic (creating a risk for intraoperative awareness), or permit hypoxic mixtures under certain circumstances.
   - **Negative pressure leak test** (10 sec.) is recommended.
   - Repeat for each vaporizer.

6. **Turn master switch on.**
7. Test flowmeters.
   - Check for damage, full range, hypoxic guard.

8. Calibrate oxygen monitor (FDA Step 9)
   - It's not the alphas and betas which kill them, it's the little green O's. - John Garde
   - Final line of defense against hypoxic mixtures.
   - Trust it until you can prove it wrong.
   - Mandatory for all general anesthetics, or when using the breathing circuit (for example during a propofol or other sedation)
   - Calibrate/daily check: expose to room air and allow to equilibrate (2 min). Then expose to oxygen source and ensure it reads near 100%

9. Check initial status of breathing system (FDA Step 10)
   - Assemble circuit with all accessories.

10. Test ventilation systems and unidirectional valves (FDA Step 12)
    - Test ventilator and observe action of unidirectional valves.

11. Perform leak check of breathing system (FDA Step 11)
    - The "usual" high pressure check.
    - Let the gas out of the circuit through the popoff [APL] valve, not the elbow.

12. Adjust and check scavenging system. (FDA Step 8)
    - If active (suction) is applied to a closed scavenger interface, check the positive and negative pressure relief valves of the interface.
    - If open interface, ensure that adequate suction is applied (the indicator float between the scribed lines).

13. Check, calibrate, set alarm limits of all monitors

    - Vaporizers off
    - Bag/Vent switch to "bag" mode
    - APL open
    - Zero flows on flowmeters
    - Suction adequate
    - Breathing system ready

Note: May omit or abbreviate #1-9 between cases.

Importance of the gas machine checklist

As recently as May 2000 (Health Devices 2000;29:188-9) it was reported that failure to check a disposable breathing circuit led to a patient fatality. Studies have shown the need for providers to improve their skills at checking gas machines with known faults (or perhaps the need for improved equipment)- see AANA Journal
The Closed Claims study of gas delivery equipment (Anesthesiology 1997;87:741-8) concluded that misuse of equipment was three times more prevalent than equipment failure, and that educational and preventive strategies were needed.

**Risk management, quality assurance, standards, and medicolegal**

Risk Management encompasses pre and post-op visits, avoiding treating patients indifferently, maintaining vigilance and high standards of care, peer review, and continuing education. For anesthesia equipment, it means daily checks and appropriate maintenance. The Safe Medical Device Act 1990 mandates a report to the FDA when equipment contributes to severe injury or death. Preventive maintenance should be done at regular intervals as called for in the operating manuals by qualified, factory-trained and approved service technicians. Vaporizers should be inspected, tested and calibrated per manufacturer’s guidelines.

Quality assurance deals with objective, systematic monitoring, and the evaluation of the quality and appropriateness of patient care. Waste anesthesia gas testing can help to protect personnel and identify machines with problems. Anesthesia personnel can be held liable for knowledge of material in the anesthesia gas machine operating manual, maintenance guide, and any warnings given by the manufacturer (which are monitored and approved by the FDA the same way drug package inserts are).

AANA Monitoring Standards 1992 have implications for equipment. Capnography and pulse oximetry are so ubiquitous, that they may be considered integral parts of the machine itself. Gas machines are required to have a breathing system disconnect monitor with alarm, an oxygen analyzer, and an oxygen supply failure alarm. These monitoring standards also mandate a safety check daily and between cases (as needed), preventive maintenance, and machines that conform to national and state standards. The FDA Checklist for anesthesia equipment also emphasizes ascending ventilator bellows, and certain monitors (capnograph, pulse oximeter, oxygen analyzer, spirometer, and a breathing system pressure monitor with high and low pressure alarms).

**Cleaning and sterilization**

It is controversial whether equipment can transmit infection, though some cases have certainly been documented. Most, if not all, would agree that sterilization is essential after use on a patient with known or suspected infection of the respiratory tract, especially with virulent organisms like *Pseudomonas aeruginosa*. Likewise, we should protect compromised patients from contamination arising from our equipment. In any case, handwashing between patients, as well as universal precautions are mandatory in anesthetic practice. Housekeeping during administration of anesthesia will limit the spread of contamination:

- Always work from a clean surface
- Used articles should be physically separate from this area, and allowed to soak if they become soiled

Cleaning equipment means removal of foreign matter without special attempts to kill microorganisms. Equipment should be pre-rinsed as soon as possible after use to prevent drying of organic material; then soaked, removal of soil, rinsing and drying.
Sterilization

Moist heat methods

- **Pasteurization** (less than 100 degrees C) disinfects but doesn't sterilize (destroys many but not all organisms).
- **Boiling** kills all forms of bacteria, most spores, practically all viruses if boiled at least 30 minutes.
- **Autoclaving** (steam sterilization under pressure) kills all bacteria, spores and viruses.

Liquid sterilization

Useful for heat sensitive equipment, but recontamination possible during drying and re-wrapping. Of several agents (chlorhexidine Hibitane®, phenolic compounds, hexachlorophene, ethyl or isopropyl alcohols), **glutaraldehyde** is the only one effective against both tubercule bacillus and viruses.

The Steris system uses peracetic acid in a low-temperature, 30 minute cycle to sterilize objects such as laryngoscope blades and fiberoptic laryngoscopes.

Chemical gas sterilization

**Ethylene oxide** (ETO) is a synthetic gas widely used, especially for heat or moisture-sensitive items like rubber and plastic. Kills bacteria, spores, fungi, larger viruses. Can be various patient reactions if not aerated (in wrapper) sufficiently after ETO exposure. The gas is also explosive and toxic.

Other means

Gamma radiation kills all bacteria, spores and viruses. Used for sterilization of disposable equipment - not practical for everyday needs of hospitals.

Care of specific equipment

- **Carts & gas machine** - wipe top, front, sides with detergent/germicide (D/G) daily and place a clean covering on top; clean entire cart inside and out weekly or after contaminated cases
- **Breathing circuits, ETT, face masks, airways, resuscitation bags** - generally single use, or follow department policy & manufacturer’s guidelines
- **Absorber, unidirectional valves, relief valve, bellows** - follow manufacturer’s instructions, use disposable components or filters on the circle system for known infected cases
- **Blades, Magills** - cleanse, glutaraldehyde (or Steris) sterilization, store clean
- **Headstraps, BP cuffs** - Items in contact with intact skin need periodic cleansing, or should be cleansed if soiled

The [Centers for Disease Control](https://www.cdc.gov) has a collection of useful information relating to bloodborne & universal precautions.
New (and old) Gas Machines

Advanced ventilators are among the biggest differences between new and older gas machines. (Review previous section on this site on ventilators now.)

