Vaporizers & gas delivery

Outline hazards of anaesthetic machines

Outline arrangements of flow meters on the anaesthetic machine

Outline vaporizer arrangements on the anaesthetic machine

Classify breathing systems

Briefly outline the protocol for checking the anaesthetic machine

Vaporizers

Oxygen therapy

Gas cylinders

Suction ports

Low Flow Anaesthesia
Outline hazards of anaesthetic machines.

Physical design
- Mobile and able to fall over
- Must be stable at up to 8° tilt

Medical gas supply
- Misconnection: pipeline, wall outlet, cylinder
- Contamination
  - Wrong gas due to backflow from mixing devices
  - Errors in gas manufacture and processing
  - Solvents or particulate matter from welding

Gas regulators
- Cooling with gas expansion may freeze valve seats
- Heating with rapid pressurization on opening gas cylinders may ignite grease
- Regulators may allow transition from pipeline to cylinder supply without alarm

Rotameters
- Bobbin & tube mismatched
  - Transposed in servicing, over- or under-read
- Gas leak
  - Test with application of soapy water
- Selective oxygen leak
  - Reason for oxygen mixing downstream
  - Can still occur with leak in flowmeter before bypass tube

Mechanical failure
- Damage to bobbin, stops, needle valve
- CO₂-related incidents
  - If CO₂ rotameter is fitted
- Contamination of flowmeter assembly
- Float not visible at top of tube
  - Flowmeter fully open but not noticed

Valves
- Resistance, obstruction, incompetence
  - Due to wear, moisture, misassembly, damage

Vaporizers
- Agent impurities, breakdown products
- Mounting problems
  - Leaks, interlock failure
- Output control problems
- Filling problems
  - Incorrect agent, overfilling, underfilling
- Free-standing vaporizers
  - Tipping, misconnection
  - Placement after oxygen flush
- Thymol accumulation

Breathing systems
- All systems
  - Leaks
  - Potential infection risk
  - Humidifier disconnection or overheating
- Circle system
  - Valve failure
    - Rebreathing, high circuit pressure
  - Absorber problems
    - Leaks, reaction with volatile agents, inhalation of dust, streaming of flow, exhaustion of soda lime
  - Condensation in circuit: inadvertent PEEP
Uncertainty in gas composition at low flows without agent monitoring
Mapleson systems
Potential for significant rebreathing at low flows

Ventilators
Hazards are model-specific
Pressure
Delivery of high airway pressures
Gas composition
Contamination of circuit gas with driver gas
Leak of circuit gas
Flow
Under- or over-ventilation
Failure to deliver adequate volume in pressure-cycled modes
Alarms
Failure to detect disconnection due to resistance in breathing system
Inadvertent inactivation
Failure or absence of power failure or “off” alarm
Potential disease transmission

Monitoring systems
Electrical safety
Patient isolation
Power backup
Alarms
Failure due to inactivation or inappropriate settings
Injury associated with monitor placement
e.g. Temperature probe epistaxis, BP cuff bruising
Misreading
Monitor misplacement or device failure
Outline arrangements of flow meters on the anaesthetic machine.

Flowmeter
   A device to control and indicate flow of medical gases accurately.

Standard requirements
   Flow control knob should be adjacent to flow indicator
   Oxygen control knob has a characteristic profile: 8 equally spaced flutes
   Oxygen flowmeter must be on the left (UK, Europe, Australia) or right (US)
   Axial pressure on the knob must not greatly alter flow
   Only one flow control for each gas
   Oxygen must be delivered downstream in the flowmeter manifold
   Mixer must not deliver <25% \( \text{O}_2 \)
Outline vaporizer arrangements on the anaesthetic machine.

**Principle**
- Vaporizer delivers a calibrated concentration of anaesthetic vapour into gas passing through the device
- Gas is divided into bypass and vaporization chambers
  - Gas in bypass chamber remains unchanged
  - Gas in vaporization chamber is saturated with anaesthetic vapour
- Delivery is dependent on flow, temperature and gas pressure
  - Temperature compensation is integral in modern vaporizers
  - Output falls at high flows
  - Pumping effect is prevented by vaporizer design
  - Pressure effect is minor

**Classification**
- Draw-over vs plenum (plenum: uses vapour-saturated gas)
- Variable bypass vs measured flow
- Vaporization method
- Location (in-circuit vs out-of-circuit)
- Temperature compensation
- Pressure compensation
- Resistance
- Agent specificity

