SAFETY AND QUALITY IN ANAESTHETIC PRACTICE

Outline the standards to which reusable anaesthetic equipment needs to be cleaned and/or treated

Background:

- Definitions
  - **asepsis**: prevention of microbial contamination of living tissues or sterile materials
  - **disinfection**: inactivation of non-sporing organisms using either thermal or chemical means
  - **sterilization**: complete destruction of all micro-organisms including spores
- Equipment management dependent on site into which it comes in contact → classified as non-critical, semi-critical, critical
  - **Critical**: device will penetrate skin or mucous membranes, enter vascular system or sterile space → requires sterilization
  - **Semi critical**: device in contact with intact mucous membranes or may become contaminated with readily transmissible organisms → require high level disinfection or sterilization
  - **Non-critical**: contacts intact skin or does not contact patient → require low level disinfection or cleaning

Prevention of infection

- **anaesthetic apparatus**
  - Devices to be sited in the upper airway
    - Facemasks: ontaminated by secretions (semi critical) → cleaning + disinfection post use
    - Laryngoscopes: may penetrate skin / mucous membranes (critical) → sterilisation
  - Anaesthetic breathing systems
    - New bacterial filter for each patient
    - If high risk then change between patients unless HME bacterial filter used
    - Breathing bags cleaned eith detergent + water
  - Sampling lines for side stream gas analysis
    - Sterilized before reuse
    - Do not return sampled gas unless passed through viral filter
  - Anaesthetic machines
    - Routine daily sterilization or disinfection of internal components not necessary if bacterial/ viral filter used between patient and circuit
    - Bellows, unidirectional valves, CO2 absorbers should be cleaned and disinfected periodically
  - Surfaces + monitors
    - E.g. NIBP cuff + tubing, pulse oximeter, stethoscopes, ECG cables, exterior of machines + monitors
    - Temperature probes = single use
    - Cleaned between each patient with detergent + water
  - Flexible laryngoscopes + bronchoscopes
    - Semi critical: cleaning + high level disinfection or sterilisation
  - USS probes
    - Surface probes:
      - non critical i.e. intact skin/ TTE → disinfected
      - semi critical e.g. regional blocks/ vascular access → sterile cover + anything contaminated is critical clean
      - semi critical/ critical: internal probes

Outline the mandatory safety requirements for anaesthetic machines.

ANZCA statement on the minimum safety requirements for anaesthetic machines and worstations for clinical practice

- All anaesthetic machines in clinical use should comply with ANZCA standards
- Process:
  - Anaesthetic machine **safety assessment**
    - Assessed for safety, reliability, functionality 1x per year
    - Any machines that fail to comply with one or more safety requirement are actioned: i.e. removed from clinical use, updated, replaced
  - **Safety requirements**
    - Connections for medical gas cylinders, yokes, regulators must be pin indexed
    - Reserve supply of O2 must be attached to machine + easy activation should O2 supply failure occur
    - Non-interchangeabel gas hose connections on gas inlet + outlet
    - Display of gas supply line + cylinder pressure
    - O2 supply failure warning device
      - Activate automatically when O2 supply pressure falls below critical level
      - Generate alarm
      - Cut off supply of gases other than air or O2 to common fresh gas outlet
      - Cancel alarm only when O2 supply pressure restored
    - Only 1 gas flow control knob for each gas
    - If nitrous oxide able to be delivered, machine must not deliver hypoxic mix
    - Vaporizer interlock system
    - High pressure relief valve – prevents ↑↑↑ pressures
    - Anaesthetic gas scavenging system connections different diameter to other connections
    - High priority alarm when:
      - ↑↑airway pressure
      - ↓↓airway pressure
    - Protected on/off switch
    - Backup power supply
  - Adequate **maintenance** ongoing
    - Maintenance record + problem log
    - Consider for replacement

BASIC SCIENCES RELEVANT TO ANAESTHESIA EQUIPMENT, MEASUREMENT, AND SAFETY

Describe basic physics applicable to anaesthesia in particular:

Behaviour of fluids (gases and liquids)

Explain the difference between viscosity and density. Outline the effect of changes in viscosity and density on the flow of gases and liquids: PAST QUESTION

Viscosity

- measure of fluids internal resistance to flow
- usually refers to dynamic viscosity = fluids resistance to shearing flows
- kinematic viscosity = dynamic viscosity / density
- SI unit = Pa•S
- Common non SI unit = poise = 0.1 Pa•S

Density

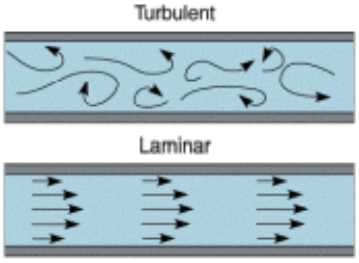
- Mass of a substance per unit volume
- SI unit = kg/m3
- Gases with similar viscosities may have very different densities and vice versa

Determinants of laminar vs. turbulent flow

- Flow = measure of volume of fluid or gas moved per unit time (e.g. ml/min)
- Flow of fluid in a tube may be laminar or turbulent
- **Laminar flow** = orderly flow whereby fluid travels in smooth streams parallel to vessel wall
- **Turbulent flow** = disorderly flow whereby fluid travels in eddies → lateral mixing
- Probability of turbulent flow occurring depends on: fluid factors and vessel factors
    - Fluid factors: summarised by Reynolds number

$$Re = 2\rho Rv/\eta$$

Where,
ρ = density
R = vessel radius
v = flow rate
η = viscosity
Re > 2000 → more likely to have turbulent flow
Re < 2000 → more likely to have laminar flow



- I.e. higher fluid density → ↑ likely to have turbulent flow
- I.e. higher fluid viscosity → ↑likely to have laminar flow

Resistance to laminar vs. turbulent flow

- for laminar flow, resistance ∝ to fluid viscosity and is given by Hagen Poiseuille equation

$$R = 8\eta L/\pi r^4$$

Where,

η = viscosity
L = length of vessel
r = radius of vessel

- for turbulent flow, resistance ∝ fluid density and is less dependent on viscosity

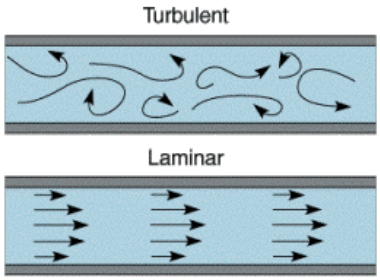
clinical example

- Heliox = mix of He and O2
- He has similar viscosity to N2 but much lower density therefore relative to air, Heliox has:
    - ↑probability of laminar flow
    - ↓resistance to turbulent flow → ↓WOB

Describe the differences between laminar and turbulent flow. List the factors that increase the probability of turbulent flow: PAST QUESTION

Background

- flow = quantity of fluid (i.e. gas or liwuid) passing a point in unit time
- Laminar flow = orderly flow whereby fluid travels in smooth streamlines parallel to vessel wall
- Turbulent flow = disorderly flow whereby fluid travels in eddies → lateral mixing

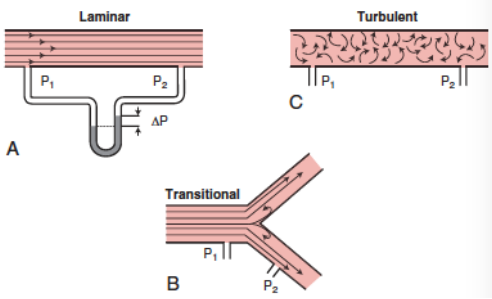


Properties of laminar flow

- occurs in straight smooth-walled tubes
- air/ gas moves in concentric tubes parallel to walls → velocity of air at centre = 2x at walls
- linear relationship between pressure and flow
- flow rate ∝ pressure difference with ratio of proportionality being resistance
- for laminar flow, resistance is ***independent*** of flow rate
- resistance to laminar flow is governed by **Hagan-Poiseille** equation
    - R = 8ηL/πr4
    - where R is resistance; n = viscosity; l = length of tube; r = radius
    - Therefore resistance is:
        - proportional to: **viscosity** of gas; **length** of tube
        - inversely proportional to: **radius**
        - ***independent of density***
        - also proportional to **velocity**: **P = k x v** where P = pressure, k = constant, v = velocity (flow rate)

Properties of turbulent flow

- flow is not smooth → forms swirls (eddie currents) causing lateral mixing
- relationship between flow rate and pressure = complex and depends on degree of turbulence
    - flow rate roughly ∝ square root of pressure (i.e. to double flow rate, need 4 fold ↑in pressure)
    - flow rate = inversely ∝ square root of density and vessel length
- Basically:
    - Pressure ∝ flow2
    - Resistance ∝ density
    - Resistance independent of viscosity
    - Resistance ↑ with ↓vessel radius
- Resistance (ratio of pressure to flow rate) is dependent on flow rate



Summary of differences in factors affecting laminar and turbulent flow

- Velocity
    - Laminar flow occurs up to a certain velocity. Above
- Driving pressure

Probability of turbulent flow

- Type of flow predicted by **Reynolds Number**
    - **2rdv/n** where r = radius; d = density; v = velocity; n = viscosity
    - gives ratio of inertial to viscous forces
    - <2000 = laminar flow; >4000 = turbulent
- Therefore it can be seen that:
    - ↑density → more conducive to turbulent flow
    - ↓density → more conducive to laminar flow e.g. warming of gases → ↓density; Heliox = mix He and O2 → ↓density than air → ↑laminar flow
    - ↑vessel caliber → conducive to turbulent flow
- Additionally:
    - Irregularities in vessel wall → ↑probability turbulent flow
    - Branching in vessel wall → ↑probability of turbulent flow

Electrical concepts, current, potential difference, resistance, impedance, inductance and capacitance

Charge

- the property of a subatomic particle which causes it to experience a force when close to other charged particles
- Measured in coulombs (C)

Current

- flow of electrons through a conductor. Measured in amps (A)
-

Potential difference

Resistance

- describes to what extent a substance reduces the flow of electrons through it
- measured in ohms
- substances with high resistance insulators
- substances with low resistance = conductors

Impedance

- describes to what extent the flow of alternating current is reduced when passing through a substance. Impedance can be thought of as 'resistance for AC circuits', and is a combination of resistance and reactance.
- Reactance is formed by two things:
    - Induction of voltage in conductors by the alternating magnetic field of AC flow
    - Capacitance induced by voltages between these conductors

Inductance

- the generation of current when a conductor moves through a magnetic field

Capacitance

- the ability of an object to store charge, measured in Fards (F)
- one farad is when one vol across the capacitor stores one coulomb of charge
- a capacitor is an electrical component consisting of 2 conductors separated by an insulator (called a dielectric)
- When a direct current flows, electrons (a negative charge) build up on one of these conductors (called a plate), whilst an electron deficit (positive charge) occurs on the other plate
- Current will flow until the build up of charge is equal to the voltage of the power source
- Current can be rapidly discharged when the circuit is changed
- An alternating current can flow freely across a capacitor, and causes no buildup of charge
-

Frequency

Amplitude

Principles of humidification and use of humidifiers

Define humidity:

- Humidity = measure of the amount of water vapour in gas (e.g. air)
- **Forms of humidity:**
  - **Absolute humidity:**
    - the mass of water vapour per unit volume of a gas (kg/m^3)
    - temperature independent
  - **Relative humidity:**
    - measures the % saturation of air at current temp
    - Ratio of vapour pressure of water in air compared with the SVP of water at that temp
    - I.e. Relative humidity = absolute humidity of gas / absolute humidity of gas fully saturated with water vapour at same temp
    - Temperature dependent
- Mechanism:
  - Nose optimised for humidification: septum + turbinates ↑SA and create turbulent flow → ↑contact of air with mucosal surfaces
  - Mouth breathing ↓s humidity of inspired air to 60%
  - Fluid lining airway → acts as heat + moisture exchanger
    - Nasopharynx: relative humidity = 90%
    - 2nd generation bronchi: relative humidity = 100% BTPS = water vapour pressure 44mmHg with absolute humidity = 44g/m3

Importance of humidification:

- Optimal function requires relative humidity >75%
- Inspired gas is normally humidified in the nose and mouth before entering the lower respiratory tract
- Inadequate humidification of inspired gas results in:
  - Acute:
    - Impaired ciliary and mucous belt function
    - Tenacious mucus, crusting of secretions
    - ↑airway resistance and ↓compliance
    - heat loss by evaporation
  - Chronic
    - Squamous metaplasia
    - ↓FRC
    - ↑shunt
    - impaired surfactant function
    - atelectasis
- Importance in anaesthetic circuit
  - Prevent heat loss – water has very high latent heat of vapourisation (2.4ML/kg_
  - Prevent water loss
  - Maintain mucociliary function
  - Encourage mucous flow and avoid crusting of airway secretions

Measurement of humidity

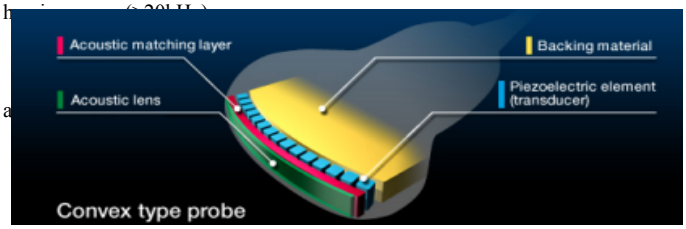
- Instrument that measures humidity = hygrometer
- Difficult to accurately measure
- Different hygrometers that can measure humidity:
  - Hair hygrometer
    - Measures relative humidity
    - Hair changes elasticity depending on humidity → Δelasticity can be related to Δhumidity
    - ↑humidity → ↑hair length
  - Wet and dry bulb (psychrometer)
    - Measures both temp + relative humidity
    - 2 thermometers used: one wrapped in wick (wet thermometer) + dry thermometer
    - amount of evaporative cooling occurring = function of humidity → at 100% humidity, no evaporative cooling will occur; as humidity ↓ → evaporative cooling → cool wet thermometer → temp difference
  - Regnaults hydrometer
    - Measures absolute and relative humidity
    - Shiny plate at known temp → cooled + observed when condensation 1st occurs (dew point)
    - Dew point used to derive water content (absolute humidity)
    - Use thermometer and table to determine relative humidity at temp of interest
  - Electrical transducers
    - Metals where capacitance or resistance varies with humidity → can be measured to calculate humidity