This page is a general survey of gas machines available for purchase, or older machines still in use in North America. For each gas machine model you may find comments, important features, a picture, how it fits in with your current equipment, and limited specifications (like size, number of vaporizers or flowmeters).

Dräger Medical Inc. (Telford, Pennsylvania)

Narkomed 6400 and 6000

{PRIVATE "TYPE=PICT;ALT=NM 6000"}NM 6000. Click on the thumbnail, or on the underlined text, to see the larger version (67 KB).

{PRIVATE "TYPE=PICT;ALT=NM 6000-Flowmeters, Vapor 2000"}NM 6000-Flowmeters, Vapor 2000. Click on the thumbnail, or on the underlined text, to see the larger version (100 KB).

{PRIVATE "TYPE=PICT;ALT=NM 6000-Vent controls"}NM 6000-Vent controls. Click on the thumbnail, or on the underlined text, to see the larger version (78 KB).

- Monitoring included:
  - Volume, Pressure, inspired Oxygen (VPO)
    - Galvanic cell oxygen analysis. Two sensors whose values are compared. New sensors need a 15 minute warmup/waiting period before calibration.
  - Gas monitoring (infrared agent and CO2)
  - Ultrasonic flow sensor in the breathing circuit (unique to this machine). Pressure transducers measure the flight time of two ultrasonic waves passing upstream and downstream in the airway flow path, yielding velocity and flow of gas in the breathing circuit. Displays tidal (VT) and minute (VE) volume, respiratory rate, respiratory volume waveform.
  - An integrated patient monitoring module is available as an option, so that all parameters are displayed on a single touch screen. This includes: ECG (up to seven leads), ST Segment Analysis, 4 invasive blood pressures, non-invasive blood pressure, pulse oximetry, temperature (2 sites), thermodilution cardiac output, and output for communication with defibrillators and intra-aortic balloon pumps.

- Ventilator: Piston ventilator (Divan) with tidal volume corrected for leaks, patient and breathing circuit compliance, and fresh gas flow (by fresh gas decoupling). "Fresh gas low" error warns of piston entraining room air. Modes volume control (VCV), pressure control (PCV), synchronized intermittent mandatory ventilation (SIMV), Manual/Spontaneous. There is no "bag/vent" switch, since changing
ventilator mode is controlled electronically. It is accurate to very low tidal volumes (range 10-1400 mL). Use pediatric circle system hoses for VT less than 200 mL (repeat vent self-test when changing circuits).

- **Machine checklist:** From cold startup, 1 minute power-on self test, then 5 minute ventilator self-test. Can bypass ventilator test 10 days or ten times only, after which ventilator is unavailable until its self-test is performed. Because circuit compliance is measured and tidal volume is adjusted accordingly, the manufacturer discourages expandable circuit hoses. Periodic leak test is performed during use. The machine checkout basically follows FDA guidelines but there are some non-trivial differences. For example, the manufacturer recommends breathing through each circuit limb to test check valves, and disconnecting the oxygen wall hose to check oxygen pipeline pressure-failure device. Users must review operator's manual to check the machine correctly.

- **Flowmeters:** traditional mechanical/pneumatic (needle valves and glass flowtubes), but electronic capture of fresh gas flows has recently been added. Minimum oxygen flow 150 mL/min. Pneumatic ORC (oxygen ratio controller) for hypoxic guard.

- **Vaporizers:** Variable-bypass vaporizers are used, and these may be removed without tools. Vapor 2000.

- **Breathing circuit:** The absorber head is warmed, and the breathing circuit is lower volume (1.5 L absorbent volume). Only loose carbon dioxide absorbent granules may be used. The machine is not compatible with non-rebreathing circuits.

- **Scavenger:** Open scavenger interface, or passive.

- **Electrical power failure:** 30 minute battery reserve with fresh gas, vaporizers, monitors, and ventilator operational.

- **Other features:** Low flow wizard. Ventilator override switch assures that if ventilator fails manual/spontaneous breathing can be re-established. Fresh gas decoupling causes manual breathing bag to fluctuate during mechanical ventilator cycle, which serves as a further disconnect alarm.

- **Web site:** Narkomed 6400

- **Weight:** 225 kg

- **Comments/Where this machine fits:** Modern, top of the line machine with an excellent ventilator. May choose integrated patient monitoring from Dräger, or use any other vendor's.

**Fabius GS**

{PRIVATE "TYPE=PICT;ALT=Fabius GS"}Fabius GS. Click on the thumbnail, or on the underlined text, to see the larger version (36 KB).
• **Monitoring** included:
  
  • Volume, Pressure, inspired Oxygen (VPO)
    
    • Galvanic cell oxygen analysis. New sensors need a 15 minute warmup/waiting period before calibration.
  
  • Thermal anemometry ("hot wire") flow sensor in the breathing circuit (unique to this machine and the Julian). May be sensitive to radio-frequency interference (from electrosurgery units).
    
    Displays tidal (VT) and minute (VE) volume, respiratory rate, respiratory pressure waveform.
  
• **Ventilator:** Piston ventilator with tidal volume corrected for leaks, patient and breathing circuit compliance, and fresh gas flow (by fresh gas decoupling). Vertical piston visible during cycling in window to left of flowmeters. "Fresh gas low" error warns of piston entraining room air (negative pressure threshold -2 to -5 cm of water). Modes volume control (VCV), pressure control (PCV), Manual/Spontaneous. There is no "bag/vent" switch, since changing ventilator mode is controlled electronically. It is accurate to very low tidal volumes (range 20-1400 mL). Use pediatric circle system hoses for low VT, and repeat leak/compliance test when changing circuits. Can view measured respiratory parameters or ventilator settings, but not both simultaneously.
  
• **Machine checklist:** Basically a manual FDA-style checklist with a few electronic self-tests (system, leaks, flow sensor, oxygen sensor).
  
• **Flowmeters:** Vertically arranged needle valves, digital numeric flow display, total fresh gas flow glass flowtubes, and graphic display of each flow on a separate screen. Electronic capture of fresh gas flows. No minimum oxygen flow. S-ORC (sensitive-oxygen ratio controller) for hypoxic guard.
  
• **Vaporizers:** Variable-bypass vaporizers are used, and these may be removed without tools. Vapor 2000, Vapor 19, or Tec 6.
  
• **Breathing circuit:** The absorber head is not warmed. The breathing circuit is lower volume (2.8 L of which 1.5 L is absorbent volume). Only loose carbon dioxide absorbent granules may be used. Manufacturer recommends changing if the machine has been idle for 48 hours, or each week on Monday. Cannot be used with non-rebreathing circuits.
  