**Position**
- Historically in-circuit or out-of-circuit
- Now usually placed out-of-circuit between flowmeters and common gas outlet or replaced by electronic direct injection of vapour
- Interlock to prevent multiple vaporizers being on concurrently
  - Prevents transfer of vapour from upstream to downstream vaporizer
  - Reduced output of upstream agent
  - Contamination of downstream vaporizer
  - Contamination also minimized by placing higher SVP agent downstream

**Modern plenum vaporizers**
- Variable bypass, VOC, temperature compensated, backpressure resistant, high resistance, agent specific
- Most use wick vaporization except TEC6, Engstrom Elsa, Datex ADU

**Models**
- Ohmeda TEC series
- Penlon PPV ∑ and ∑ Elite
- Blease Datum
- Vapamasta
- Dräger 19.3
Classify breathing systems.

Rebreathing

Mapleson A
Magill
Most efficient for SV, requiring 70% of MV as FGF
3 x MV required for IPPV
Lack
Mapleson A with coaxial expiratory tubing

Mapleson B, C
Rarely used, closed bag requires high FGF

Mapleson D
Bain
Low resistance, single tube, FGF 70-80 ml/kg/min

Mapleson E
Replaced by Mapleson F (Jackson-Rees' modification)

Mapleson F
Common use for paediatric anaesthesia
FGF 2-3 times MV

Switchable devices
Several varieties for switchable A/D circuit types

Non-rebreathing valve systems
Laerdal bag
Triservice apparatus
T-piece oxygen/air inlet, drawover vaporizers, self-inflating bag, non-
rebreathing valve

CO2 absorption systems
Water's to-and-fro system
Mapleson C with absorber near patient, obsolete
Circle systems
   Many configurations
Commonly
   APL valve in expiratory limb before absorber
   FGF in inspiratory limb after absorber
Nomenclature depends on component arrangements
   VIC/VOC, closed/semi-closed, coaxial/not-coaxial
Advantages
   Economical of gases and vapour
   Hypocarbia easy to achieve
   Good heat and water conservation
Disadvantages
   Large number of parts, risk of faults, complex ventilator required
   Bulky, cleaning difficult
   Soda lime dust can be inhaled
   Trichloroethylene cannot be used
Briefly outline the protocol for checking the anaesthetic machine.

Level 1
- Detailed service check by manufacturer's personnel or technician
- Detailed documentation of checking and calibration
- Label visible to anaesthetist of next scheduled check
- Gas delivery: Quantify and minimize leaks, exclude crossed pipelines, check valves, check O₂ failure device
- Accuracy of vaporizers
- Compliance with Standards

Level 2
- Anaesthetist or technician check at the start of a list
  - High pressure system: Cylinder and pipeline supply, cylinders off
    - Single gas test for oxygen
  - Low pressure system: Control valves and flowmeters
    - Hypoxic interlock device
- Vaporizers: Filled, ports closed, correctly seated, no leak on or off, electricity supply
- Precircuit leak test
- Breathing system: Check connections
- Leak test (<300 ml/min at 30 cmH₂O)
- Check valves: one way and APL
- Ventilator, function, leak, alarms
- Scavenging at correct pressure
- Spare self-inflating bag
- Other apparatus: Intubation equipment, suction, gas analysis, monitoring, IV infusion, warming, humidifier, filters
- Final check: Vaporizers off, purge with oxygen or air

Level 3
- Brief check before each case
- If vaporizer or breathing circuit is changed, recheck
- Recheck other apparatus
Vaporizers

Tec 6

Separate gas and vapour circuits
Fresh gas flow passes a fixed resistance in vaporizer
   Pressure upstream of the resistance is “working pressure”
   Proportional to gas flow
Desflurane is heated to 39°C (1300 mmHg absolute)
   Pressure downregulated to “working pressure” by differential pressure
   transducer, electronics and regulating valve
Desflurane passes through a variable resistance controlled by the
   concentration dial on the vaporizer
   Desflurane output varies with working pressure and concentration
   selected
Carrier gas affects working pressure
   Lower desflurane output with N₂O
Altitude does not affect concentration delivered (unlike variable bypass vaporizers)
   Lower partial pressure delivered at lower ambient pressure
   Potential for awareness
Vaporizer requires adjustment for ambient pressure
Oxygen therapy

Fixed performance
  High flow Venturi masks
    \( \text{O}_2 \) flow of 6-8 l/min entrains air
    Total flow 40-60 l/min, \( \text{FiO}_2 \) 25-60%
  Anaesthetic circuits, CPAP or PEEP machines
    Require air-tight fit
    Reservoir allows fixed \( \text{FiO}_2 \) (20-100%)