Principles of ultrasound imaging and use of doppler

Explain the physical principles of ultrasound imaging: PAST QUESTION

Background

- USS = way of imaging internal soft tissue structures though reflection + detection of sound waves
- Uses oscillating pressure wave with frequency above the normal human h
- frequency range used for medial USS imaging = 2-15MHz



USS production and emission

- Piezoelectric crystals within transmitter probe deform when a voltage is a
- USS wave subjected to:
  - Backing material: ↓excessive vibrations → directs USS beam + ↑axial resolution
  - Acoustic matching layer: ↓internal USS reflection produced 2^{o} sig differences in acoustic impedance between components of probe
  - Acoustic lens: focuses USS beam

USS detection

- Reflected waves detected by the probe: sound waves cause crystals to vibrate → transduced into an electrical signal → converted to image

- Reverse of the piezoelectric effect

Properties of USS waves

- Wavelength: distance between 2 points of peak compression
- Frequency: number of cycles per second (Hz)
  - ↑frequency = ↑resolution but ↓penetration
  - ↓frequency = ↓resolution but ↑penetration
- Wavelength and frequency are inversely related i.e. USS of ↑frequency has short wavelength and vice versa
- velocity = speed at which sound waves are propagated
  - sound waves travel through different materials at different speeds
  - bone > blood > tissue > fat > air
- amplitude: maximum displacement of a pressure wave

Effect of tissues on USS

At tissue interfaces, the wave may be:

- Absorbed
  - Amount of absorption depends on:
    - Tissue type: attenuation of bone > muscle > fat > blood > water
    - Frequency: ↑frequency = ↑attenuation; ↓frequency → ↑tissue penetration → better imaging of deeper structures
- Reflected
  - Sound bounces back from tissue interface and returns to probe
  - Dependent on:
    - Difference in sound conduction between 2 tissues
    - Angle of incidence (close to 90o improves reflection)
    - Smoothness of tissue plane
  - Amplitude determines echogenicity (whiteness of object)
  - Time taken for sound to return determines depth
  - Acoustic impedance = resistance of a material to pressure wave propagation
  - Need for gel at air/tissue interface
- Transmitted
  - Sound passes through tissue, and may be reflected or absorbed at deeper tissues
- Scattered
  - Sound reflected form tissue but not received by the probe
- Attenuated
  - Loss of sound wave with ↑ depth
  - Managed by ↑gain (gain = amplification of returned signal)

Velocity-frequency-wavelength relationship

- resolution of USS image depends on wavelength → shorter wavelength = ↑resolving power
- wave equation states that: velocity = frequency x wavelength
  - as speed of USS is constant in given medium → therefore ↑frequency → shorter wavelength
  - Consequence = improvement in resolution (shorter wavelength) means ↓tissue penetration (higher frequency)

Modes of USS imaging

- 2D pictures require array of crystals
- B: Brightness mode = pulsed USS emission in 1 dimension
  - 2D B mode imaging is created by plotting axial dimension (x-axis) vs. latency (y-axis) vs. amplitude of reflected wave (brightness)
  - use = create cross sectional image → visualise anatomy
- M (motion) mode = USS emission in a single direction → reflected waves detected
  - 1D M mode image created by plotting time (x axis) vs. latency (y axis) vs. amplitude of reflected wave (brightness)
  - use = monitor movement e.g. of heart valve over time along one dimension
- Doppler mode = B mode USS emission → USS wave interact with moving structure → doppler shift in reflected wave → detected
  - 2D B mode image with superimposed colour representation of Doppler shift (red = away, blue = towards transducer)

Doppler effect

- Using **doppler shift** to establish the velocity of the moving object which is reflecting the sound waves
- Normally USS wave reflected from a stationary object has same frequency as emitted wave
- **Doppler effect** = Δfrequency of a wave for an observer moving relative to its source
  - E.g. if moving towards transducer → doppler shift of reflected wave → reflected wave has ↑frequency than emitted wave
  - Doppler shift in frequency is related to the relative velocity between transducer and target by the doppler shift equation
    - $\Delta f = \frac{\Delta v}{c} f_0$
    - Where Δf = doppler frequency shift; Δv = relative velocity, c = speed of USS in medium; f0 = initial USS frequency
  - Doppler shift for emitted USS bean that hits target tangentially (i.e. at angle) → equation rewritten to:

∴ above equation is rewritten to

$$\Delta f = \frac{2\Delta v \cos\theta}{c} f_0$$

∴ velocity of target may be calculated from knowing:
(1) Doppler frequency shift – Δf
(2) incident angle – θ
(3) emitted ultrasound frequency – f_0
(4) speed of ultrasound in target medium – c

Application of doppler effect in the measurement of cardiac output

- ECHO can use the principle of doppler shift to measure the speed of blood flow across the aortic valve as a function of time
- Rate of blood flow is not constant during cardiac cycle → integrating velocity-time curve for one heartbeat (i.e. velocity time integral "VTI") = way of obtaining weighted average velocity over a cardiac cycle

- M mode across aortic valve → possible to measure the aortic valve diameter → used to estimate the aortic valve area
- SV = velocity-time integral over one cardiac cycle x aortic valve area
- CO can then be estimated by SV x HR
- Therefore CO = VTI x $area_{aortic\ valve}$ x HR

Describe the methods of measurement applicable to anaesthesia, including clinical utility, complications and sources of error in particular:

SI units

Measurement of volumes, flows, and pressures, including transducers.

Transducer:

- converts one form of energy to another.
- pressure transducers convert a pressure signal to an electrical signal
- Requires several components:
  - Catheter
  - Tubing
  - Stopcock
  - Flush
  - Transducer
- System must be calibrated in 2 ways:
  - Static calibration: calibrates to a known zero
    - Involves:
      - Leveling transducer: i.e. level of RA; Δtransducer level → ΔBP due to Δhydrostatic pressure (in cmH2O)
      - Zeroing transducer: open transducer to air; zeroing on monitor
        - Δmeasured pressure when transducer open to air → due to drift (artifactual measurement error due to damage to the cable, transducer, or monitor)
  - Dynamic calibration: accurate representation of changes in the system
    - Dynamic response is a function of:
      - Damping
        - How rapidly an oscillating system will come to rest
        - quantified by the damping coefficient or damping ratio
          - Describes to what extent the magnitude of an oscillation falls with each successive oscillation
          - Calculated from the ratio of the amplitudes of successive oscillations in a convoluted fashion
      - Resonant frequency
        - How rapidly a system will oscillate when disturbed and left alone → when damping is low, it will be close to the natural frequency (or undmamped resonant frequency)
        - Damping and natural frequency are used as they are both easily measured + accurate in describing the dynamic response
        - These properties are actually determined by the systems elasticity, mass, and friction
- Pressure waveforms:
  - The dynamic response required is dependent on the nature of the pressure wave to be measured
  - Accurately reproducing an arterial waveform requires a system with a greater dynamic response compared to a venous waveform
  - An arterial pressure waveform is a periodic (repeating) complex wave, that can be represented mathematically by **Fourier analysis**
  - Fourier analysis involves expressing a complex (arterial) wave as the sum of many simple sine waves of varying frequencies and amplitudes
  - The frequency of the arterial wave (i.e., the pulse rate) is known as the **fundamental frequency**
  - The sine waves used to reproduce it must have a frequency that is a *multiple* (or **harmonic**) of the fundamental frequency
    - Increasing the number of harmonics allows better reproduction of high-frequency components, such as rapid heart rates or a steep systolic upstroke
  - Accurate reproduction of an **arterial** waveform requires up to **10 harmonics** - or **10 times the pulse rate**
  - An arterial pressure transducer should therefore have a dynamic response of **30Hz**
    - This allows accurate reproduction of blood pressure in heart rates up to 180bpm (180 bpm = 3Hz, 3Hz x 10 = 30Hz)

Resonance

- If high frequency components of the pressure waveform approach the natural frequency of the system, then the system will resonate
- This results in a distorted output signal and a small **overshoot in systolic pressure**.

Damping

- A pressure transduction system should be adequately damped:
  - An **optimally** damped waveform has a damping of **0.64**. It demonstrates:
    - A rapid return to baseline following a **step-change**, with **one overshoot and one undershoot**
  - A **critically damped** waveform has a damping cofficient of **1**. It demonstrates:
    - The most rapid return to baseline possible following a step-change **without overshooting**
  - An **overdamped** waveform has a damping coefficient of **>1**. It demonstrates:
    - A slow return to baseline following a step-change with no oscillations
    - Slurred upstroke
    - Absent dicrotic notch
    - Loss of fine detail
  - An **underdamped** waveform has a damping coefficient close to 0 (e.g. **0.03**). It demonstrates:
    - A very rapid return to baseline following a step-change with several oscillations
    - Systolic pressure overshoot
    - Artifactual bumps

Fundamentals of pressure measurement

- pressure exerted by a static fluid is due to the weigh tof the fluid and is a function of:
  - fluid density in kg/L
  - acceleration (effect of gravity in m2)
  - height of the column of fluid
- can be derived as:
  - pressure = force/ area = mass x acceleration / area
  - density = mass/ volume, therefore mass = vol x density
  - combining above: pressure = density x vol x acceleration / area = density x length x acceleration

Measurement of blood pressure

Non-invasive blood pressure measurement

Blood pressure

Blood pressure arises from the force of contraction of the myocardium acting on the blood contained in the heart

- BP varies with site of measurement
  - due to: hydrostatic effects, caliber of vessel, vessel distance from the heart
  - Standard reference point = level of the RA
  - Diurnal variation: ↓during sleep
  - Minor changes of pressure during resp cycle; more marked during IPPV
- MAP = CO x SVR
- MAP = diastolic pressure + 1/3 pulse pressure

Non invasive

- Via oscillometry = uses pressure transducer to monitor the pulsatile changes in pressure that are caused by the flow of blood through an artery that is restricted by occluding cuff
- Method
  - Cuff (distensible bladder surrounded by nondistensible bag) applied ot measuring site over artery (common brachial)
  - Cuff width: 20% > arm diameter; centre of bladder on medial side over brachial artery
  - Manual process: cuff inflated to pressure > SBP → released rate of 2-3mmHg/ sec
  - Automatic: pressure transducer measures pressure + oscillations
  - SBP = reappearance of peripheral pulse: pressure oscillations, manual palpation of radial pulse → auscultation over brachial artery allows detection by 1st phase Korotkoff sound i.e. the point at which sounds from blood flow in the artery first appear
- Results:
  - SBP: 1st sig rise in oscillations; manual palpation of radial pulse; auscultation over brachial artery → 1st phase korotkoff sound
  - DBP: oscillations drop significantly in side (least reliable of the measures)
  - HR: frequency of oscillations
  - Phases:
    - 2nd phase: slight muffling
    - 3rd phase: ↑vol of auscultation sounds
    - 4th phase: abrupt ↓sound level;
    - 5th phase: final loss of all sound; represents DBP

Sources of error

- inappropriate cuff size
- arrhythmias
- movement artifact
- hypotension
- calibration errors

Limitations

- pain from repeated measurements
- frequency of measurements limited by time taken for measurements
- limb oedema, venous stasis, nerve compression with repeated cuff inflations
- interference with pulse oximetry

Describe the principles and sources of error in the measurement of systemic arterial blood pressure using an automated oscillometric non-invasive monitor: PAST QUESTION 81%

Background

- automated non-invasive BP monitors commonly used in anaesthesia use principle of oscillometry
- oscillometry = variation in oscillatory amplitude of pressure within a deflating cuff overlying an artery

Set up and principles of automatic oscillometric NIBP

- set up = cuff containing inflatable bladder, connected to
  - 1. air insufflation port
  - 2. Pressure transduction port
- method:
  - correct position of correct size cuff over artery
  - inflate cuff to pressure > that to completely occlude artery
  - slowly deflate cuff
  - transduce gauge pressure and pulse pressure wave of cuff
  - analyse oscillatory signal

Oscillometric analysis

- oscillations due to pulsatile blood flow past the partially compressed artery
- **SBP**: 1st set of oscillations = blood flow able to overcome external compression by cuff
- **MAP**: point of maximal oscillatory amplitude = buckling or max compliance in artery
- **DBP**. Different methods of defining DBP
  - 1. Point of maximal ↓in rate of change of oscillatory amplitude
  - 2. Assuming diastole = fixed fraction of cardiac cycle i.e. 2/3
    - MAP= SBP/3 + 2xDBP/3 therefore…
    - DBP = (3MAP – SBP) / 2
  - 3. Point when amplitude of oscillation is fixed proportion of the maximum e.g. DBP occurs when oscillatory amplitude is 0.85 of MAP
  - 4. Proprietary algorithm

Sources of error

- Patient errors
  - Irregular pulse rate +/- rhythm e.g. AF
  - Excessive patient movement during measurement
  - Inaccurate when measuring very low BP
  - Calcified non-compressible artery
  - Pain caused by high cuff pressure influences baseline NIBP

- Equipment errors
  - Inappropriate cuff size: cuff length should be 2/3 of upper arm; diameter 20% > arm diameter. Small cuff → overestimation of NIBP
  - Cuff not placed at heart level
  - External compression of cuff
  - Calibration or transducer error

Invasive blood pressure measurement

Blood pressure

BP arises from the force of contraction of myocardium acting on blood contained in heart

- BP varies with site of measurement
  - due to: hydrostatic effects, caliber of vessel, vessel distance from the heart
  - Standard reference point = level of the RA
  - Diurnal variation: ↓during sleep
  - Minor changes of pressure during resp cycle; more marked during IPPV
- MAP = CO x SVR
- MAP = diastolic pressure + 1/3 pulse pressure