• **Scavenger:** Open scavenger interface.
  
• **Electrical power failure:** 45 minute battery reserve with fresh gas, vaporizers, integrated monitors, and ventilator operational. Patient monitors will not function, as they are not part of the gas machine.
Pneumatic functions remain after battery is exhausted (vaporizers, S-ORC, APL valve, flowmeters, breathing pressure gauge, cylinder and pipeline pressure gauges, total fresh gas flowmeter).

- **Other features:** Desflurane compensation must be entered by the operator when this agent is used, to prevent inaccuracy in respiratory flow measurement. Fresh gas decoupling causes manual breathing bag to fluctuate during mechanical ventilator cycle, which serves as a further disconnect alarm.

- **Web site:** [Fabius GS](#)
- **Weight:** 101 kg without cylinders and vaporizers.
- **Comments/Where this machine fits:** Modern, top of the line machine with an excellent ventilator. An economical choice particularly if one wishes to retain one's current patient monitoring system. Must supply own patient monitors, and gas analysis.

**Narkomed GS**

*Narkomed GS.* Click on the thumbnail, or on the underlined text, to see the larger version (59 KB).
• **Monitoring** included:
  - Volume, Pressure, inspired Oxygen (VPO)
  - Galvanic cell oxygen analysis.
  - Electronic Wright respirometer style flow sensor

• **Ventilator:** Ascending bellows pneumatic double-circuit AV2+ style ventilator without tidal volume compensation. Modes volume control (VCV), Manual/Spontaneous. Mechanical "bag/vent" switch.

• **Machine checklist:** Manual FDA-style checklist.

• **Flowmeters:** Traditional needle valve with glass flowtube display.

• **Vaporizers:** Variable-bypass vaporizers are used. Vapor 19 or Tec 6.

• **Breathing circuit:** Traditional absorber head. The breathing circuit is higher volume (dual absorbent canisters). May use loose granules or prefilled canisters. May be used with non-rebreathing circuits.

• **Scavenger:** Open, closed, or passive scavenger interface.

• **Electrical power failure:** Most functions except patient monitoring are preserved during power failure, as this is a basic pneumatic-mechanical machine. The VPO display will be lost after battery exhaustion.

• **Other features:**
  - Web site: [Narkomed GS](#)
  - Weight: 170 kg

• **Comments/Where this machine fits:** This gas machine is intuitive, and economical. Little new technology to learn. Must supply own patient monitors, and gas analysis.

**Julian**

Click on the thumbnail, or on the underlined text, to see the larger version (72 KB).

Click on the thumbnail, or on the underlined text, to see the larger version (69 KB).

Click on the thumbnail, or on the underlined text, to see the larger version (92 KB).

• **Monitoring** included:
• Volume, Pressure, inspired Oxygen (VPO)
  • Galvanic cell oxygen analysis.

• Thermal anemometry (“hot wire”) flow sensor in the breathing circuit (unique to this machine and the Fabius GS). May be sensitive to radio-frequency interference (from electrosurgery units). Displays tidal (VT) and minute (VE) volume, respiratory rate, respiratory pressure waveform.

• Infrared gas analysis and capnography.

• Pulse oximetry may be integrated as an option.

• **Ventilator:** Descending (“hanging”) bellows, pneumatically driven dual circuit ventilator with tidal volume compensation for leaks, breathing circuit compliance, and fresh gas flow. Modes volume control (VCV), pressure control (PCV), Manual/Spontaneous. There is no “bag/vent” switch, since changing ventilator mode is controlled electronically. It is accurate to very low tidal volumes (range 50-1400 mL). Use pediatric circle system hoses for VT less than 200 mL, and repeat leak/compliance test when changing circuits.

• **Machine checklist:** Basically a manual FDA-style checklist with a few electronic self-tests (system, leaks/compliance, oxygen sensor).

• **Flowmeters:** One of the more unique features of this machine. Total fresh gas flow, carrier gas (nitrous oxide or air), and desired inspired oxygen concentration are set. Entirely electronically controlled; no needle valves or glass flowtubes. Digital numeric flow display, and optional graphic display of each flow on a separate screen. Electronic capture of fresh gas flows. No minimum oxygen flow, electronic hypoxic guard system. "Safety O2" flowmeter as mechanical backup.

• **Vaporizers:** Variable-bypass vaporizers are used, and these may be removed without tools. Vapor 2000, or Vapor 19.

• **Breathing circuit:** The absorber head is warmed. The breathing circuit is higher volume (4.5 L without hoses of which 1.5 L is absorbent volume). Only loose carbon dioxide absorbent granules may be used. Cannot be used with non-rebreathing circuits.

• **Scavenger:** Open scavenger interface.

• **Electrical power failure:** 30 minute battery reserve with fresh gas, vaporizers, integrated monitors, and ventilator operational. Patient monitors will not function, as they are not part of the gas machine.

• **Other features:** Breathing system designed to be compact, easily disassembled for cleaning.

• **Web site:**
  • Web site: Julian

• **Weight:** 90 kg without cylinders and vaporizers.

• **Comments/Where this machine fits:** Modern, compact machine with significant design features that diverge from what most US-trained anesthetists are familiar with. Must supply own patient monitors.
Narkomed MRI-2

Monitoring included:
- Volume, Pressure, inspired Oxygen (VPO)
  - Galvanic cell oxygen analysis.


Flowmeters: Traditional needle valve with glass flowtube display.

Vaporizers: Variable-bypass vaporizers are used. Vapor 19.
• **Breathing circuit**: Traditional absorber head. The breathing circuit is higher volume (dual absorbent canisters). May use loose granules or prefilled canisters. May be used with non-rebreathing circuits.

• **Scavenger**: Open, closed, or passive scavenger interface.

• **Electrical power failure**: Most functions except patient monitoring are preserved during power failure, as this is a basic pneumatic-mechanical machine.

• **Other features**: Distributed as "Magnitude-AS" by Invivo Research (who makes MRI-compatible patient monitors).

• **Web site**: [Narkomed MRI](http://www.narkomed.com)

• **Weight**: (unknown)

• **Comments/Where this machine fits**: Traditional gas machine suited for MRI environment. Must supply own patient monitors, and gas analysis.

**Narkomed Mobile and Narkomed M**

Click on the thumbnail, or on the underlined text, to see the larger version (45 KB).

• **Monitoring** included:
• Volume, Pressure, inspired Oxygen (VPO)
  • Galvanic cell oxygen analysis.

• Ventilator: Ascending bellows pneumatic double-circuit AV2+ style ventilator without tidal volume compensation. Modes volume control (VCV), Manual/Spontaneous. Mechanical "bag/vent" switch.


