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
  - CO_2-related incidents
    - If CO_2 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

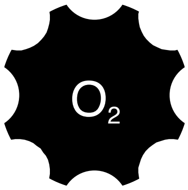
Outline arrangements of flow meters on the anaesthetic machine.

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% 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

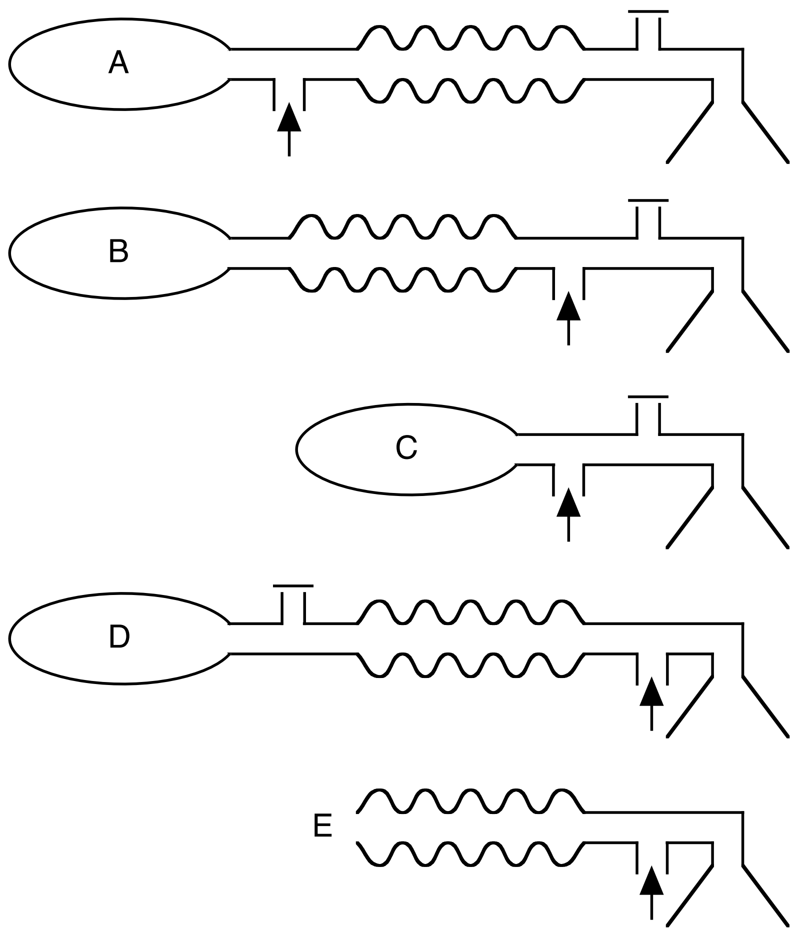
Classification
- Draw-over vs plenum (plenum: uses vapour-saturated gas)
- Variable bypass vs measured flow
- Vaporization method
- Location (in-circuit vs out-of-circuit)
- Temperature compensation
- Pressure compensation
- Resistance
- Agent specificity

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

CO_2 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 O_2 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 cmH_2O)
  - 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 N_2O
- 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
  - O_2 flow of 6-8 l/min entrains air
  - Total flow 40-60 l/min, FiO_2 25-60%
- Anaesthetic circuits, CPAP or PEEP machines
  - Require air-tight fit
  - Reservoir allows fixed FiO_2 (20-100%)

Variable performance
- No capacity
  - Nasal catheters
    - FiO_2 depends on flow rate and PIFR
- Small capacity
  - Simple face masks (e.g. Hudson mask)
    - O_2 flow and PIFR determine FiO_2

O_2 flow	**FiO_2 (approx.)**
4	0.35
6	0.50
8	0.55
10	0.60
12	0.65
15	0.70

  - Tracheostomy masks, T-piece circuit, face tent (soft bowl-shaped mask)
- Large capacity
  - Face masks with reservoir bags
    - Higher 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, CIG (X location, nn year), Tubemakers, Luxfer Holdings, National Vulcan Engineering Insurance Group
    - 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 culinder wtihout valve
    - Name or symbol of gas and colouring to identify contents
        - ISO standard

Gas	**Pins**	**Colour**
CO_2	1,6	grey
O_2	2,5	black (with white shoulder for medical O_2)
air	1,5	grey with black and white shoulder
N_2O	3,5	blue
He	4,6	brown
C_3H_6	3,6	orange
N_2		grey with black shoulder
Entonox	single	blue with blue and white shoulder
Heliox	4,6	brown with black and white shoulder
Carbogen	2,6	black with grey and white shoulder

-
    - 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: N_2O, CO_2, C_3H_6
    - 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

OR	4
PACU, ICU	3
Delivery	2 + 1 for baby
Resus	2
Coronary care, anaesthetic room, etc.	1

Each port
- 40 l/min free flow
- -60 kPa (-500 mmHg, -600 cmH_2O)
- 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 O_2)
  - 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 cmH_2O)
  - 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 N_2O
  - High flows required to get enough N_2O into patient (≈15 l)
- Difficult to deliver enough volatile agent for early uptake
  - Halothane and isoflurane slow equilibration F_A/F_I
- 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 O_2 with a little air
  - Elimiates all these problems
    - Desfluane in O_2 gives easy pharmacokinetics
    - Accurate delivery with gas analysis
    - Sample gas returned to circuit
    - $FGF = \dot{V}O_2$ 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?
    - Desfluane: 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 O_2
- Drop flow to 2 l/min
  - Add desflurane ≈12%
    - FiDes **never** reaches 12%
- Watch E_TDes
  - Drop flows as E_TDes reaches desired value (e.g. 6%)
  - Reach estimated $\dot{V}O_2$ at 12% Des (or higher) in fresh gas
    - e.g. 250 ml/min
  - Then adjust FGF %Des to target E_TDes
  - Increase flows if you need to adjust E_TDes 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 FiO_2?
- Leave 100 ml/min air on
  - At high O2 flows, FiO_2 is still ≈100%
  - Once at metabolic flows FiO_2 will slowly fall
    - Turn air off and replace with O_2 once at target FiO_2

But what does it cost?

- Desflurane is expensive: $170 per 240 ml bottle
  - 300 ml/min FGF with 10% desfluane
    - = 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 $\dot{V}O_2$ or $^3/_4$ power of weight

Try it at RVEEH

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