Invasive

- direct measurement of BP involving: cannulation of artery, infuser system, transducer, and recorder
- peripheral artery chosen: ↓threat to limb is clot or haematoma forms
- radial artery 1st choice: modified Allen test
- continuous flushing system with heparinized saline pressurized container at pressure > SBP → passes from container through a constriction, adjusted so that flow cannot >4ml/hr
- Strain gauge transducer:
  - converts one form of energy to another; pressure transducer converts a pressure signal to an electrical signal
  - Fibreoptic transducer-tipper pressure-monitoring catheter
  - Employs a mirror coated moving diaphragm which reflects light carried to the tip by an optical fibre
  - Position of the diaphragm changes in response to changes in pressure → determines the fraction of the incident light that is reflected back down a 2nd fibre
  - Other end of the catheter connects to an optoelectronic module which converts the light into an electrical signal
  - Associated electronics interpret the reflected light intensity in terms of pressure
- Final waveform:
  - Can be displayed on oscilloscope or recorder tracing
  - Form of the pressure wave alters as blood flows to the periphery:
    - narrower and ↑amplitude in peripheral arteries
    - dorsalis pedis > rad artery > aorta
    - modification of wave pattern is caused by Δdiameter of vessels and their elasticity + reflection of wave pattern from vessel walls
  - MAP = area under curve / time (time usually is 1)
- Resonance and damping
  - Movement of the diaphragm of the pressure transducer converts the BP change into an electrical signal
  - Oscillations occurring at the resonant frequency produce a sine wave which is superimposed on the BP waveform → avoided if resonant frequency is outside the range of frequencies present in BP waveform – shorter, wider, stiffer catheter
  - Damping
    - Any restriction to the transmission of BP from artery to transducer diaphragm → displayed BP will be damped or smoothed
    - Can be due to: air bubbles in catheter or transducer chamber (absorb pressure change in saline column), clot formation in cannula (restricts movement of saline column) → ↓deflection of transducer diaphragm and size of measured waveform

Invasive vs non invasive

	Advantages	Disadvantages
Direct	- Potential accuracy - Continuous display → permits immediate response - Better reliability if pressure is continuously varying e.g. AF, fluctuating pulse rate	- risk of arterial damage - ↑cost - need for technical skill
Indirect	- harmless provided measurements not made too frequently - easy + cheap	- Fail to record BP below certain minimum - Intermittent recording

Describe the effects of resonance and damping on an invasive arterial blood pressure tracing: PAST QUESTION

Arterial BP may be monitored invasively using an arterial cannula connected ot a pressure transducer

- the arterial BP oscillations → oscillations in the arterial line tube fluid column setup → oscillation transmitted ot the transducer → converted to an electrical signal
- the arterial line tube fluid column transducer system = second order system ie it oscillates in response to a primary oscillation (arterial blood flow)
- accuracy of second order systems are influenced by **resonance** and **damping** within the system. These are **dynamic factors**
- NB static factors refer to:
  - Zero errors i.e. incorrect positioning/height of transducer relative to reference
  - Gain errors i.e. non-linear signal response, incorrect calibration, drift

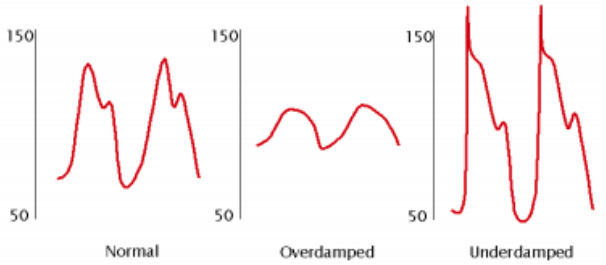
Resonance

- **resonance** = tendency for system to oscillate with ↑amplitude at certain frequencies (i.e. at natural frequencies)
- **natural frequencies** = frequencies adopted by the system if it is disturbed then allowed to oscillate free
- lowest natural frequency of a system = **fundamental frequency**
  - all other natural frequencies = multiples of the fundamental frequency
  - e.g. if fundamental frequency of a system = 1Hz, then 2nd harmonic frequency = 2Hz, 3rd harmonic = 3Hz etc
  - HR 30-180bmp correspond to fundamental frequencies of 0.5-3Hz
- If natural frequency of arterial line set up = natural frequency (or harmonics) of arterial pulsation → resonance → amplification of oscillation → error
- The natural frequency of arterial line set up must be at least 8-10x natural

frequency of arterial blood pulsations i.e. >30Hz to avoid the effects of resonance
    - Usually, natural frequency of arterial line setup = 200Hz. Number of factors may ↓ this:
    - Natural frequency of arterial line set up is:
        - ∝ diameter of tubing
        - inversely ∝ to √length of tubing
        - inversely ∝ compliance
        - inversely ∝ fluid density
        - therefore ↑length of tubing, ↓stiffness of tubing, ↑fluid density (e.g. blood clot) → ↓natural frequency → potentially ↑resonance
    - consequences of ↑resonance
        - falsely ↑systolic arterial pressure
        - falsely ↓diastolic arterial pressure
        - MAP relatively unaffected

Damping

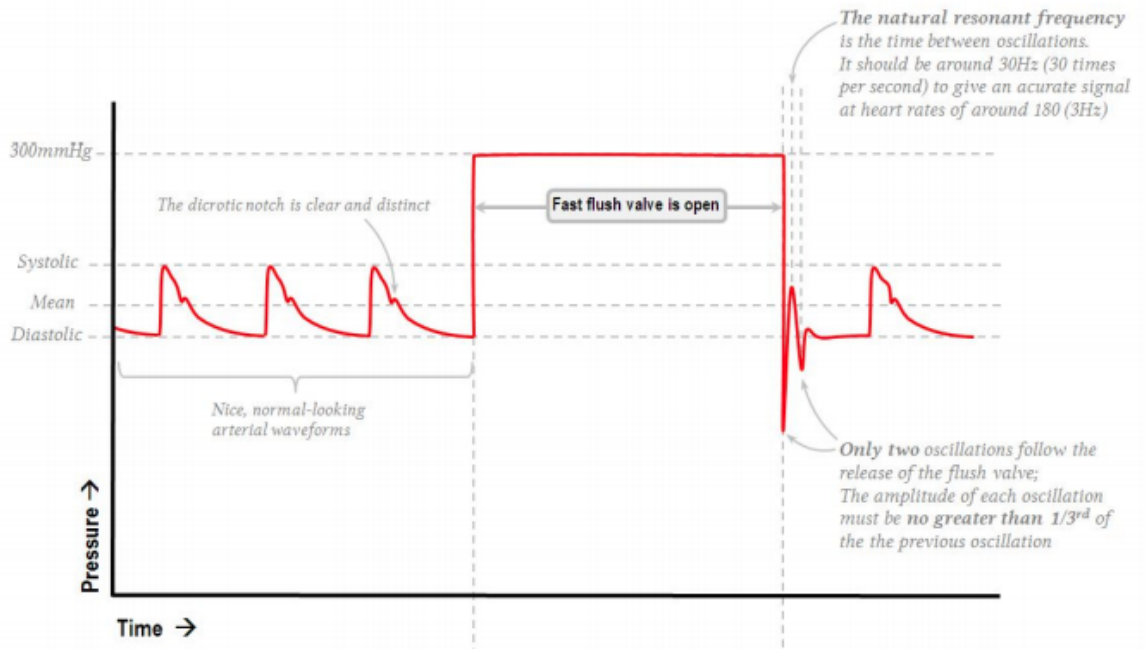
- damping = the tendency of a system to resist oscillations via dissipation of energy
- Overdamped system will rapidly stop oscillations
- Underdamped system will very slowly stop oscillations
- Undamped system will continue to oscillate indefinitely
- Damping coefficient = degree of speed with which an oscillating system returns to baseline
    - 0: pressure waveform oscillates at F0 → no ↓oscillations over time
    - 1: ↓quickly to baseline → no overshoot (critical damping)
    - 0.64: 64% of critical damping: ideal; overshoot minimised; apl



- Factors that ↑damping:
    - Kinked tube
    - ↑compliance of tubing
    - ↑length of tubing
    - blood clot in tubing
    - air bubble in tubing
- Consequences of overdamping
    - Underestimate SBP
    - Overestimate DBP
    - MAP relatively unaffected
    - Loss of details of arterial pressure oscillation e.g. lost dicrotic notch
    - Can also alter the natural frequency
    - Damping affects different harmonic to different extent → phase distortion

Quantifying resonance and damping *(examiners comments = this is advanced material)*

- can be approximately quantified using **fast flush test**
- when flush valve is squeezed → square pressure wave delivered → when let go of flush valve, the arterial line system will respond to the pressure wave as below:
- Frequency of oscillation following fast flush test = natural frequency
- Amplitude of oscillation following fast flush test → can be used to calculate the damping coefficient



Optimal damping

Quantifying damping with following formula:

$$D = \sqrt{\frac{[\ln(D_2/D_1)]^2}{\pi^2 + [\ln(D_2/D_1)]^2}}$$

- where D= damping coefficient

- D1 = amplitude of 1st oscillation after fast flush test
- D2 = amplitude of 2nd oscillation after fast flush test
- When D2/D1 = ~7% i.e. small overshoot → D = 0.64 (optimal damping)
- Rough rule: optimal damping occurs when there are 2 oscillations following release of flush valve, where the amplitude of each oscillation is ~7% of previous oscillation
- Advantages of optimal damping
    - Amplitude distortion minimised → <2% overshoot/undershoot at frequencies <2/3 natural frequency of arterial line setup
    - Phase distortion is minimised → same distortion for all harmonics
    - Maximal frequency response obtained → accuracy maintained up to 2/3 natural frequency. This accuracy range is better than at any other damping coefficients

Measurement of cardiac output

Explain how cardiac output is measured using a thermodilution technique: PAST QUESTION

Cardiac output

- CO = volume of blood ejected from the heart per unit time
- Resting CO of typical 70kg male = 5L/min
- CO measurement can be performed:
    - Invasively
        - Thermodilution
        - TOE
        - Arterial waveform analysis: PiCCO, Vigileo
    - Non invasively
        - TTE
        - MRI
        - Thoracic impedance

Thermodilution

- Gold standard
- Based on **Fick principle** → based on law of conservation of mass where amount of indicator substance taken up or added by an oran per unit time = AV difference in substance x blood flow
- In case of thermodilution: heat lost from the blood = heat gained by injectate

Procedure:

- PAC (Swan-Ganz) inserted into IJ
- Position tip of PAC lumen #1 at RA/SVC junction
- Position tip of PAC lumen #2 (which contains thermistor) in pulmonary artery
- Balloon at the tip to float into position
- Inject known vol (e.g. 10mL) of cold fluid (e.g. NS) of known temp (e.g. 3oC) through lumen 1
- Collect thermistor reading and construct temperature vs. time curve
- Repeat and obtain average
- Calculate CO from the temp vs. time curve constructed

Principles

- Variation of the **indicator-dilution technique** – whereby the indicator = cold fluid of known heat content (i.e. temp and heat capacity)
    - After bolus of cold fluid into SVC → mixing of cold with warm blood → ↓temp of blood (detected by thermistor) → as more warm blood flows through heart → cold bolus is "washed out" → temp returns to baseline
    - Faster rate of blood flow (i.e. ↑CO) → faster the cold fluid bolus is washed out → faster temp returns to baseline → smaller AUC
    - Therefore: knowing the AUC of temp-time curve enables calculation of CO

Mathematical derivation of CO

- Uses Fick principle
- Single compartment pharmacokinetics
    - Removal of injected cols saline bolus from heart can be modeled using single compartment pharmacokinetics
    - Where:
        - Single compartment = heart
        - CO = clearance = dose/ AUC
    - When this is applied to heat transfer,

$$\text{Dose} = \text{heat from indicator} = \rho \times V \times C_p \times (T_{inject} - T_{blood})$$

$$\text{AUC} = \text{area under heat-time curve} = \rho \times C_p \times \int_0^{\infty} \Delta T(t)\,dt$$

Where,
ρ = density of blood (assumed to be same as injectate)
V = volume injected
C_p = heat capacity of blood (assumed to be same as injectate)
T_{inject} = temperature of injectate
T_{blood} = initial temperature of blood
        - ΔT(t) = temperature difference from baseline as a function of time
    - therefore:
        - $$CO = \frac{dose}{AUC} = \frac{V \times (T_{inject} - T_{blood})}{area\ under\ \Delta temp - time\ curve}$$ = **Stewart-Hamilton equation** for thermodilution

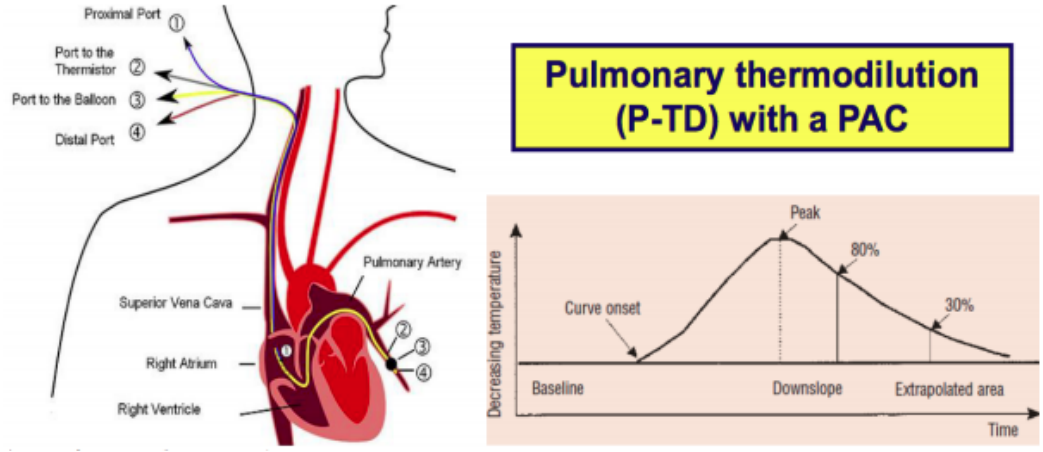
Errors

- Measurement error
    - Thermistor
    - Vol injected / dead space of PAC
        - Incorrect vol of injectate: too much = underestimates CO; too little = overestimates CO
    - Poorly positioned PAC: must be positioned in West zone 3 for blood flow to occur past the tip nd measured temp accurate
    - Integration of temp – time curve
    - Natural variability: CO varies up to 10% with Δintrathoracic pressure during respiration → mean of 3-5 measurements should be taken +

measurements at end expiration
    - Arrhythmias
- Assumptions
    - injectate and blood has same density and heat capacity
    - thermal equilibrium established by the time mixture reaches thermistor
    - injectate is warmed by blood only (not true in low flow states → injectate also warmed by wall of vessels/ myocardium)
    - unidirectional blood flow (not true in TR - results in retrograde ejection of injectate back past the valve)
    - cold injectate does not impact CO (may depress CO)

Advantages and disadvantages

- Advantages
    - Easy to repeat
    - Does not need blood sampling
    - Does not need injection of dye → nil toxicity
    - No recirculation error when compared to dye-dilution method
- Disadvantages
    - Invasive: requires PAC → carries all risks associated with PAC insertion
    - Cold fluid may induce arrhythmias
    - Fluid load (very small)