• Flowmeters: Traditional needle valve with glass flowtube display.

• Vaporizers: Variable-bypass vaporizers are used. Vapor 19.

• Breathing circuit: Traditional absorber head. The breathing circuit is medium volume (single absorbent canister). May use loose granules or prefilled canisters. May be used with non-rebreathing circuits.

• Scavenger: Open or closed scavenger interface.

• Electrical power failure: Most functions except patient monitoring are preserved during power failure, as this is a basic pneumatic-mechanical machine.

• Other features: The M is designed for shipment and transportation by truck, ship, or air.

• Web site: Narkomed Mobile, Narkomed Military

• Weight: 75 kg

• Comments/Where this machine fits: Obviously, the strong suit here is the light weight and compact size, making the machine well-suited for anesthesia outside the OR, in the office environment, or whenever a machine must be transported by hand. Must supply own patient monitors, and gas analysis.

Narkomed 2C
Monitoring included: Volume, Pressure, Oxygen (inspired).

Important features: Ascending bellows ventilator (AV2+). Modes VCV, Manual/Spontaneous. Mechanical/pneumatic flowmeters (needle valves and glass flowtubes) and vaporizers. Traditional size and configuration of absorber head and higher-volume breathing circuit. Loose absorbent granules or canisters. Removable vaporizers. Can be used with non-rebreathing circuits. Open or closed scavenger interface.

- Web site: Narkomed 2C
- Weight: (unknown)


Narkomed 4
• Monitoring included:
  • Volume, Pressure, Oxygen (inspired).
  • Gas analysis (Capnography, Agent monitoring).
  • Non-invasive BP, Pulse oximetry.
• Important features: Ascending bellows ventilator (AV2+). Modes VCV, Manual/Spontaneous.
Mechanical/pneumatic flowmeters (needle valves and glass flowtubes) and vaporizers. Traditional size and configuration of absorber head and higher-volume breathing circuit. Loose absorbent granules or
canisters. Removable vaporizers. Can be used with non-rebreathing circuits. Open or closed scavenger interface.

- Web site: Narkomed 4
- Weight: unknown
- Comments/Where this machine fits: Traditional design and ventilator with a higher degree of integrated monitoring. No longer in production since 2001.

Datex-Ohmeda (Madison Wisconsin)

S/5 ADU (also known as S/5 or AS/3 ADU){PRIVATE "TYPE=PICT;ALT=ADU"}ADU. Click on the thumbnail, or on the underlined text, to see the larger version (67 KB).
ADU screens. (TOP) Click on the thumbnail, or on the underlined text, to see the larger version (69 KB).

NM Block monitoring. (DOWN) Click on the thumbnail, or on the underlined text, to see the larger version (56 KB).
ADU spirometry. Click on the thumbnail, or on the underlined text, to see the larger version (94 KB).

- **Monitoring** included:
  - Volume, Pressure, inspired Oxygen (VPO)
    - Paramagnetic oxygen analysis (much longer sensor life).
  - Gas monitoring (agent and carbon dioxide)
  - Physiologic monitoring (EKG, NIBP, Pulse oximetry, Invasive pressures, Cardiac output, Neuromuscular block [optional])
  - Spirometry (flow-volume and pressure-volume respiratory loops)

- **Ventilator**: Ascending (“standing”) bellows, dual circuit, pneumatically-driven ventilator with tidal volume corrected for leaks, compliance, and fresh gas flow (by D-Lite sensor at Y-piece). Modes VCV, PCV,
SIMV, Manual/Spontaneous. Accurate to very low tidal volumes (20-1400 mL). The "bag/vent" switch activates the mechanical ventilator in one step.

- **Machine checklist:** An almost-completely automated checklist routine which conforms to FDA recommendations. Since the D-Lite sensor is removed from the breathing circuit during checkout, one must perform a high-pressure check of the breathing circuit after reassembly. Users must review operator’s manual to check the machine correctly.

- **Flowmeters:** Traditional mechanical needle valves, no glass flowtubes. Flow is displayed a a bar graph on computer display screen. Backup common gas outlet flowmeter recommended (but optional). Electronic capture of fresh gas flows. No minimum oxygen flow. No valve stops (can damage needle valves if they are closed too tightly).

- **Vaporizers:** Variable-bypass vaporizers are used, and these may be removed without tools. Aladin vaporizer cassettes are tippable, since they do not contain the electronic controls (these are within the gas machine). Desflurane cassette does not need supplied heat. Vaporizers are not interchangeable with any other model.

- **Breathing circuit:** The breathing circuit is lower volume (only 750 mL absorbent volume). Only the manufacturer's carbon dioxide absorbent canisters may be used, which are single-use, or refillable with loose granules. The machine is technically compatible with non-rebreathing circuits, but the need for them is questionable since the ventilator can handle patients who weigh as little as 3 kg.

- **Scavenger:** Open scavenger interface. Scavenger suction adequacy indicated on optional glass flowmeter.

- **Electrical power failure:** 30 minute battery reserve with fresh gas, vaporizers, and ventilator operational. Patient monitoring (right screen) is lost unless main electrical power (or generator backup) is available-like most gas machines.

- **Other features:** Certain disposables are only available from the manufacturer (spirometry tubing, D-Lite sensor, absorbent granule canisters).

- **Web site:** S/5 ADU

- **Weight:** 110 to 130 kg

- **Comments/Where this machine fits:** Modern, top of the line machine with an excellent ventilator. All monitoring is integrated. Because the physiologic monitoring is built-in, previously-used monitors cannot be "set on top" and used.

Read more about [clinical advantages of the ADU design](#).
Aestiva/5, and Aestiva/5 MRI

{PRIVATE "TYPE=PICT;ALT=Aestiva"}Aestiva. Click on the thumbnail, or on the underlined text, to see the larger version (44 KB).
Monitoring included:
- Volume, Pressure, inspired Oxygen (VPO)

Ventilator: Model 7900 ascending ("standing") bellows, dual circuit, pneumatically-driven ventilator with tidal volume corrected for leaks, compliance, and fresh gas flow. Variable orifice flow sensors that accomplish this only compensate for compliance losses proximal to their location near the breathing circuit unidirectional valves, so compliance losses in the breathing circuit are not compensated. Modes
VCV, PCV, SIMV (optional), pressure support ventilation (PSV, optional but unique to this ventilator), Manual/Spontaneous. Accurate to very low tidal volumes (20-1500 mL). The "bag/vent" switch activates the mechanical ventilator in one step.