Variable performance
  No capacity
    Nasal catheters
      \( \text{FiO}_2 \) depends on flow rate and PIFR
  Small capacity
    Simple face masks (e.g. Hudson mask)
      \( \text{O}_2 \) flow and PIFR determine \( \text{FiO}_2 \)

<table>
<thead>
<tr>
<th>( \text{O}_2 ) flow</th>
<th>( \text{FiO}_2 ) (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.35</td>
</tr>
<tr>
<td>6</td>
<td>0.50</td>
</tr>
<tr>
<td>8</td>
<td>0.55</td>
</tr>
<tr>
<td>10</td>
<td>0.60</td>
</tr>
<tr>
<td>12</td>
<td>0.65</td>
</tr>
<tr>
<td>15</td>
<td>0.70</td>
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</table>

  Tracheostomy masks, T-piece circuit, face tent (soft bowl-shaped mask)

Large capacity
  Face masks with reservoir bags
    Higher \( \text{FiO}_2 \), risk of rebreathing if disconnected
  Head boxes, incubators, tents
Gas cylinders

Markings specified by AS2030 (1977)

Requirements

ID number
Owner’s mark
CIG, LAA, MD, NZIG

Water capacity
Mass of water required to fill cylinder at 15˚C

Test pressure
Testing station mark and date

British Tube Mills, Australia Liquid Air, Gas Cylinders, Tubemakers, Luxfer

Manufacturer’s mark
May be combined with testing station mark

Standards specification mark
For cylinder type e.g. AS B114 for alloy steel cylinders

Tare mass
Weight of empty cylinder without valve

Name or symbol of gas and colouring to identify contents
ISO standard

<table>
<thead>
<tr>
<th>Gas</th>
<th>Pins</th>
<th>Colour</th>
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<tbody>
<tr>
<td>CO₂</td>
<td>1,6</td>
<td>grey</td>
</tr>
<tr>
<td>O₂</td>
<td>2,5</td>
<td>black (with white shoulder for medical O₂)</td>
</tr>
<tr>
<td>air</td>
<td>1,5</td>
<td>grey with black and white shoulder</td>
</tr>
<tr>
<td>N₂O</td>
<td>3,5</td>
<td>blue</td>
</tr>
<tr>
<td>He</td>
<td>4,6</td>
<td>brown</td>
</tr>
<tr>
<td>C₃H₆</td>
<td>3,6</td>
<td>orange</td>
</tr>
<tr>
<td>N₂</td>
<td></td>
<td>grey with black shoulder</td>
</tr>
<tr>
<td>Entonox</td>
<td>single</td>
<td>blue with blue and white shoulder</td>
</tr>
<tr>
<td>Heliox</td>
<td>4,6</td>
<td>brown with black and white shoulder</td>
</tr>
<tr>
<td>Carbogen</td>
<td>2,6</td>
<td>black with grey and white shoulder</td>
</tr>
</tbody>
</table>

Aluminium ring on neck of cylinders containing liquifiable gas

Tare weight with valve, date, test station, number and “ET” if eductor tube present

Plastic tab on some aluminium cylinders to detect excessive heat exposure

Star indicates use for dry gas only

Filling ratio

Used for liquifiable gases: N₂O, CO₂, C₃H₆

Ratio of mass of gas to water capacity at 15˚C

Specification to ensure pressure does not exceed 80% of test pressure at 65˚C
Suction ports

AS 2896, AS 2120.3

Number of ports

<table>
<thead>
<tr>
<th>Location</th>
<th>Number</th>
</tr>
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<tbody>
<tr>
<td>OR</td>
<td>4</td>
</tr>
<tr>
<td>PACU, ICU</td>
<td>3</td>
</tr>
<tr>
<td>Delivery</td>
<td>2 + 1 for baby</td>
</tr>
<tr>
<td>Resus</td>
<td>2</td>
</tr>
<tr>
<td>Coronary care, anaesthetic room, etc.</td>
<td>1</td>
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</table>

Each port

- 40 l/min free flow
- -60 kPa (-500 mmHg, -600 cmH₂O)
- Time constant ≤ 4 s

Central vacuum source

- At least two pumps with automatic switching
- Each capable of meeting peak demand
- Reservoir tank