Explain the principles of Doppler ultrasound used to measure cardiac output (using echocardiography): PAST QUESTION

USS:

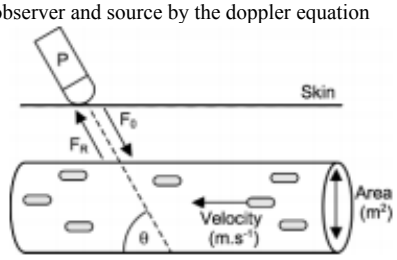
- USS = way of imaging internal soft tissue structures though reflection + detection of sound waves
- Utilises piezoelectric effect: application of voltage leads to vibration of a crystal (acts as transducer)

Doppler effect = change in frequency of a wave for an observer moving relative to its source

- used during ECHO to visualise direction of blood flow and estimate CO
- principle: doppler frequency shift is related to the relative velocity between observer and source by the doppler equation

Doppler equation:

$$\Delta V = \frac{\Delta F c}{2 F_0 \cos\theta}$$



Where ΔV = Reflector (RBC) velocity, ΔF = Frequency shift, c = ultrasound velocity, F_0 = Frequency of emitted ultrasound and θ = Angle of incidence (Doppler angle)

-
    - USS waves emitted from probe (P) at frequency (F0)
    - If reflected of stationary object → USS waves retain original frequency (F0)
    - If reflected off moving object → USS waves have new frequency (FR)
        - Moving away: rarefaction → longer amplitude therefore FR <F0
        - Moving towards: compression → shorter amplitude therefore FR > F0
        - Phase shift (ΔF) = FR – F0
    - ↑angle of incidence → ↑error (USS machines assume beam parallel to blood flow i.e. angle = 0)

Doppler USS for CO measurement

- Piezoelectric effect: ability of certain materials to convert electrical energy into mechanical energy
    - USS probes emit USS waves and generate electrical signal from received USS waves
    - USS imaging used high frequency (2-15MHz) with an average speed of 1540m/s through body tissues
- **CO output measurements**
    - **CO = HR x LVOTarea x $LVOT_{VTI}$**
        - CO = HR x SV
        - SV = LVOTarea x $LVOT_{VTI}$
    - LVOTarea
        - Measure LVOT diameter in PLAX
        - LVOTarea = π x $(LVOTdiameter)^2$ / 4

- $LVOT_{VTI}$: velocity time integral
  - As velocity is not constant during cardiac cycle → VTI is used as a time weighted average
  - Measured in apical 5 chamber view using pulse wave doppler aligned to LV outflow
- Advantages
  - Non invasive + simple (all calculations done by algorithms built into USS machine)
- Limitations
  - Non-uniform flow within a vessel (laminar, turbulent) → error
  - Inaccurate with irregular rhythm
  - Depends on accuracy of LVOTdiameter measurement (any error is squared)
  - Non-alignment of doppler beam → underestimate VTE (assumption angle = 0 fails)
  - Less accurate than thermodilution technique

Measurement of temperature

Temperature = tendency of a body to transfer heat energy to another body
- measured in degrees
- different from heat = kinetic energy content of a body; measured in joules
- temp and heat are related by the specific heat capacity: describes how much energy (J) must be applied to a body to ↑temp from 14-15oC without a change in state

Measurement of temperature
- **Non electrical**
  - **liquid expansion thermometry**
    - used in mercury thermometers
    - consists of: graduated evacuated capillary of negligible vol, attached to mercury reservoir separated by constriction ring
    - mechanism:
      - when heated: kinetic energy of mercury ↑ and it expands → forcing it up the capillary
      - as the thermal expansion coefficient for all liquids is very small, the capillary must be of very small vol to create a useable device
      - the speed that this occurs is related to the time constant of the system. ~30s; measurement takes ~4time constants (~2min)
    - Pros: easy to use, accurate, reusable, sterilisable, cheap
    - Cons: slow response; glass can break; inaccurate at low temp or high temp
  - **Bimetallic strip thermometer**
    - 2 strips of metal with different thermal expansion coefficients fixed together in coil → expands different extent when heated → moves dial
  - **Bourdon gauge thermometer**
    - Sensing element contains volatile fluid → content expands when heated → moves dial
- **Electrical**
  - **Resistance thermometer**
    - Platinum wire ↑electrical resistance with ↑temp: voltage drop across the wire will correspond to temp of the wire; Δresistance is linear across temp range
  - **Thermistor**
    - Metal semiconductor (metal oxide) which Δresistance in predictable non-linear fashion with temp
    - Resistance of bead of metal oxide ↓s exponentially with ↑temp
    - Much cheaper than resistance methods
    - Degree of voltage drop is small and can be amplified using wheatstone bridge
    - Disadvantage = calibration may be impaired if exposed to high temp (e.g. sterilisation process)
  - **Thermocouple**
    - At junction of 2 dissimilar metals, a potential difference will be produced ∝ temp = Seebeck effect
    - Non linear (wash in exponent)
    - Degrade over time

Differentiate between the terms heat and temperature. Explain the principles of a mercury thermometer and a thermistor, indicating their advantage and disadvantages: PAST QUESTION 82%

Background
- Heat = form of energy. SI unit = Joule ($kg \bullet m^2/s^2$)
- Temperature is the thermal state of a substance which measures the tendency of a system to undergo heat transfer. SI unit = Kelvin
- A body with higher temp will transfer heat to a body with lower temp that is in thermal contact (corollary of 2nd law of thermodynamics)

Measuring temp
- **Non-electrical techniques**
  - **Mercury** or alcohol thermometer
    - Utilises liquid expansion thermometry
    - consists of: graduated evacuated capillary of negligible vol, attached to mercury reservoir separated by constriction ring
    - mechanism:
      - when heated: kinetic energy of mercury ↑ and it expands → forcing it up the capillary
      - as the thermal expansion coefficient for all liquids is very small, the capillary must be of very small vol to create a useable device
      - the speed that this occurs is related to the time constant of the system. ~30s; measurement takes ~4time constants (~2min)
    - Pros: easy to use, accurate, reusable, sterilisable, cheap
    - Cons: slow response; glass can break; inaccurate at low temp or high temp
  - Bimetallic strip thermometer
  - Bourdon gauge thermometer
- **Electrical**
  - Resistance thermometer
  - **Thermistor**
    - Metal semiconductor (metal oxide) which Δresistance in predictable non-linear fashion with temp
    - Resistance of bead of metal oxide ↓s exponentially with ↑temp
    - Much cheaper than resistance methods
    - Degree of voltage drop is small and can be amplified using wheatstone bridge
    - Disadvantage = calibration may be impaired if exposed to high temp (e.g. sterilisation process)

- Infrared (tympanic) thermometers

Oximetry

Pulse and tissue oximetry

- Spectrophotometric technique to measure O2 sats in blood sample
- uses absorption of visible + infrared radiation at several wavelengths
- Can be divided into:
  - Direct co-oximetry: requires blood specimen and spectrophotometer
  - Pulse oximetry: using non invasive finger or ear probe
- Employs **Beer Lambert law**
  - describe absorption of radiation by sample in general
    - $A = \log(I_0/I_t) = \varepsilon \times c \times l$
    - Where e, I_0 and I_t = baseline and transmitted intensities, ε = molar absorptivity (a constant), c = concentration; l = path length
  - I.e. absorption of light passing through a substance is directly ∝to:
    - distance it travels through the substance +
    - concentration of attenuating species within the substance

Principles

- Different Hb molecules (e.g. oxyHb, deoxyHb, metHb, carbodyHb, foetalHb) have different absorption spectra
- By measuring absorption spectrum of blood sample at multiple wavelengths → enable extrapolation of the concentrations of various Hb species
- Oximetry usually measures at least 2 wavelengths:
  - oxygenated + deoxygenated Hb absorb light of different wavelengths to different extents
    - DeoxyHb: red (660nm)
    - OxyHb: infrared (940nm)
  - Relative absorbance allows determination of proportion of oxy/ deoxyHb
- Isobestic point (600nm and 800nm): where absorbances of oxy + deoxyHb are identical → depend only on Hb concentration

How it works:

- radiation from red (660nm) + infrared (940nm) light emitting diodes passes through a finger → photocell detects transmitted radiation
- output processed electronically → pulse waveform + the arterial O2 sat
- During pulsatile flow, the expansion and contraction of the blood vessels alters the distance and Hb concentrations → changing the absorption spectra of blood (as per the Beer-Lambert Law)
  - Non pulsatile elements are due to tissues and venous blood → these are subtracted from the total → leaving the pulsatile element = represents the arterial component
  - The ratio of absorbances of the pulsatile elements and the non pulsatile elements is called R
  - R is compared with a set of standardised values to deliver a calculated SpO2
    - R of 0.4: SpO2 100%
    - R of 1: SpO2 85%
    - R of 2: SpO2 50%
- O2 content
  - oxyhb gives indication of O2 content of the blood
  - O2 content = (blood O2 saturation x Hb concentration

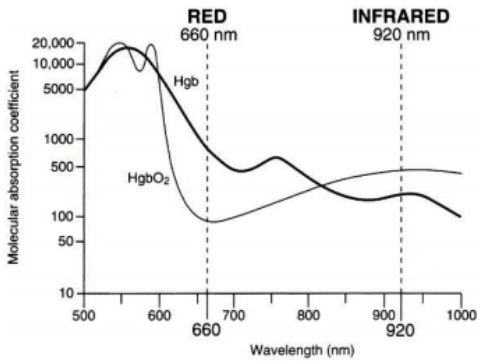
Limitations

- Requires detectable pulsatile flow
- Confounded by ambient light
- Absorption spectra confounded by haemoglobinopathies
  - carboxyHb: absorbs 660nm light → pulse oximeter reads high
  - methhaemoglobinaemia → SpO2 to trend towards 85% as it absorbs 940nm light > 660nm light
  - methylene blue → SpO2 to read <65% for several minutes

Explain how oximetry can be used to estimate the partial pressure of oxygen in a blood sample: PAST QUESTION

Oximetry

- Measuring the oxygen carrying state of Hb (i.e. saturation) using its absorption of visible li
  employing the Beer Lambert law
- Can be divided into:
  - Direct co-oximetry: requires blood specimen and spectrophotometer
  - Pulse oximetry: using non invasive finger or ear probe



Principle

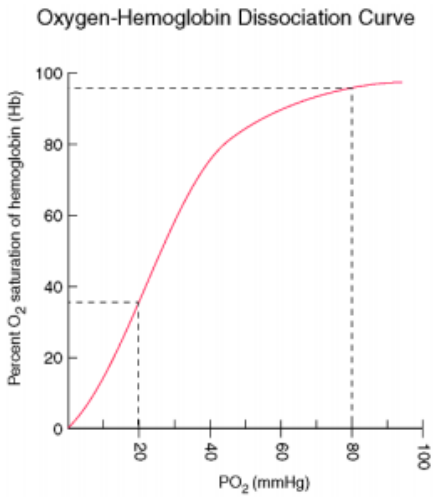
- Different Hb molecules (e.g. oxyHb, deoxyHb, metHb, carbodyHb, foetalHb) have differer
- By measuring the absorption spectrum of blood sample at multiple wavelengths → enable
- Oximetry usually measures at least 2 wavelengths:
  - oxygenated + deoxygenated Hb absorb light of different wavelengths to differer
    - DeoxyHb: red (660nm)
    - OxyHb: infrared (940nm)
  - Relative absorbance allows determination of proportion of oxy/ deoxyHb

Beer-Lambert Law

- Beers – Lamberts law describe absorption of radiation by sample in general
  - $A = \log(I_0/I_t) = \varepsilon \times c \times l$
  - Where e, I_0 and I_t = baseline and transmitted intensities, ε = molar absorptivity (a constant), c = concentration; l = path length
- I.e absorption of light passing through a substance is directly ∝to:
  - distance it travels through the substance +
  - concentration of attenuating species within the substance
- light is absorbed by artery, vein, or tissue
  - Arterial absorption = pulsatile
  - Venous and tissue absorption = constant
  - If ac = pulsatile arterial absorption and dc = non-pulsatile absorption → then R ratio = (ac/dc)red / ac/dc)infrared

O2 Hb dissociation curve

- extrapolation of PaO2 from OHDC is complicated by:
  - position of OHDC can be left or right shifted
    - RIGHT shift: ↓pH, ↑pACO2, ↑2,3DPG, ↑temp
    - LEFT shift: ↑pH, ↓PaCO2, ↓2,3DPG, ↓temp
    - Therefore need to compensate for above parameters
  - Flat top portion of OHDC
    - Small Δoxyhb saturation measured → large Δextrapolated PaO2
    - Therefore any errors in measurement of oxyhb saturation is amplified



Explain the reasons why a pulse oximeter may give incorrect readings: PAST QUESTION

Reasons for error

1. **intrinsic limitations of central processor**
   - algorithm in central processor for converting transmittance to SpO2 is usually calibrated using healthy volunteers beathing hypoxic gas mixtures with resulting sats 70-100%
   - low measured SpO2 → ↑deviation from calibration group → ↑error
     - SpO2 70-100 %→ +/- 2%
     - SpO2 50-70% → +/- 3-4%
     - SpO2 <50% → not calibrated; extrapolated
2. **Errors at probe level**
   - Error with light emission
     - Oximetry probe needs to emit light at specific wavelengths (usually 660 and 940nm)
     - Any deviation from specifici wavelengths (e.g. fault in LED) → error
     - Excessive contamination by ambient light
   - Error with signal detection
     - I.e. issue with detector (e.g. cracked)
   - Error with probe placement
     - Incorrect sized probe → e.g. doesn't cover entire finger → light "shunt" → error
     - Probe excessively compressing finger → vasoconstriction → false ↓SpO2
3. **Patient factors**
   - Vasoconstriction e.g. ↓CO states, hypothermia → ↓signal to noise ratio → false ↓SpO2
   - Venous pulsation e.g. TR
   - Movement e.g. shivering, movement disorder
   - Haemoglobinopathies
     - metHb → falsely approach SpO2 85%
     - carboxyHb → falsely high (COHb absorbs at 660nm but minimally at 940nm)940nm
     - cyanide poisoning → falsely high
   - Dyes
     - Intravascular e.g. methylene blue → falsely ↓SpO2
     - External e.g. nail polish → can falsely ↓SpO2