- **Machine checklist:** Manual FDA checklist. Users must review operator’s manual to check the machine correctly.
- **Flowmeters:** Traditional mechanical needle valves and glass flowtubes. No electronic capture of fresh gas flows. Minimum oxygen flow 50 mL/min.
- **Vaporizers:** Variable-bypass vaporizers are used (Tec 4, 5, 6, 7), and these may be removed without tools.
- **Breathing circuit:** The breathing circuit is higher volume (5.5 L, including dual canisters of 1.35 kg absorbent each). Loose fill granules or prepackaged absorbent. The machine is compatible with non-rebreathing circuits.
- **Scavenger:** Closed scavenger interface.
- **Electrical power failure:** 30 minute battery reserve with fresh gas, vaporizers, and ventilator operational.
- **Other features:** Also available in an MRI-compatible version.
- **Web site:** [Aestiva, Aestiva MRI](#)
- **Weight:** Aestiva 136-154 kg; Aestiva MRI 136 kg
- **Comments/Where this machine fits:** Traditional size and design gas machine, updated configuration of absorber head (easier disassembly and cleaning). Excellent ventilator capable of PCV- first gas machine to feature Pressure support mode. Variable orifice flow sensors have shown some sensitivity to moisture in the breathing circuit in the past. Must purchase own gas analysis and patient physiologic monitors.

**Modulus SE**
Monitoring included: Volume, Pressure, Oxygen (inspired).

Important features: Ascending bellows ventilator (7800 or SmartVent 7900). Modes CMV, PCV (with SmartVent), Manual/Spontaneous. Mechanical/pneumatic flowmeters (needle valves and glass flowtubes) and vaporizers. Traditional size, configuration of absorber head and higher-volume breathing
circuit. Loose absorbent granules or canisters. Removable vaporizers. Can be used with non-rebreathing circuits. Open or closed scavenger interface.

- Web site: Not listed any longer on Datex-Ohmeda web site
- Weight: 139 kg
- Comments/Where this machine fits: Traditional design and ventilator.

**Excel 210, 110**
Click on the thumbnail, or on the underlined text, to see the larger version (79 KB).
Monitoring included: Volume, Pressure, Oxygen (inspired).

Important features: Ascending bellows ventilator (7000 or 7800). Modes CMV, Manual/Spontaneous. Mechanical/pneumatic flowmeters (needle valves and glass flowtubes) and vaporizers. Traditional size, configuration of absorber head and higher-volume breathing circuit. Loose absorbent granules or
canisters. Removable vaporizers. Can be used with non-rebreathing circuits. Open or closed scavenger interface.

- Web site: Not listed any longer on Datex-Ohmeda web site
- Weight: 120 kg
- Comments/Where this machine fits: Traditional design and ventilator.

Siemens

Kion

![Kion](PRIVATE TYPE=PICT;ALT=Kion). Click on the thumbnail, or on the underlined text, to see the larger version (64 KB).

- Monitoring included: Volume, Pressure, Oxygen (inspired), Capnography and Agent monitoring.
- Web site: [Kion](#); click on "Anaesthesia Systems", then Kion on the left)
- Weight: 183 kg
- Comments/Where this machine fits: Modern, top of the line machine from a company that makes excellent ventilators. Design factors are very different than other machines, and only a small number of Kions are installed in US.

Purchasing new gas machines

What to consider when buying a new gas machine

How is anesthesia going to change in the next 15 years?

- No one knows - but there are some indications already from patient population and demographics. The patient population will be both younger, older, sicker and bigger than today. This puts stress on the ventilation ability. Buy the best ventilator you can with volume and pressure control.
- More spontaneous breathing. The LMA is revolutionizing anesthesia practice. Buy a ventilator that allows pressure limited volume ventilation - limit the pressure to 20 cm H2O to protect the airway and have the familiarity and ease of volume control.
- Make sure that the pressure control is able to ventilate the difficult patients.
• Make sure that the system doesn’t restrict your future options. Make sure the machine you purchase will allow the exporting of fresh gas values to any information system or automated record-keeper. Make sure that whatever you buy can support an electronic anesthesia record. You can be sure that in the next 15 years these will become standard.

• With monitoring make sure that you are comfortable with the integrated monitoring.

**Education and training**

An anesthetist who knew how to use an Excel could easily walk up to a Modulus or any of the Narkomedes and use them with very few problems, and essentially no training time or reading. However, the new machine features such as advanced ventilation modes, computer and monitor integration, and the electronic checklist are very different than anything that has gone before. Even the new products from one manufacturer are substantially different—look at the three different approaches to flowmeters in the Narkomed 6000 (mechanical needle valves and glass flowtubes), Fabius GS (vertically-arranged mechanical needle valves, electronic display of flows backed up by common gas outlet flowmeter), and Julian (all electronic, digital display in which the inspired oxygen, carrier gas flow, and total fresh gas flow are set). Comfort with one make and model translates much less to other models than it used to.

Furthermore, anesthesia practice is changing. Spontaneous ventilation for longer than a few moments during general anesthesia was rare. Now because of the laryngeal mask airway it is much more common. Cost of the volatile agents is substantial enough that low flows are undergoing somewhat of a renaissance. When users at a total fresh gas flow of 1 L/min find inspired oxygen dropping slowly, or a 2-3% difference between dialed and end-tidal desflurane in the middle of a case, they have trouble remembering that these are more or less expected findings.

Comfort with the monitoring technology can be an issue. I know that a little ball in a glass tube would drop unless gas is flowing—a physical fact that I can sense. You mean my trust must now repose in a green bar graph?? The new machines simply cannot be used safely without a personal and institutional commitment to time spent in training and reading.

**Operating costs**

With the new machines, operating costs are likely to be higher for disposables (spirometry tubing, carbon dioxide granule canisters on the S/5 ADU). This can be balanced by several tactics:

• High efficiency filters, changed with the mask and elbow for every patient. The flexible corrugated breathing circuit hoses, spirometry tubing, and D-Lite sensor can be changed daily.

• Emphasis on low flows to decrease usage of volatile agent

• Use loose carbon dioxide granules rather than single-use canisters

**Installation of new machines**

A few pearls from folks who have "been there":

1. Make sure the machine you purchase will allow the exporting of fresh gas values to any information system or automated record-keeper. Make sure that whatever you buy can support an electronic anesthesia record. You can be sure that in the next 15 years these will become standard.

2. With monitoring make sure that you are comfortable with the integrated monitoring.

3. Education and training

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   - With monitoring make sure that you are comfortable with the integrated monitoring.

   - Education and training

   - Operating costs

   - Installation of new machines
• Budget weekend training time. Don't skimp here- and make it mandatory for all attendings, CRNA's, students, and residents. Buy them lunch and arrange to get CEs or CMEs.

• Work closely with the manufacturer's installation team. Invest some time in trying to foresee problems.

• Don't assume in a multi-building installation, that everything that worked well in your new ambulatory center will function identically in your aging main OR.