Venturi suction

- Dry gas flow entrains gas from suction device
- Obstruction of gas flow outlet can result in high positive pressure
  - Large venturis have a safety device to prevent pressurization
- Twin-O-Vac commonly used for portable suction
  - 16 l/min or -55 kPa (using 22 l/min O₂)
  - Not up to AS 2120, but better than nothing
  - No protection against pressurization

Scavenging

- Must be separate from suction (different sleeve index)
- 30 mm or 19 mm connections
  - Usually pink 30 mm hose
- Passive
  - Simple hose from circuit to external vent (with fluid trap)
  - Able to transfer 75 l/min with acceptable back-pressure (≈0.5 cmH₂O)
  - Must be gas-tight
  - Obstruction may cause raised circuit pressure
- Active
  - Suction applied to 3 l reservoir with indicator for 20-30 l/min flow through vents
  - 30 mm tubing to circuit
  - Able to absorb 4 l bolus of exhaust without contamination of theatre
  - Multiple vents on reservoir to prevent negative circuit pressure with occlusion
Low Flow Anaesthesia

Problems with low flows
- Difficult pharmacokinetics with N₂O
  - High flows required to get enough N₂O into patient (≈15 l)
- Difficult to deliver enough volatile agent for early uptake
  - Halothane and isoflurane slow equilibration Fₐ/Fᵢ
- Difficult to deliver accurate volatile dose with low FGF
- Leak-free circuit required
- Gas analysis outflow to circuit required

Easy low flow anaesthesia
- Cato machine using desflurane in O₂ with a little air
  - Eliminates all these problems
    - Desflurane in O₂ gives easy pharmacokinetics
    - Accurate delivery with gas analysis
    - Sample gas returned to circuit
    - $FGF = VO_2$ is possible

Remaining contraindications
- Volatile compounds arising from the patient
  - Diabetic ketoacidosis, hepatic failure
- Toxic breakdown products
  - Sevoflurane: “compound A”
    - How low is it safe to go?
  - Desflurane: CO with dry soda lime
    - Case report from UCSF
  - Malignant hyperthermia, soda lime exhaustion...

How do you do it?
- Preoxygenate, induce at 6 l/min O₂
- Drop flow to 2 l/min
  - Add desflurane ≈12%
    - FiDes never reaches 12%
- Watch $E_T$ and $Des$
  - Drop flows as $E_T$ and Des reaches desired value (e.g. 6%)
  - Reach estimated $VO_2$ at 12% Des (or higher) in fresh gas
    - e.g. 250 ml/min
  - Then adjust FGF %Des to target $E_T$ and Des
  - Increase flows if you need to adjust $E_T$ and Des quickly
- Watch reservoir bag
  - Getting empty: increase FGF 50-100 ml/min
  - Staying full: decrease FGF 50-100 ml/min
  - Changes take a while to have an effect
    - 2 l reservoir takes 20 min to fill at 100 ml/min

Don’t like high FiO₂?
- Leave 100 ml/min air on
  - At high O₂ flows, FiO₂ is still ≈100%
  - Once at metabolic flows FiO₂ will slowly fall
    - Turn air off and replace with O₂ once at target FiO₂
But what does it cost?

Desflurane is expensive: $170 per 240 ml bottle
  300 ml/min FGF with 10% desflurane
    = 30 ml/min desflurane gas
    = 1.8 l/h desflurane gas
    = 9 ml/h desflurane liquid
    = $6.38 per hour
  3 l/min FGF with 4% desflurane
    = $25.50 per hour

Compare with sevoflurane: $336 per 250 ml bottle
  1.5 l/min FGF with 1.5% sevoflurane
    = 22.5 ml/min sevoflurane gas
    = 1.35 l/h sevoflurane gas
    = 6.75 ml/h sevoflurane liquid
    = $9.07 per hour

Compare with isoflurane: $145 per 250 ml bottle
  1.5 l/min FGF with 1.5% isoflurane
    = $3.92 per hour
  But higher flows required at the start of a case

What about TIVA costs?

Propofol TCI costs $27.04 per 50 ml
  Assume TCI at about 60 ml/h
    = $32.45 per hour

Generic propofol costs $9.20 per 50 ml
  = $11.04 per hour (at 60 ml/h)

Remifentanil costs $17.50 per mg
  Assume 15 µg/min
    = $15.75 per hour

With IV agents you waste what remains in the syringe at the end
TIVA costs rise linearly with patient weight
Inhalational agent costs rise with $VO_2$ or $\frac{3}{4}$ power of weight

Try it at RVEEH

Datex ADUs will tally gas use for you
Make VRU list even more interesting