Gas analysis, including capnography

ABG analysis

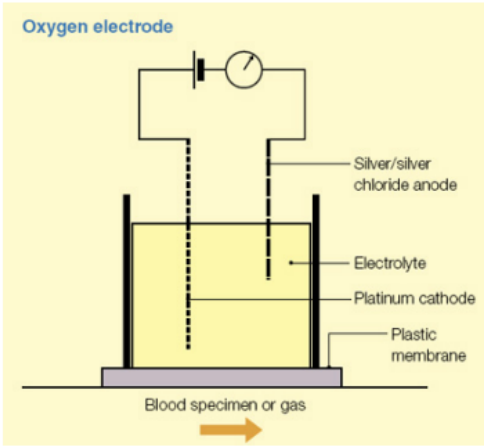
Acid base disturbance described by 3 parameters

- [H+] measured using pH electrode (measured directly)
- CO2 measured using Severinghaus CO2 electrode (measured directly)
- [HCO3] calculated from Henderson-hasselbach equation using pCO2 and pH

Describe how the partial pressure of oxygen in a blood sample is measured using a Clark electrode: PAST QUESTION 28%

Clark (polarographic) oxygen electrode measures the oxygen partial pressure in blood sample

- ***Clark electrode*** = O2 electrode
  - Cathode: platinum
  - Anode: AgCl
  - Salt bridge: KCl
    - completes electrical circuit
    - allows transport of electrons between electrodes
- External power source: applies potential difference between anode and cathode (0.6V)
- Current flow measured by movement of electrons from:
  - Anode: Ag + Cl- → AgCl + e- (oxidation)
  - Cathode: O2 + 2H2O + e- → 4OH- (reduction)
  - ↑O2 will ↑reaction at cathode → current flow (linear relationship at 0.6V)
- Plastic semi-permeable membrane
  - Separates blood from electrolyte → prevents deposition of blood cells/ proteins directly onto electrode
  - Plastic membrane allows O2 to freely diffuse across → O2 tension in blood reaches equilibrium with that in electrolyte of the Clark electrode
- Temperature buffer on monitor
  - Clark electrode needs to be buffered at known temp → otherwise electrode temp must be known and temp correction applied



Principles

- blood comes in contact with plastic membrane
- dissolved O2 diffuses across plastic membrane following difference in O2 tension
- O2 tension of electrolyte comes to equilibrium with blood sample
- O2 undergoes reduction at cathode → forms OH-, while Ag undergoes oxidation at anode
- Redox reaction produces electromotive force → produces current in circuit → measured by galvanometer
- Electromotive force i.e. redox potential ∝ to O2 tension at cathode → therefore measured current → derive redox potential → calculate O2 tension in blood sample
- Clark electrode needs to be frequently calibrated using solutions with known O2 tension in order to ensure accuracy and precision

Factors affecting accuracy

- Temp
  - Redox potentials very sensitive to temp
  - O2 electrode needs to be kept within 0.1oC of known temp
- current voltage relationship
  - at 0.6V the current-voltage relationship is relatively flat and thus less affected by small variations in applied voltage
  - large deviations from 0.6V → current voltage relationship very sensitive to small changes in applied voltage → inaccuracy
- voltage O2 tension relationship
  - at 0.6V the relationship between voltage and O2 tension is relatively linear.
  - Deviation from external applied voltage of 0.6V → non linearity in above relationship → inaccuracies
- protein deposition on plastic membrane
  - affects O2 equilibration → inaccuracy

Briefly describe the measurement of pH in a blood sample using a pH electrode: PAST QUESTION

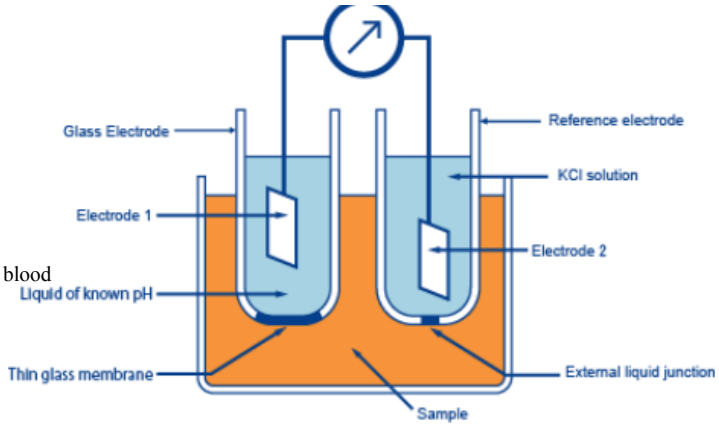
Background

- pH = $-\log_{10}H+ \sim = -\log_{10}[H+]$
- Can be measured using a pH electrode
- Principle: the electrical potential generated across a H sensitive glass membrane ∝ pH difference across that mambrane

pH electrode

Consists of:

- 2x half cells connected by galvanometer and blood to form compl
  - **LEFT** half cell = **sealed glass** electrode:
    - Ag/AgCl electrode core encased in glass
    - H+ within glass kept constant by buffer sol
    - pH sensitive glass membrane in contact wit
  - **RIGHT** half cell = **reference** electrode:
    - Ag/AgCl electrode core bathed in saturated
    - Saturated KCl provides relatively constant
    - Liquid junction – various types
    - semipermeable membrane separates it from blood
- Galvanometer: measures electrical current as a result of electromotive force
- Some pH probes also contain a temp sensor
- Sample e.g. blood



Principles

- Relies on the principle that 2 solutions with different H+ activities will develop a potential difference between them (∝ concentration gradient)
- The only variable in the circuit, given constant temp = difference in pH between buffer and sample
- When glass + reference electrodes are exposed to blood sample → forms complete circuit
- H+ passes through glass along conc gradient
  - Variable potential difference is generated in the measuring chamber, as H+ ions are buffered and conc gradient maintained
  - Constant potential difference is generated in the reference chamber, as there is no buffer of H+ ions in the KCl solution i.e. produces reference electromotive force independent of sample pH
- the difference in electromotive force between glass and reference electrode generates current in circuit → current measured by galvanometer → calculates pH of blood sample → potential difference between measuring + reference electrodes ∝ [H+] in blood ∝ pH

to maintain accuracy of pH electrode

- **calibration** against 2 known pH phosphate solutions
- system must be **temperature controlled** to 37°C
  - temp can affect activity of H+ ions and thus pH

- modern pH electrodes contain temp compensation electrode that measured temp and ajusts pH accordingly – based on Rosenthal equation: ΔpH = ΔT x -0.015
- reference electrode is semipermeable + composition of internal solution will change over time → needs **replacing**

Capnography

Capnography

Capnography = continuous measurement of [CO2] (and therefore CO2 partial pressure) in resp gas → displayed as PCO2 plotted against time

- Several mechanisms exist:
  - Infrared spectroscopy
  - Colourimetric methods
  - Rayman scattering
  - Gas chromatography
- Uses
  - Definitive test for successful placement of ETT in trachea
  - Confirmation of lung ventilation
  - Indicator of:
    - tube displacement
    - cuff or circuit leaks
    - severely ↓CO
    - rebreathing
    - ventilation inequalities
    - PaCO2
    - Waveform: obstructive pattern, ↓CO
    - Est physiological deadspace (Bohr)

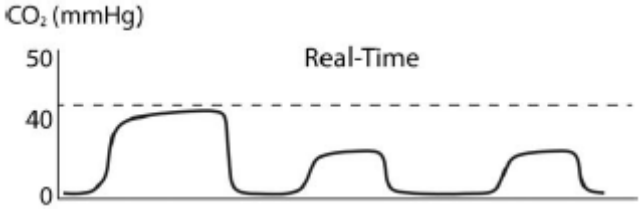


Figure 2 With a large cuff leak and controlled ventilation, gas will pass around the cuff during inspiration and expiration. Both the end tidal CO2 and the mixed expired CO2 (area under the curve) will be reduced.

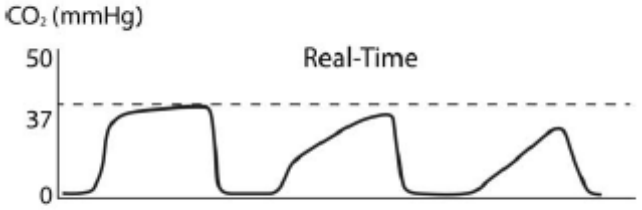


Figure 3 With airway obstruction there will be delayed mixing of expired gas containing CO2 and inspired gas, hence the sloping upstroke. The plateau will tend to slope also due to the variation in time constants of emptying alveoli.

How it works

- resp gases continuously directed past CO2 analyser (usually infrared)
- analyser measures infrared absorbance at preset wavelength
- absorbance signal sent to electric processor
- [CO2] calculated using Beer-Lamberts law
- result displayed in real time

Infrared spectroscopy

- different gases absorb different infrared wavelengths to different degrees
- IR radiation emitted by hot wire
- CO2 absorbs infrared radiation at a peak wavelength of 4280nm
- Intensity of transmitted IR radiation measured by detector
- Beer-Lambert law: A= log(Iemitted/ Idetected) = molar absorptivity x concentration x path length
  - Knowing Iemitted/ Idetected, molar absorptivity, and path legth → able to calculate for concentration of CO2
- Process repeated to allow monitoring CO2 concentration in real time

Main vs. side stream capnograph

- main stream:
  - CO2 sensor series with breathing circuit
  - Advantages: no sampling tube, no obstruction, rapid response (no delay), no alteration in circuit pressure (suitable for neonates); not affected by water vapour pressure
  - Disadvantages: adds weight to patient end; long electrical cord; sensor window may clog with airway secretions; bulker; more costly
  -
- Side stream capnograph:
  - resp gas continuously aspirated from breathing circuit and directed to external CO2 sensor
  - Advantages: cheaper, minimal weight, easier to connect, adapts to patient position, can be used with nasal prongs
  - Disadvantages: delay in signal, sample tube may obstruct, water vapour may condense in sample tube and alter PCO2, ↓pressure within breathing circuit (not used for neonates)

Causes of a difference between measured end-tidal CO2 and PaCO2

- ETCO2 = CO2 in expired gas measured at mouth or ETT at end expiration
- Normally assumed that ETCO2 = PaCO2 = PACO2
- The arterial-end tidal CO2 partial pressure difference is directly related to the alveolar dead space fraction

Causes for difference

- Can be patient or equipment + physiological or non-physiological
- Physiological causes:
  - Normal value for ET difference is 3-5mmHg
  - Due to:
    - Inherent V/Q mismatch within lung due to gravity → alveolar dead space (physiological)
    - Enghodd modification (to calculation of alveolar dead space)
- Non physiological causes
  - ↑alveolar dead space fraction
    - ↑high V/Q units (West zone 1; Palv >Pa)
    - ↑Palv: PPV, PEEP, positioning
    - ↓Pa: hypoperfusion, HPV, PE
  - ↑PaCO2
    - ↑production: MH
    - ↑absorption: circuit rebreathing, pneumoperitoneum
    - ↓elimination: hypoventilation
  - measurement errors for PaCO2
    - gas machine
    - collection problem: sampling delay, non-arterial puncture, cont with heparin
    - temperature correction
  - measurement errors for PETCO2

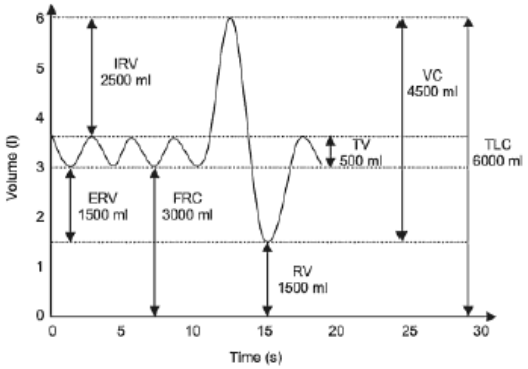
- infrared spectrophotometer problem: fluid in sample line, calibration error
- collision broadening: e.g. N2O
- non true end tidal e.g. obstructive disease with very slow alveoli

Methods used to measure respiratory function, including: o Forced expiratory volume o Peak expiratory flow rate o Vital capacity o Flow-volume loops o Functional residual capacity and residual volume

A lung volume is measured directly: spirometer or gas dilution
A lung capacity = sum of ≥2 lung volumes; therefore a derived value

4 lung volumes:

- V_T :500ml; vol of air inspired per breath during normal quiet breathing
- IRV: vol of additional air that can be inspired over and above VT: 2500ml or 45ml/kg
- ERV: vol of additional air that can be expired following normal tidal exhalation: 1500ml or 10-15ml/kg
- RV: vol of air that remains in lungs following max exhalation (i.e. after ERV): 1500ml or 15-20ml/kg



Measurement

- ERV, VT, and IRV
  - Measured directly using spirometry (flow meter)
  - Any capacity which is the sum of these (IC, VC) can therefore be calculated
- RV
  - cannot be measured by spirometry → FRC + TLV cannot be calculated
  - RV measured by:
    - Gas dilution: relies on conservation of mass + poor He solubility + no He diffusion across alveolar capillary border
    - Body plethysmography: relies on Boyles law
    - N2 washout

4 lung capacities

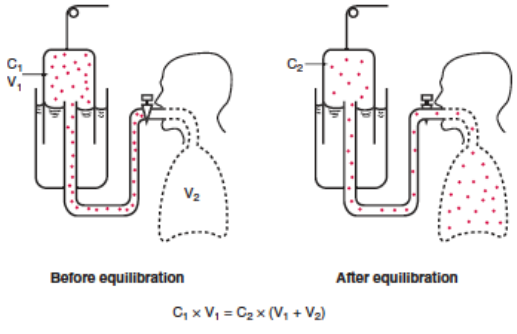
1. Vital capacity: VC = ERV + V_T + IRV = 4500ml or ~60ml/kg; VC <15ml/kg suggestive of need for ventilation
2. Inspiratory capacity: **IC = V_T + IRV**; 3000ml
3. Total lung capacity: TLC = RV + ERV + V_T + IRV = 6000ml or 80ml/kg
4. **FRC**
   a. Vol of air in lungs at end of normal expiration
   b. FRC = RV + ERV = 3000ml normal adult; 30ml/kg
   c. Physiological importance
      i. O2 reserve: buffers swings in PAO2; allows blood in pulmonary circulation to become oxygenated throughout the resp cycle; esp. relevant during apnoea
      ii. Prevention of alveolar collapse: prevents atelectasis + ↓WOB
      iii. Maintain lung volume and closing capacity