• Check for suction adequacy. Open scavenger interfaces demand a lot of suction.

• Make a plan for disposables early. Four days before "go-live", we found that our former breathing circuits, which we had "assumed" would fit, wouldn't.

• Involve in the planning those anesthetists who are most familiar with obstetrics, pediatrics, ambulatory, and cardiovascular. All these areas have special needs for equipment.

• Consider the pluses and minuses of integrated monitoring. The gas machine will last 10-15 years. Will you get tired of an integrated monitor before then, or wish you weren't locked into one company's monitoring solution? On the other hand, integrated monitors are compact, and there's a logic to the whole system that is very comfortable, once the initial learning curve is climbed.

• Your temperature probe and transducer sales representatives will be happy to get cabling for you that lets their disposable sensors talk to anyone's monitor.

Test Yourself

How do you calibrate an oxygen analyzer?

There are two types: a galvanic type sensor (an older "plug in" type), and the paramagnetic. For the galvanic oxygen sensor, calibrate to room air (the time to 90% response is 15-20 seconds, so if it takes longer than 40-60 seconds to read 21%, change the sensor). Then expose to 100% oxygen and ensure it reads close. You may recalibrate at 100%, but it is not necessary with all monitors. Newer paramagnetic sensors use internal calibration routines. So they only need periodic (every 3-6 months) exposure to calibration gas, and they last for years.

What can you do to fix an oxygen analyzer that is reading an FIO2 of 0.16 (and declining) during a general anesthetic?

Don't attempt to fix it- you must trust monitors until you can prove they are wrong.

1. Call for help
2. Turn on emergency oxygen cylinder and disconnect pipeline from wall
3. If inspired oxygen concentration doesn't increase (with adequate fresh gas flow [FGF]), manually ventilate the lungs with an ambu bag and room air (use oxygen if a portable tank is available)
4. Start CPR early

If desaturation is the problem, check midaxillary breath sounds - a common cause of decreased oxygen saturation is endobronchial intubation.

**What is the normal working pressure in the anesthesia gas machine and cylinders?**

The hospital pipeline is the primary source of all gases and the pressure within the pipelines is 50 psi, which is the normal working pressure of most machines. Cylinder oxygen is supplied at around 2000 psi (regulated to approximately 45 psi after it enters the machine). Nitrous oxide cylinders hold a pressure of 745 psi when full. Air cylinder pressures are similar to oxygen.

**Can you give an anesthetic when there is no connection for hoses? Or if a cylinder is missing?**

The hanger yoke: orients cylinders, provides unidirectional flow, and ensures a gas-tight seal. The check valve in the cylinder yoke functions to: minimize trans-filling, allow change of cylinders during use, and minimize leaks to atmosphere if a yoke is empty.

There is a check valve in each pipeline inlet as well. So you can give an anesthetic even when there is no connection to the hospital pipeline, or if a tank is missing.

**What is the first device that will inform you of a crossover (non-oxygen gas in the oxygen pipeline)? Is it the fail-safe? The hypoxic guard?**

It is important to recognize that the fail-safe guards against decreased oxygen pressure and not against crossovers or mislabeled contents. As long as there is any pressure in the oxygen line, nitrous oxide (and any other gases) will continue flowing. If oxygen pressure is lost, the fail-safe shuts off the flow of all other gases.

The hypoxic guard system works on oxygen pressure as well. It controls the ratio of oxygen and nitrous oxide so that there is a minimum 25% oxygen. It does not analyze what is in the oxygen pipeline for the presence of oxygen. The first device to inform one of a crossover will likely be the oxygen analyzer. The second monitor to respond to a crossover (especially if you ignore the first) might be the pulse oximeter, depending on circumstances.

**For suspected crossover, what two actions must be taken?**

1. Turn on backup oxygen cylinder
2. Then disconnect oxygen supply source at the wall.

If you do not disconnect the pipeline supply hose at the wall, the pipeline pressure exerted on the oxygen cylinder regulator diaphragm (downstream side) keeps the cylinder gas from flowing, since the pipeline is maintained at a slightly higher pressure (50 psi) than the cylinder regulator (45 psi). The situation is similar to dropping the level of the main intravenous fluid bag when you want a piggyback to run - whichever is higher will flow.
What should you do if you lose oxygen pipeline pressure?

Just like a crossover,

1. Open the emergency oxygen cylinder fully (not just the three or four quick turns used for checking)
2. Disconnect the pipeline connection at the wall.

Why? Something is wrong with the oxygen pipeline. What if the supply problem evolves into a non-oxygen gas in the oxygen pipeline? If so, it will flow (pipeline pressure 50 psi) rather than your oxygen cylinder source (down-regulated to 45 psi). If you are lucky, the oxygen alarm will sound to warn you of the change (you do set your alarms, don’t you?).

If for some reason the oxygen analyzer does not warn of the crossover, the pulse oximeter will— but only after the oxygen has been washed out, by ventilation from the patient's functional residual capacity and vessel-rich group. So disconnect the pipeline connection at the wall if oxygen pipeline pressure is lost. It's also easier to remember one strategy which works for any problem with the pipeline, than to remember that sometimes you must, and sometimes it is optional, to disconnect. And use that oxygen analyzer always!

The pipeline supply of oxygen has failed. How can you make your emergency E tank oxygen supply last as long as possible?

Driving a vent with cylinders will cause their rapid depletion. So manually ventilate the patient, assist spontaneous ventilation if possible, use air or nitrous oxide with oxygen if possible, and use low flows.

Your pipeline supply fails, and your cylinder gauge shows 1000 psi. How long will your emergency oxygen supply last?

Calculate:

\[
\text{Contents L} / \text{Gauge Pressure} = \text{Capacity L} / \text{Service Pressure}
\]

In the example, \( x \ text{L}/1000 \text{psi} = 660 \text{L}/1900 \text{psi} \) and \( x = 347 \text{L} \). If you are flowing 2 L/min oxygen, the tank will last 173.5 minutes. For compressed gases which are stored as liquids (nitrous oxide, carbon dioxide), the relationship between pressure and contents is not proportional.

What are the only two circumstances when a cylinder valve should be open?

The cylinder should be turned off except when checking, or when the pipeline is unavailable— otherwise, silent depletion may occur. Pipeline pressure may decrease below 45 psi with flushing or ventilator use. If it does, oxygen will flow from an opened cylinder. Enough may be lost over a period of days or weeks to empty the tank. Then no reserve will be available if the pipeline supply fails.
What circumstances can permit a hypoxic mixture even when the hypoxic guard system is employed?

1. Wrong supply gas in oxygen pipeline or cylinder
2. Defective pneumatics or mechanics (the hypoxic guard system is broken)
3. Leaks down stream of flowmeter control valves
4. Inert gas administration (a third gas such as helium).

The hypoxic guard system only connects oxygen and nitrous oxide (the ADU also takes desflurane into account). It is possible to create a hypoxic mixture when you give desflurane in air. Neither traditional machines nor newer gas machines will prevent this. But both will give visible and audible alarms.

The patient's breaths are stacking up in the chest and the circuit pressure is sustained at a high level. What can you do in the few seconds before the patient is injured?

Obstruction of the scavenger, or failure of the ventilator relief valve, may cause transmission of excess positive pressure to the patient. If suspicious, disconnect the gas collection tubing from the back of the APL valve (if possible), or turn off vacuum at the scavenger interface (a negative pressure relief valve failure can, depending on APL design, lead to accumulation of positive pressure in the chest). If you can't disconnect the gas collection tubing, ventilate manually. If the ventilator relief valve is at fault, this should be successful. If manual ventilation fails, disconnect the patient from the breathing circuit and ventilate by an Ambu bag.

What is the most common site of disconnections? What is the most important monitor for disconnection?

The most common site is the Y-piece. Monitors for disconnection (apnea alarms) can be based on gas flow (tidal volume), circuit pressure (if peak inspiratory pressure is below threshold an alarm rings), chemistry (carbon dioxide) or acoustic (sound of the precordial, or normal sounds of the ventilator cycle). The most important is the precordial (or esophageal) stethoscope. Capnography is thought to be more important by some. The precordial is stated as most important in many references because it is inexpensive, reliable (cannot break or fail), and its "alarms" cannot be silenced. Ever do a case with all your capnography alarms turned off?

Disconnection is the most common preventable equipment-related cause of mishaps. Keep your vigilance high by:

- consistently using a precordial or esophageal stethoscope
- if you turn the vent off (for an xray for example), keep your finger on the switch
- use apnea alarms and don't silence them
- be extremely careful just after initiating ventilation- or whenever ventilation is interrupted: observe and listen to the chest for a few breathing cycles. Never take for granted that flipping the switches will cause ventilation to occur, or that you will always remember to turn the ventilator back on after an xray.
What can you do to protect the patient, the next patient, and yourself when caring for an infected or immunocompromised patient?

Cleaning the bellows is necessary after anesthetizing a patient with diseases transmitted by oral secretions - so with AIDS or respiratory disease, one or more of the following approaches should be used. Don't use mechanical ventilators, use bacterial filters at the Y or on each limb, use disposable soda lime assembly, or change soda lime after each case.

Name a major barotrauma risk factor which you control.

Oxygen flush during the ventilator inspiratory phase may cause barotrauma, since excess volume cannot be vented (the ventilator relief valve is closed). Just as the APL valve must be closed during manual ventilation to prevent gas loss to the scavenger, the ventilator relief valve is closed during the inspiratory phase of mechanical ventilation.

What is the preferred bellows design, ascending or descending?

The disadvantages of the descending bellows are unrecognized disconnection (due to their design, they may fill even when disconnected from the patient), and also collection of exhaled humidity in bellows (risking infection and lessening delivered tidal volume). To tell if a bellows is ascending ("standing") or descending ("hanging"), look at them during expiration (remember- ascend and descend have "e"s in them). The modern type is ascending. Only one current machine, the Dräger Julian, uses a hanging bellows, but incorporates capnography and sensors to detect failure of the bellows to fill, both of which may lessen unrecognized disconnects.

Every ventilator is activated differently. What's the best way to initiate mechanical ventilation so you don't forget steps?

Since you may work with a variety of ventilators, all of whom have different controls, safely initiate mechanical ventilation by:

1. Bag/vent switch to vent ("auto")
2. Turn ventilator power switch on, and review mode, volume or pressure, and rate settings
3. Check for chest expansion with the first breathing cycles.

With this sequence you can never go wrong. Don't take for granted that turning a few knobs will cause ventilation- check for chest movement.

You have an emergency, life-threatening situation and you have not checked the machine, nor do you have time to do so. What must be checked even when time is at a premium?

A minimum safety test can be done even when time is critically short:
1. Do a high-pressure test of the breathing circuit (ensures no leaks are present distal to common gas outlet)

2. When placing the mask on the patient's face to pre-oxygenate them, always observe or palpate the breathing bag for fluctuation (ensures adequate gas flow, good mask fit, and a breathing patient)

3. Check your suction.

What is the best way to preoxygenate?

- Fresh gas flow 4-6 L/min
- APL valve open fully
- Ensure a tight mask fit
- May use 3-5 minutes of tidal breathing, or 4 to 8 vital capacity breaths

Tight mask fit is the most significant factor, since lack of a tight fit cannot be compensated for by increasing time (because the patient will not breathing 100% oxygen with a loose fit- see Anesthesiology 1999;91:603-5). Every time you place a mask on a patient's face, look back at the breathing bag (to ensure it is fluctuating with respirations) and the oxygen flowmeter (to ensure it is on). Pay attention to complaints that it "smells funny"- you may have left a vaporizer on.

In the middle of a case, your soda lime is exhausted. Should you change it?

In a traditional machine (Modulus or Excel), no. Increase the fresh gas flow (FGF) to 5 to 8 L/min for an adult (1 to 1.5 times minute ventilation). Petty (and Ehrenwerth & Eisenkraft) claim that this practically does away with the need for soda lime since this semi-open configuration is essentially non-rebreathing. Soda lime can be more easily changed in the ADU, without interrupting ventilation.

How can you tell if your patient is in respiratory acidosis from rebreathing carbon dioxide?

Failure of inspiratory or expiratory unidirectional valves, and problems with carbon dioxide absorbent granules (indicator fails, channeling, exhaustion) are the principal causes of rebreathing. While most instances should be detected by noting the increase in inspired carbon dioxide on the capnograph, it is still worthwhile to periodically review the clinical signs of respiratory acidosis:

- Rise (and later a fall) in heart rate and blood pressure
- Hyperpnea
- Signs of sympathetic nervous system activation (flushed, arrhythmia, sweating)
- Increased bleeding at surgical site.

Dark blood is not a sign of acidosis.
How should an open scavenging interface be set?

Keep the indicator float between the lines, and remember that the audible suction sound is an indication that it is functioning properly. This is unlike the closed interface, where if you can hear a hiss, waste gas is escaping into the room. The open interface is safer for the patient (open to atmosphere, so there is no chance of excess positive or negative pressure being transmitted to the breathing circuit), but less safe for the caregiver if you don’t know how to use it (potential waste gas exposure).

You can smell isoflurane during a case. What should you do?