↓FRC	↑FRC
1. position: supine → ↓1L 2. ↑intraabdo pressure: obesity, pregnancy, acute abdomen, laparoscopic surgery 3. anaesthesia 4. ↓age 5. lung disease: pulmonary fibrosis, pulmonary oedema, atelectasis, ARDS	1. PEEP: 2. Emphysema: lung elastic tissue destroyed → ↓inward elastic recoil 3. ↑age: ↑quantity of lung elastic tissue 4. asthma: air trapping + high intrinsic PEEP

Measurement in more detail:

1. ERV, VT, and IRV
   - measured directly using spirometry
   - Spirometer = flow meter
     - Pt exhales as fast as possible through flow meter
     - Flow-time curve is produced
     - This curve can be integrated to find volume
   - Any capacity which is the sum of these (IC, VC) can therefore be calculated

2. RV
   - cannot be measured by spirometry as it cannot be exhaled → therefore FRC and TLV cannot be calculated
   - RV can be measured using: gas dilution, body plethysmography, or N2 washout
   - **1. Gas dilution**
     - Relies on 2 principles:
       - 1. Conservation of mass
       - 2. Poor He solubility → does not diffuse across alveolar-capillary barrier
     - Only communicating gas can be measured – therefore will underestimate FRC in gas trapping
     - At end tidal expiration a spirometer containing known [He] is opened to pt → He equilibrates between lungs and spirometer → expired [He] measured
     - From law of conservation of mass:
       - C1V1= C2V2
         - Before equilibration
           - C1 = initial concentration in spirometer
           - V1 = initial vol of spirometer
         - After equilibration:
           - total vol (V2) = V1 + FRC
           - C2 = amount of He in spirometer (lower)



- He cannot diffuse across he alveolar capillary barrier to the amount of He before equilibration = amount of He after equilibration
    - C1V1 = C2 (V1 + FRC)
    - FRC = V1 x (C1-C2) / C2

- **2. Body plethysmography**
    - Relies on: Boyles law – at constant temperature, the vol of a fixed mass of gas is inversely proportional to its absolute pressure: PxV = a constant
    - Pt sits in airtight box → pt inhales against closed mouthpiece → resp effort ↑AP diameter of thoracic cage → ↑ lung vol. Gas remaining in lung expands → as lung vol ↑s → vol in body plethysmograph ↓s by equal amount
    - 1st the Δvol in box is calculated:
        - before closure of mouthpiece, box pressure (P1) and box vol (V1) are known
        - after inspiration against closed mouthpiece, box pressure P2 is measured
        - V2 = V1 - ΔV
        - P1V1 = P2 (V1-ΔV)
    - Then the lungs are considered:
        - Before closure of mouthpiece, mouthpiece pressure (P3) is known
        - Mouthpiece coses at end of tidal expiration, so initial lung vol (V3) is FRC
        - After inspiration, mouthpiece pressure P4 is measured
        - ↑in lung vol = ↓ in box vol = ΔV (already calculated from above)
    - Therefore: P3xFRC = P4 (FRC + ΔV)
    - All values except FRC are known → therefore FRC can be calculated:
        - FRC = P4ΔV/ P3-P4
- **3. N2 washout method**
    - N2 makes up 79% of dry inspired air
    - Spirometer circuit with N2 analysewr
    - At end of tidal expiration (i.e. FRC), pt breathes 100% O2 → as pt breathes in and out, N2 is replaced by O2 → test finishes when expired N2 is <1%
    - Total vol of expired N2 is calculated from total vol of expired gas x concentration of N2 within collected gas
    - FRC = total expired N2 col x [N2]f / [N2]i where [N2f] is final fractional N2 concentration of expired gas and [N2]i is the initial fractional N2 concentration of expired gas

Body plethysmograph vs. helium dilution technique:

- Body plethysmograph measures total vol of gas in lung, including trapped behind closed airways (not communicating with mouth)
- Helium dilution method measures only communicating gas or ventilated lung vol
- In young, normal subjects these vols are virtually the same, but in patients with lung disease, the ventilated vol may be considerably less that the total vol because of gas trapped behind obstructed airways

- PFTs are used to quantify an individual pts respiratory physiology.
- clinical uses are:
    - dx of respiratory disease
    - grading severity + guide pharmacological mx
    - estimation of surgical risk esp. thoracic
- Spirometer is used. Classified as:
    - Volume sensing
    - Flow sensing

Measurement

Spirometry can measure:

- All static lung volumes and capacities except RV, TLC, and FRC
- Dynamic spirometry i.e. lung measurements that depend on flow rate:
    - FEV1
    - Forced vital capacity (FVC)
    - Peak expiratory flow rate (PEFR)
    - Expiratory flow volume curve
    - Flow volume loops

1. Forced spirometry

- simple bedside test used for dx of restrictive and obstructive lung disease
- From full inspiration, pt breathes out as hard and fast as possible into spirometer to full expiration → expiratory volume-time graph
- 2 parameters measured: FEV1 and FVC. These are compared with predicted values based on normal pts matched for age, gender, height

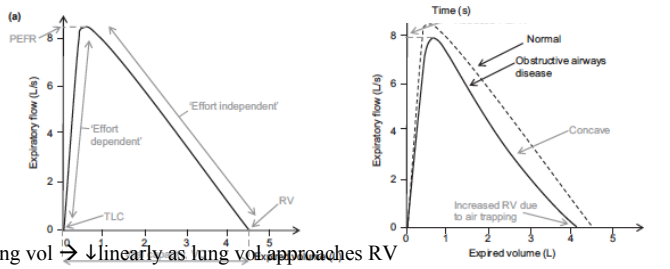
Obstructive vs. restrictive lung disorders

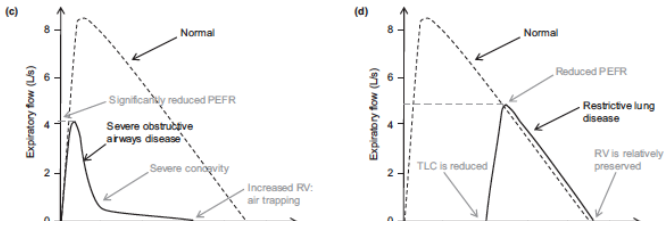
- **obstructive** airways disease (asthma, COPD)
    - FEV1 <80% predicted
    - FEV1/FVC ratio <0.7
    - Severity of disease can be assessed using FEV1
        - Mild: FEV1 50-79% predicted
        - Moderate: FEV1 30-49% predicted
        - Severe: FEV1 <30% predicted
    - Differentiation between asthma and COPD is based on reversibility of airway obstruction.
        - Forced spirometry performed before and 15mins post administration of bronchodilator → improvement in FEV1 of 400ml = significant airway reversibility → asthma
- **Restrictive** lung diseases (fibrosis, kyphoscoliosis, resp muscle weakness)
    - FEV1 <80% predicted
    - FVC <80% predicted
    - FEV1/FVC ratio >0.7 (“normal” or high)

2. expiratory flow volume *curve*

- expiratory flow plotted against expired volume

- gives additional diagnostic information
- shape of curve: due to airway radius at different lung volumes:
  - Start of forced expiration:
    - ↑lung vol → stretched parenchyma →↑airway radius →
    - Expiratory muscles generate ↑intrapleural pressure → g
    - Effort dependent: the greater the +ve Ppl generated by e
  - As forced expiration continues
    - ↓lung vol → ↓stretch on parenchyma → ↓airway radius
    - Ppl remains high → small airways compressed → ↑resis
    - Any ↑ in expiratory pressure will ↑airway resistance prc
    - Expiratory flow = effort independent → dependent on lung vol → ↓linearly as lung vol approaches RV
- normal expiratory flow volume curve
  - initial rapid rise in expiratory flow → max at PEFR = effort dependent part
  - followed by steady uniform ↓ in flow rate until all air expired = effort independent → limited by dynamic airway compression
- **obstructive** airways disease
  - ↓PEFR: small airway obstruction ↑s resistance to gas flow → ↓expiratory flow rate → ↓PEFR
  - Effort independent part = concave– degree of concavity related to severity of disease
  - RV ↑ due to gas trapping: ↑ severity → ↑↑ air trapping
- **Restrictive** lung disease
  - ↓PEFR
  - effort independent part remains linear (as there is no dynamic airway
  - ↓TLC but RV unchanged





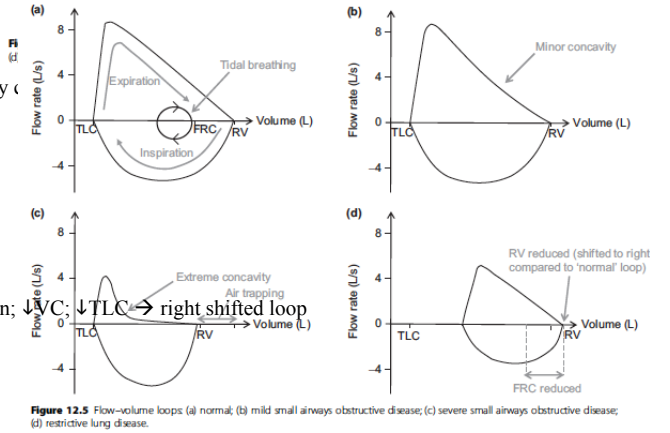


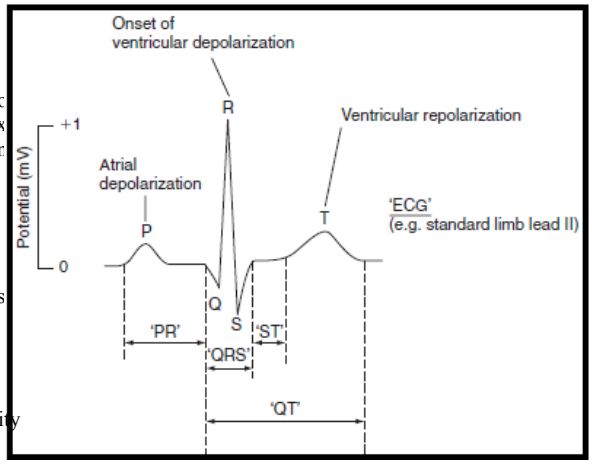
Figure 12.5 Flow–volume loops (a) normal; (b) mild small airways obstructive disease; (c) severe small airways obstructive disease; (d) restrictive lung disease.

3. Flow volume *loop*

- inspiratory flow vol curve + expiratory flow vol curve
- used if diagnostic uncertainty about location of airway obstruction
- obstructive airways disease:
  - exp portion: ↓PERF; concave; ↑RV
  - insp portion: unaffected
- restrictive airways disease
  - exp portion: ↓PEFR, normal appearance of effort independent potion; ↓VC; ↓TLC → right shifted loop
- variable extrathoracic airway obstruction
  - e.g. vocal cord palsy
  - extrathoracic = level above 6th tracheal ring
  - "variable" = airway obstruction moves with Δairway pressure throughout resp cycle
  - lung volumes unchanged
  - insp: lesion pulled into trachea → ↓insp flow
  - exp: lesion pushed out of trachea → exp flow unaffected
- variable intrathoracic obstruction
  - e.g. tumour
  - "intrathoracic" = airway obstruction at or below 6th tracheal ring
  - insp: airway calibre ↑s → insp flow unimpeded
  - exp: airway calibre ↓s → exp flow ↓

Draw the ECG depicting one cardiac cycle for lead II. Label diagram and give normal values. What is the PR interval and what factors can affect this: PAST QUESTION 50%

- Small square = 1mm = 0.04s
- Large square = 5mm = 0.2s
- HR = 300/ large squares
- P wave = atrial depolarisation
- PR interval = 0.12-0.2 → 3-5 small squares; time taken for excitation to spread thro
- QRS = ventricular depolarisation (0.06-0.1s → <3 small squares): time taken for ex
- QT interval (0.3-0.4s → <2 large squares): duration of ventricular depolarisation ar
- T wave = ventricular repolarisation



What factors affect PR interval

- same as affect pacemaker cell activity
- prolong:
  - ANS: ↑vagal tone (ACh ↑membrane K permeability and hyperpolarises
  - Cardiac: heart block, carditis
  - Physiological: hypokalaemia, hypothermia, hyper or hypo Mg2+
  - Drugs: adenosine, digoxin, CCB, BB
- Shorten
  - ANS: ↑SNS tone (NAd, ↑membrane Ca2+ permeability and ↑excitabilit
  - Cardiac: accessory pathway (WPW, bundle of kent, shorter time to depolarisation
- Variable: mobitz type II
- PR depression: atrial injury; pericarditis

ENVIRONMENTAL SAFETY

Describe microshock and macroshock and the mechanisms for preventing these, with particular reference to ensuring the compatibility of medical procedure, treatment area, and medical equipment used

Electrical principles

- Charge:
  - property of subatomic particle which causes it to experience a force when close to other charged particles.
  - Measured in coulombs (C)
- Current:
  - flow of electrons through a conductor.
  - Measured in amps (A)
- Voltage:
  - strength of the force that causes movement of electrons.
  - Quoted relative to ground (or earth).
  - If potential exists – current will flow from that object to the earth via the path of least resistance → if this path contains a person → electrical injury may result
- Resistance
  - To what extent a substance ↓flow of electrons through it
  - Measured in ohms
  - Substances with ↑resistance = insulators
  - Substances with ↓resistance = conductors
- Inductance
  - Property of a conductor by which a change in current induces an electromotive force in the conductor and nearby conductors
- Capacitance
  - Ability of an object to store electrical charge
  - Measured in Fards (F) where 1 farad = when 1 volt across the capacitor stores 1 coulomb of charge
  - Capacitor = electrical component consisting of 2 conductors separated by an insulator ("dielectric")
  - When direct current flows → electrons (-ve charge) build up on one of these conductors (plate), while an electron deficit (+ve charge) occurs on the other plate
    - Current will flow until the build up of charge is equal to the voltage of the power source
    - Current can be rapidly discharged when the circuit is changed
  - An alternating current can flow freely across a capacitor and causes no build up of charge
- Impedance
  - Describeds to what extent the flow of alternating current is ↓when passing through a substance
  - Thought of as resistance for AC circuits and is a combination of resistance and reactance
    - Reactance = function of 2 things:
      - Induction of voltage in conductors by the alternating magnetic field of AC flow
      - Capacitance induced by voltages between these conductors