The smell of gas during a case is abnormal and the cause should be sought. The threshold for smelling volatile agents is quoted as between 5 to 300 ppm, so if you can smell any, the concentration is above the NIOSH standard (not more than 2 ppm). Look for:

- poor mask fit
- using unscavenged technique like insufflation
- flow from breathing system into room air (volatile agent turned on before the mask is on, or not turned off before suctioning)
- anesthetics exhaled into the room at end of case
- spilled liquid agent
- uncuffed tracheal tube, leaks around laryngeal mask airway cuff
- machine not checked regularly for leaks

Reasons related to the scavenger include: open interface with no suction on, closed interface without enough suction, obstructed gas disposal tubing.

Nitrous oxide exposure may be more insidious. It cannot be smelled and it has proven ill effects on the reproductive system (both men & women). If you are concerned, beyond simply not using it, consider disconnecting the gas machine hose from the wall pipeline outlet at the beginning of the day (this junction is a prominent cause of leaks) or at the end of the day. Make sure your gas analysis system is scavenged. Participate or at least get informed about your department’s pollution control program. Fill vaporizers at the end of the day rather than the beginning.

If your fresh gas flow is 4 L/min, what volume is passing through the scavenger each minute?

Barotrauma must result unless the same amount leaves the circuit each minute as enters; 4 L/min are exiting.
The fresh gas flow must be decreased to not more than 2 L/min immediately after tracheal intubation is confirmed when you use desflurane, because this agent requires low flows. Correct?

Only if you have a prolonged period to induce while waiting for surgery to commence, and the risk of awareness doesn't bother you. (The redistribution of propofol can be fast, making a return to consciousness possible unless sufficient volatile anesthetic tension is created in the brain soon after induction.) True, you can use overpressure, but 18% of 2 L contains less desflurane molecules than 18% of 6 L, and it is the number of molecules presented to the brain per unit time that causes anesthesia.

Imagine a 1 L sink with 0.1 L/min inflow (of which 1% or 1 mL is methylene blue), and the same outflow. You want to turn the initially colorless water in the sink as blue as the inflow. Think it would go any faster using 0.5 L/min inflow (of which 1% or 5 mL is methylene blue) and the same outflow? Of course. Not because the concentration is different (both inflows are 1% methylene blue) but because the rate of inflow is a greater proportion of the capacity in the second example.

One time constant (= capacity ÷ flow) brings a system 63% of the way to equilibrium; two to 86%; three to 95%. Thus the first of the two systems will take 10 minutes to reach 63% of equilibrium (1000 mL / 100 mL). The second, higher flow system achieves the same result in 2 min (1000 mL / 500 mL).

Inflow to the anesthesia breathing system is controlled by the flowmeters. The capacity of the functional residual capacity (FRC), hoses, and breathing circuit (estimated at 6 L in a Modulus machine) can be brought to equilibrium with the inflow more quickly as the rate of inflow increases. A rational approach to assure anesthesia, while conserving volatile agent, would seem to be a "non-rebreathing" induction (fresh gas flow 4-8 L/min) followed by 1-2 L/min during maintenance ("low flow") to conserve tracheal heat and humidity, gases and agent. For a reasonable speed of emergence, choose the higher, non-rebreathing flows.

How much liquid agent does a variable-bypass vaporizer use per hour?

Ehrenwerth & Eisenkraft 1993 give the formula 3 x FGF (L/min) x volume% = mL used per hour.

To properly fill a vaporizer, should you hold up the keyed filler until it stops bubbling?

No. One can overfill with this method, if the keyed filler is faulty, or the vaporizer dial is "on". It is better to fill vaporizers only to the top etched line within the sight glass (this is the method recommended by Ohmeda and Dräger).

There are two filling mechanisms; the funnel "screw-cap filler", and the agent specific keyed filler (notches on the neck of the bottle of agent fit a special pouring device which is keyed to prevent misfilling). The filler port is low to
prevent overfilling, but this can be defeated with the method described in the question. Overfilling is dangerous because discharge of liquid anesthetic distal to the vaporizers causes overdose.

What is the checkout procedure for the Tec 6 desflurane vaporizer?

1. Press and hold the mute button until all lights and alarms activated.
2. Turn on to at least 1% and unplug the electrical connection. A "No Output" alarm should ring within seconds. This tests battery power for the alarms. This step is crucial in relation to the quick emergence characteristics of this agent- any interruption in its supply must be noted and responded to at once.

Why is it so important to check that vaporizers are filled before a case? If you run out, you can always fill them during the case, right?

True- if you recognize they are empty. But a paralyzed patient who cannot mount much sympathetic response to lack of agent (elderly, trauma, beta blocked) could be awake with stable vitals.

What are the hazards of contemporary vaporizers?

- Incorrect agent.
- Overfilling.
- Tipping

If tipped more than 45 degrees from vertical, liquid agent can obstruct the control mechanisms and risk overdose on subsequent use. A typical treatment is to flush for 20-30 minutes at high flow rates with a low concentration set on the dial. Check the operating manual for the particular vaporizer, to be sure of the method before attempting it, since the correct procedure differs for each. Only two modern vaporizers can be tipped: the Aladin cassettes in the Datex-Ohmeda S/5 ADU, and the Dräger Vapor 2000 (if the dial is set to "T").

What do you do to the machine if a patient gives a history of malignant hyperthermia?

To prepare the gas machine:

- Remove or at least drain all vaporizers and tape over the dial.
- Change all breathing circuit disposables and soda lime.
- Flush with high (10 L/min) fresh gas flow for at least 10 minutes.
- Monitor pETCO2 and core temperature in all.
- Avoid triggers (volatile agents and succinylcholine)
- Use rocuronium, particularly if rapid sequence induction is indicated. Sixty to 90 sec after rocuronium 0.6 mg/kg, intubating conditions indistinguishable from succinylcholine can be produced (at the price of a clinical duration of 30-40 min).
Note that the time and fresh gas flow requirements may differ for each model. The Siemens Kion requires at least 25 minutes for example (Anesthesiology 2002;96:941-6).

If the patient develops an acute episode of malignant hyperthermia during operation, the treatment may include:

- high fresh gas flow
- hyperventilation
- stop inhaled agents and succinylcholine
- change soda lime granules & breathing circuit (as time permits)
- the mainstay of treatment is dantrolene 2.5 mg/kg (up to 10 mg/kg).
- cooling by any and all means, NaHCO3, treatment of hyperkalemia, and other measures are also important.

You can contact the Malignant Hyperthermia Association of the United States for further information.

**What's the definition of a good anesthetic?**

When the patient is more asleep than you are. "Vigilance" and "Watchful Care" are words chosen for the seals of the professional societies for a reason!

The Anesthesia Gas Machine

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