Electrical safety in OT

Electrical injury

- when body contacts circuits at 2 points → electricity flows through body → potential for electrical shock + injury
- electricity causes injury in 2 ways:
  - Disrupts normal electrical function of cells e.g. contract muscles, disrupts normal cardiac/ nerve conduction
  - Converts to heat → burn
- Extent of electrical injury depends on:
  - Current: voltage; resistance e.g. wet vs. dry skin
  - Current density e.g. fraction of current passing through
  - Duration / location / timing of contact
  - Frequency
  - AC or DC (AC more arrhythmogenic)

Physiological effects of current / electrical shock

- Macroshock
  - current which will induce VF if applied to skin
  - typical current 100mA → much higher as most of this current is not going to ventricle → total current must be greater to achieve sufficient current density in myocardium to induce VF
- Microshock
  - current which will induce VF if directly applied to myocardium, but not when applied to skin
  - typical current: 0.05-0.1mA
  - requires skin breach
  - potential causes: guidewire, pacing lead, column of conducting fluid, CVC, PICC
- Effect of different currents:
  - 10-20uA: microshock VF
  - 1-5mA: tingling
  - 10-20mA: muscle spasm
  - 50mA: resp arrest
  - 100-300mA: macroshock VF
  - 1A: significant burns

Principles of electrical safety

- Power points: contain 3 wires: active 240V; neutral 0V relative to ground; earth (direct pathway into ground)
- An electrical circuit is completed between appliance and PowerStation by returning current to station via the earth = earth referenced power supply

Protection against electrical shock

can be in any part of the circuit

- anaesthetist + environment
  - high resistance PPE
  - avoid wet skin

- antistatic high impedance flooring
- ensure patient not in contact with unnecessary metal conductors
- appropriate humidity within OT (aim relative humidity >50%)
- body protected aeas = use of RCDs or LIMs
- cardiac protected areas = body protected area + equipotential eathing

- equipment
  - Insulation
    - class 1: earthed metal casing
    - class II: double insulated outer casing (does not require earth)
    - class III: internally powered
    - another classification = using max permissible leakage current (B<100uA, BF <100uA, C<10uA)
- Electricity supply
  - Earthing
    - Creates ↓resistance pathway → ↓current through body
    - ↓resistance pathway → very high current → trips circuit breaker/ fuse
    - fails when: current path through body has ↓resistance than earth; low resistance pathway created by earth cannot generate sufficiently high current to trip circuit breaker
  - Overcurrent protection devices = **fuses** or circuit breakers
    - Can only protect against large current surges (e.g. >10A)
    - Not appropriate in OT
  - Residual current device
    - Measures current difference between the active and neutral lines
      - In non fault: will be equal
      - In fault: current being delivered by active line but not returned via neutral current will instead flow to ground via faulty equipment/ through patient
      - Fault requires: current to flow
    - Will detect current leak of 5-10mA and "trip" within 10-20ms → protects against macroshock
    - Does not protect against: current going through body and back via neutral (rare); microshocks
  - Isolating transformers and isolation monitors
    - Creates an isolated power system such that neither live or neutral wires are grounded → contact with live wire and ground will not create a circuit
    - Tripping the line isolation monitor (LIM) does not break the circuit

Classification of electrically safe equipment:

- These classification of equipment according to the means of protection it provides against electric shock arising from contact with the mains electricity supply.
- these classifications are designed to limit macroshock
- Class I: Earthed
  - Any part that can contact the user is earthed to ground.
  - If a fault develops such that parts of the device that the user can touch are live, then there is a risk of shock. If the case is earthed, the path of least resistance should be via the earth wire. This will cause a large current to flow, and should blow a fuse, ceasing current flow.
- Class II: Double-insulated
  - All parts of the device that the user can touch have wwo layers of insulation around them. This reduces the chance of the device becoming liv
- Class III: Low-voltage
  - Device less than 40V DC/24V AC. This limits the severity of shock a device can deliver.

Classifcation of electrically safe areas

- B areas: protection against macroshock
  - Residual current devices
  - Line isolation supply
- BF areas: cardiac (microshock) protection
  - Equipotential earthing: all devices and the patients are earthed to each other by thick copper (i.e. low resistance) such that ny potential difference between the devices will be equalized via the path of least resistance i.e. the wire, not the patient
- Z areas: no particular protections

Outline the causes of fires and explosions in the operating suite and discuss methods for prevention and management (refer to the Resuscitation, trauma and crisis management clinical fundamental)

Describe the hazards of anaesthetic gas pollution and the methods of scavenging anaesthetic gases

Describe an active anaesthetic gas scavenging system: PAST QUESTION 5%

Scavenging

- Scavenging = the removal + safe disposal of waste anaesthesia gasses from the breathing circuit to avoid contamination of the theatre environment
- Hazards of anaesthetic gas pollution
  - important as continuous exposure of staff to anaesthetic gases has been implicated in:
    - cognitive impairment
    - spont abortion
    - infertility
    - haematological malignancy

Methods of scavenging

- systems are divided into:
  - Passive vs. active: based on whether disposal system requires power source
  - Open vs. closed: based on whether receiving system is open to atmosphere
- system consists of:
  - gas collection assembly
    - connects APL valve and ventilator relief valve → collects gas vented from the circuit
    - uses 30mm connector → prevents accidental connection to the breathing system
  - transfer tubing

- Receiving system / scavenging interface: structure depends on type of system
  - open interface
    - active scavenging systems use a pump to generate a pressure gradient drawing gas to the disposal assembly
    - scavenging system is open to air to prevent –ve pressure being transmitted to the patient
  - closed interface
    - passive scavenging systems use series of +ve and –ve pressure relief valves
    - when gas pressure in collection assembly >5cmH2O → +ve relief valve opens and gas enters reservoir bag
    - when gas pressure in disposal assembly <0.5cm H2O → -ve relief valve opens and gas enters disposal assembly
- disposal assembly

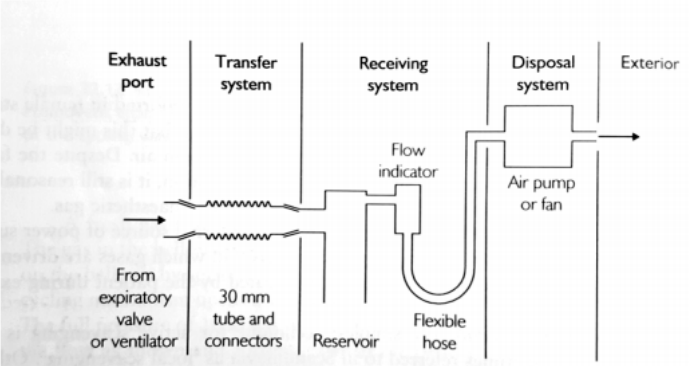


Figure 22.14 Component systems of the anaesthetic gas scavenging technique

Describe the supply of medical gases (bulk supply and cylinder) and features to ensure supply safety including pressure valves and regulators and connection systems

Production

1. **Fractional distillation**
   - O2 is produced on the industrial scale by **fractional distillation** of atmospheric air.
   - Relies on fact that different gases have different boiling points → by liquefying air and then heating gradually, each gas can be removed separately as it boils
   - Occurs in stages:
     - Atmospheric air filtered → removes dusts/ contaminants
     - Air compressed to 6atm and then cooled to < ambient temp → water vapor condenses and is removed
     - Compressed air passed through zeolite sieve → removes CO2
     - Compressed air re-expands → loses heat energy as per Gay-Lussac's Law and liquefies. Air must be cooled < boiling point of desired gases: N 77°K, O2 90°K, He4°K
     - Liquid air then fractionally distilled: temp of liquid air ↑ slowly → as boiling point of each gas reached that gas will begin to vaporize from liquid and can be collected + gases separated
2. **Oxygen concentrator**
   - Produce up to 95% O2 from air by removing nitrogen
   - Built using 2 zeolite lattices
     - Pressurized air filtered through one lattice → N + H2O vapour retained in lattice → O2 and argon concentrated → 95% O2/ 5% argon mix
     - Unused column heated to release bound N + H2O
   - Pros: cheap, reliable, avoid need for O2 delivery
   - Cons: accumulation of argon, requires continuous power; fire + explosion risk

Storage

1. **Medial gas cylinders**
   - made from chromium molybdenum or aluminium
   - used as: backup for piped supply; transport; when gas uncommonly used (e.g. nitrous oxide)
   - commonly used cylinder = CD; contains 460L of O2 at 15oC and 137bar
   - cylinders not completely filled → ↓risk overpressure + explosion if ↑temp : filling ratio = weight of liquid in full cylinder compared to weight of water that would completely fill the cylinder
   - cylinders tested for safety every 5-10 years: endoscopic examination; tensile tests; 1% destroyed to perform testing on metal
   - pros: portable + reusable
   - cons: heavy + limited supply
2. **Cylinder manifolds**
   - Forms of sets of large gas cylinders used in parallel
   - All cylinders in group are used together → when pressure ↓ below set level → pressure valve switch and gas will be drawn from another cylinder group
   - Pros: cheap + useful as backup supply
   - Cons: less capacity that VIE + fire/ explosion risk
3. **VIE**
   - Stores liquid O2
   - Vacuum insulated as must keep O2 below critical temp (-119oC) → typically stores O2 between -160oC and -180oC at 700kPa
     - Gas stored < critical temp and > boiling point
     - Amount of O2 remaining calculated from its mass
   - Doesn't require active cooling. Is cooled by: insulation + evaporation
   - Pressure relief valve to evaporate large vol of O2 rapidly if ↑demand
   - Pros: cheapest option + doesn't require power
   - Cons: set up expensive; requires back up setup; will waste large vol of O2 if not being used continuously; fire + explosion risk

Safety in medical gas supply

Many systems exist to ensure safety:

1. **Colour coding of cylinders and hoses**
   - Oxygen is white
   - Nitrogen is black

- Air is black with white shoulders
- Nitrous oxide is blue
- Helium is brown
- Heliox is brown with white shoulders
- Carbon dioxide is grey-green

2. Labelling of connections

- The pin index system
  Used to prevent the wrong gas yoke being connected to a cylinder.
  - Pins protrude from the back of the yoke
  - Holes exist on the valve block
  - Pins and holes must line up for the cylinder to be connected
  - There are six positions, divided into two groups of three
    Common combinations include:
    - Oxygen: 2-5
    - Air: 1-5
    - Nitrous oxide: 3-5
- Sleeve Index System
  Used in Australia when connecting pipeline gases.
  - Wall block contains a sleeve when prevents fitting the incorrect gas hose to the wall
  - Screw thread is identical in all cases
- Non-Interchangeable Screw Thread (NIST)
  Used (but not in Australia) when connecting pipeline gases.
  - NIST connectors have a probe and a nut
  - Probe diameter is gas-specific, preventing the wrong gas from being connected

3. Testing

- Must demonstrate
  - Correct oxygen concentrations
  - Absence of contaminatiaon
  - Delivery of adequate pressure when several other systems on the same pipeline are in use
- Testing must be performed twice on a new installation:
  - First by engineers
  - Second by a medical officer
    In theatres, this should be the director of the anaesthetic department or their delegate, who should hold fellowship of ANZCA.

Describe how the oxygen vacuum insulated evaporator works: PAST QUESTION

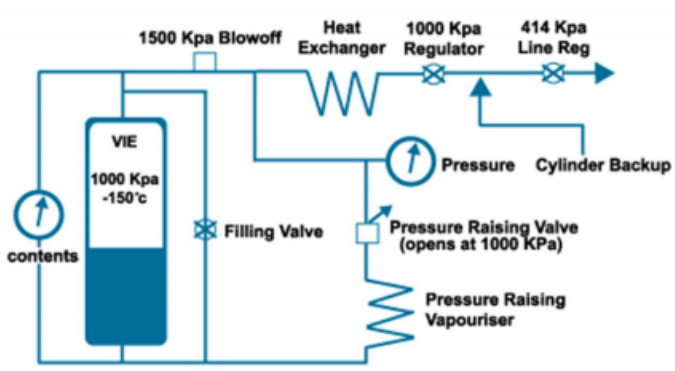
Background

- Bulk O2 supply may be stored using:
  - Cylinder manifold system
  - Vacuum insulated evaporator (VIE): more economic when requirements are high (>300L/second or >7mill L/year i.e. large hospitals)

VIE

Components

- large insulated container with double shell
  - inner shell = stainless steel
  - outer shell = carbon steel
  - space between shells = vacuum at 0.3kPa and filled with insulating powder to minimize heat transfer
- valves
  - blow off valve = prevents excessively high pressures
  - pressure raising valve and vapouriser = prevents excessively low pressures
- pressure gauges
  - internal pressure guage
  - differential pressure guage – pressure difference between top and bottom → proportional to vol of liqid O2
- system of remote alarms to indicate low contents and pressure
- heat exchanger – warms outgoing gas
- pressure regulator - ↓pressure of outgoing gas to distribution pipeline pressure (~400kPa)



How VIE works

- stores liquid O2 under pressure (1000kPa) at low temp (-150oC)
- internal temp needs to be >boiling point (-182oC at 1atm) but <critical temp (-119oC) of O2
- if internal temp >critical temp → liquid O2 boils → VIE explodes
- steady demand for O2 → liquid O2 vapourises → keeps content within VIE cool (due to latent heat of vepourisation

Effects of fluctuations in ambient temp, pressure, and O2 demand

- low demand or high ambient temp → ↑VIE temp → ↑VIE pressure
- when p >1500kPa → blow off valve opens → vaporization → cools residual content
- high demand or low ambient temp → ↓VIE temp → ↓VIE pressure
- when P<1000kPa → pressure raising valve opens → allows environmental heat to enter VIE → ↑VIE temp and pressure

Advantages + disadvantages

- advantages
  - economic for high demand
  - relatively less storage space required
  - less frequent deliveries; less manual handling
- disadvantages
  - potential for fires + explosions; burns to staff from liquid O2
  - contamination
  - wastage through blowoff valve (esp. if low demand)
  - wastage → considerable vapourisation (and wastage) required to cool delivery tube between tanker and VIE to below critical temp

Describe how medical suction is generated and how to set up and test suction systems, both fixed and portable

Describe the principles and safe operation of vaporisers

Vaporisers

- allows safe dose of anaesthetic agent to be given

Divided into:

1. **variable bypass vaporisers**
   - air fully saturated with gas is mixed with a bypass stream of gas → diluting delivered concentration
     i. plenum:
     - designed to deliver accurate agent conc over wide range of flow rates
     - requires supra-atmospheric pressure to operate

     ii. draw over:
     - less accurate
     - less thermally stable
     - driven by pt insp effort
   - aim to deliver same concentration of anaesthetic agent over range of flows. Achieved by:
     - Flow management:
       - baffles + wicks ↑SA of liquid/ gas interface → ↑rate of vaporisation
     - Temp management:
       - Temp stabilisation: use of materials with high thermal conuctivity + specific heat capacity → vaporising chamber buffers Δsurrounding temp
       - Temp compensation: adjusts flow into either vaporising chamber or bypass chamber to account for Δenvironmental temp e.g. bimetallic strip, aneroid bellows
2. **Measured flow vaporisers**
   - Have a separate stream of agent-saturated gas that is added to the gas flow
   - Requires device to:
     - Measure fresh gas flow rate
     - Adjust vapour-gas flow rate so desired conc achieved
   - E.g. des
     - Des has:
       - high SVP: requires high bypass flow rate to dilute to clinically useful conc
       - low boiling point: intermittently boils at room temp → large fluctuations in delivery
     - Tec6 vaporiser:
       - Heats des to 39oC
       - Gaseous des added to fresh gas flow: amount depends on desired conc, gresh gaas flow rate

Safety features of vaporisers

- agent specificity
- single agent administration: interlock mechanism
- tipping and overfilling: heavy construction; transport modes
- anti-pumping: valves; chamber inflow
- agent depletion: filling gauges; low pressure alarms

Summary of factors affecting vaporiser output

- flow through vaporising chamber vs. bypass
- efficiency of vaporisation: wicks + channels
- temperature: ↑temp → ↑output unless compensatory mechanism used
- time: heat lost → ↓output concentration over time
- Δcarrier gas flow rate
- carrier gas composition: Δviscosity + density
- ambient pressure + ΔSVP

Describe and classify breathing systems used in anaesthesia. Evaluate their clinical utility and hazards associated with their use.

Describe the circle breathing system: PAST QUESTION

Circle breathing system =

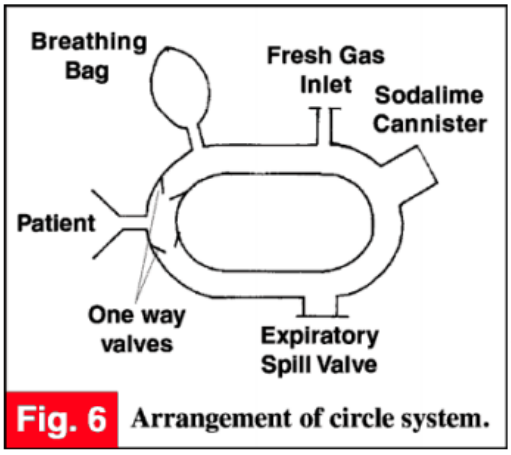
- closed (or semi closed) circuit used to deliver O2 + anaesthetic gases
- eliminates CO2
- Involves recirculation of patients resp gases

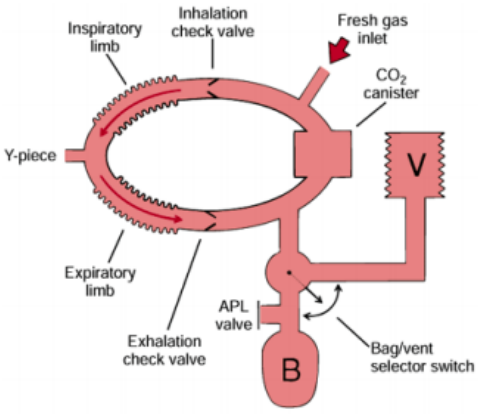
Components

- Fresh gas inflow: provides O2 to match consumption; provides gas flow to wash out expired gas
- Inspiratory and expiratory tubing: conducts gas frlow
- Inspiratory and expiratory unidirectional valves: ensures unidirectional flow and prevents mixing of insp and exp gases → ↓rebreathing
- Y connector: separates insp and exp limbs
- Adjustable pressure limiting (APL) valve: prevents high pressures within circuit; prevents patient subject to high pressures
- Reservoir bag: stores gas between resp cycles; provides tactile feedback of respiration, enables circuit to be manually pressurized
- CO2 absorbed: removes expired CO2 from circuit

Other non essential components

- ventilator
- flow meters
- vaporizer
- out of circuit sampling line + gas analyser
- heat + moisture exchanging filter





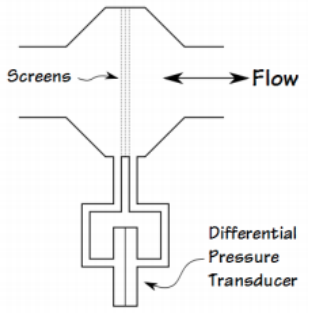
Arrangement of components may vary depending on manufacturer. NB must be able to draw

Advantages
- constant inspired concentrations
- conserves heat and humidity
- allows low fresh gas flow rates
- rebreathing of anaesthetic gases → ↓cost and pollution

disadvantages
- complex and prone to malfunction/ leaks
- ↑deadspace

Outline the principles of a pneumotachograph. What factors affect the accuracy of this device? PAST QUESTION

Pneumotachograph
- used to measure resp airflow
- indirectly derives rate of gas flow by measuring pressure differential across a barrier of known resistance
- **Flow** = amount of gas moving past a given point per unit time



How it works
- barrier e.g. gauze of known resistance placed in path of gas flow
- Resistance to airflow casued by gauze screen causes small ↓pressure across gauze
- Pressure change measured by transducer (amplified by Wheatstone Bridge) which converts pressure change into electrical signal
- as resistance is known, instantaneous flow rate could be calculated
- flow vs. time curve constructed → integration of curve = volume

Assumptions
- laminar flow: **Poiseuilles law of laminar flow** i.e. flow rate direcyly ∝ to pressure drop across barrier
- proportionality constant relating to pressure drop and flow rate is resistance (which is a known constant)
- Hagen Poiseuille equation

$$Q = \frac{\Delta P}{R} \quad \text{and} \quad R = \frac{8\eta L}{\pi r^4}$$

where,
Q = flow rate; ΔP = pressure drop; R = resistance
η = gas viscosity; L = resistor thickness; r = resistor pore radius

Factors affecting accuracy
- Deviation from laminar flow
  - Poiseuille law of laminar flow no longer holds → flow rate and pressure drop no longer follow simple linear relationship
  - Laminar flow more likely when Reynolds number is low (<2000)
  - Re = flow rate x vessel diameter x gas density / gas velocity
- Resistance deviates from known constant
  - For laminar flow: R = 8nL/ πr4
  - Variations in above parameters → alters resistance → introduces error in calculated flow rate
  - I.e. alterations in viscosity of gas: ↑n → ↑resistance
- Errors in measurement + errors introduced by measurement
  - If flow too low → resistor results in large ↓flow rate → introduces error in measured flow rate
  - If flow rate too ↑ → resistor results in very small pressure differential → difficult to accurately measure → error introduced

Different types
- Fleish pneumotachograph → fine bore parallel tubes
- Lilly/ screen pneomotachograph → layer of metal or plastic gauze
- Pilot tubes → 2 pressure ampling tubes in the centre of gas flow measure the potential different between the upstream and downstream (static) pressures

What are the normal accuracy ranges of pneumotachograph?

Describe different systems to deliver supplemental oxygen and the advantages and disadvantages of these systems

Devices for delivery of O2 classified as:

Variable performance devices

- do not deliver a fixed FiO2
  - resp flow is non-uniform
  - delivered FiO2 is dependent on O2 flow and inspiratory flow → ↑O2 flow rate will ↑FiO2, but the effect will vary depending on the device (vol, seal) and the patient
  - facemasks all deliver fresh gas flow <30L/min → intrainment of air
- Examples
  - **Nasal cannulae**
    - Prongs delivery gas at 1-4L/min
    - Flow >4L may dry mucosa → epistaxis
    - Nasopharynx acts as O2 reservoir
    - Well tolerated: allow eating/ drinking/ talking
  - **Hudson mask**
    - Simple, unsealed mask
    - Allow gas flow 5-15L/min; FiO2 25-60%
    - Flow <5L/min may result in CO2 rebreathing
    - Cheap; less well tolerated; rebreathing may occur
  - **Non rebreather**
    - Hudson mask + reservoir
    - Flow up to 12-15L
    - One way valve diverts O2 flow into reservoir during expiration → during inhalation, contents of reservoir + high flow of O2 → ↓entrainment of air → ↑FiO2 50- 80 %

Fixed performance devices

- theoretically deliver a fixed FiO2
- usually flow limited as well; so FiO2 may ↓at ↑inspiratory flows
- include:
  - **Venturi**
    - Consists of simple face mask with O2 inflow device. Apertures on the side of the cone entrain room air
    - Air is entrained via:
      - Frictional drag of molecules
      - **venturi effect**: widening of the cone → ↑fluid velocity and therefore ↓pressure as per the **Bernouli principle** (based on law of conservation of energy)
      - Entrained air ∝ flow rate → so ratio of O2 to air is constant for any given aperture size = "entrainment ratio"
      - Will deliver the specified FiO2 provided O2 flow is > minimum rate → therefore they become variable performance devices when insp flow greatly > O2 flow
      - FiO2 24-50% depending on size of orifice, O2 inflow rate, patient insp flow rate, and degree of seal

Outline how CO2 is absorbed in a circle system and the hazards associated with the use of CO2 absorption

Soda lime

- Consists of granules of:
  - 81% Ca(OH)2
  - 4% NaOH
  - 15% H2O
  - silicates: hardens granules
  - pH indicator: visual representation of uptake of CO2 by sodalime
- absorb CO2 → ↑pH of soda lime → pH indicator changes colour
- 100g soda lime can absorb 26L CO2
- Pros: cheaper to operate; conserves gases, heat and moisture; low dead space, ↓greenhouse effects
- Cons:
  - gas mix settings not delivered ot the patient
  - Nitrogen may build up in the circuit during low flow anaesthesia → potential delivery of hypoxic gas mix
  - Less portable than open circuit systems
  - ↑circuit resistance
  - requires soda lime which can be toxic: produces compound A-E from sevo and CO from des, iso, and en

Describe when a level 1 anaesthesia machine check is required. (Refer to College professional document PS31 Recommendations on Checking Anaesthesia Delivery Systems)

Anaesthesia delivery system = any equipment that can deliver vapours, LA, or IV anaesthetic agents to induce or maintain anaesthesia

Principles

- each facility is required to designate an individual responsible for:
  - servicing + maintaining equipment in accordance with guidelines
  - ensuring training in checking + use of delivery systems
  - maintaining up-to-date checking protocol
- Servicing should be: regular + recorded + displayed
- System alarms should comply with college statement on *Minimum Safety Requirements for Anaesthetic Machines and Workstations for Clinical Practice*
- System monitoring should comply with *PS18 Recommendations on Monitoring During Anaesthesia*

Anaesthesia delivery system checks

3 levels of checks

Level 1:

- detailed check; performed by trained service personnel of all systems before being placed into use – applies to all new systems + systems after servicing/ repair
- Check performed on following components:

- **Gas delivery device:** Leaks; Gas pipelines connected correctly; Non-return valves; O2 failure warning devices + gas shut off systems; Composition + flow rates of delivered gases; Electrical safety
- **Inhalational anaesthesia delivery device**: No leaks; Thermostat function; Vapour concentration; Interlocking mechanisms; Batteries / electrical safety
- **Ventilators**: Mechanical integrity; Pressure + volume delivery; Alarm functions; Batteries / electrical safety
- **IV and LA delivery devices**: Mechanical integrity; Calibrate output accuracy; Calibrate occlusion pressure; Check alarm functions; Battery / electrical safety
- **Associated equipment**: Waste scavenging system; Patient suction system
- **Documentation**

Level 2:

- **performed at the start of each list**
- Check performed on following components:
  - **service label**
  - **high pressure system**
    - reserve O2 cylinder: pressure, content, no leak
    - gas supply lines: pressures, reserve cylinders turned off
  - **low pressure system:** flow controls: flow indicators; O2 supply failure warning + antihypoxic delivery system
  - **inhalational anaesthesia delivery devices (vaporisers):** electricity connected; anaesthetic liquid level within limits; filling ports sealed; correct seating, locking, and interlocking of detachable vaporisers; test for circuit leaks
  - **Breathing systems:** Indicator colour of CO2 absorbent; Leaks: test pressure >30cm H2O at gas flow 300ml/min; Integrity of circle breathing system: connect breathing bag to Y-piece → vent manually; Compliance
  - **Automatic ventilation system**
  - **Scavenging system**
  - **Emergency ventilation system**
  - **IV and LA delivery system:** Appropriately powered; Drug container correctly loaded and labelled; Correct: syringe/ container type + vol; anaesthetic drug concentration; flow rate and units; alarm parameters
  - **Other**
    - Airway adjuncts
    - Suction
    - Breathing gas analysis devices
    - Monitoring equipment, esp. alarm limits + calibration
    - IV infusion devices
    - Humidifiers + circuit filters
  - **Final check:** Vaporisers turned off + breathing system purged with air or O2
  - **Documentation**

Level 3:

- performed before commencing anaesthesia for each patient
  - check vaporiser
  - breathing system
  - IV or LA devices
  - Other apparatus

Discuss the safety of methods for maintaining body temperature during anaesthesia and sedation, including active warming of patients

Body temp during anaesthesia

Background

- responses to ambient temp outside thermoneutral zone
  - Behavioural
  - ↓heat loss: peripheral vasoconstriction; shivering thermogenesis; non shivering thermogenesis
  - ↑heat loss: activation of sweat glands; peripheral vasodilation
- Effect of anaesthesia on thermoregulation
  - Degree of hypothermia depends on: dose of anaesthesia; neuraxial anaesthesia; surg exposure; ambient temp; patient factors
  - GA = absence of awareness; includes LOC / hypnosis +/- muscle relaxant
    - Widened interthreshold range
    - Heat redistribution: ↓metabolic heat production; ↑heat loss
    - Inability to effect response
  - 3 phases of intraop hypothermia:
    - redistribution: ↓1oC CBT <1st hour 2o peripheral vasodilation
    - linear: gradual linear ↓over 2-4hrs: heat loss >metabolic heat production
    - plateau: heat loss = metabolic heat production
  - Post op: CBT restores to baseline over 2-5hrs

Warming units

- Bair hugger therapy: forced air warming product
- Blood/ fluid warming system
- Insulators: prevent heat loss due to radiation and convection – sheets, jackets, leggings

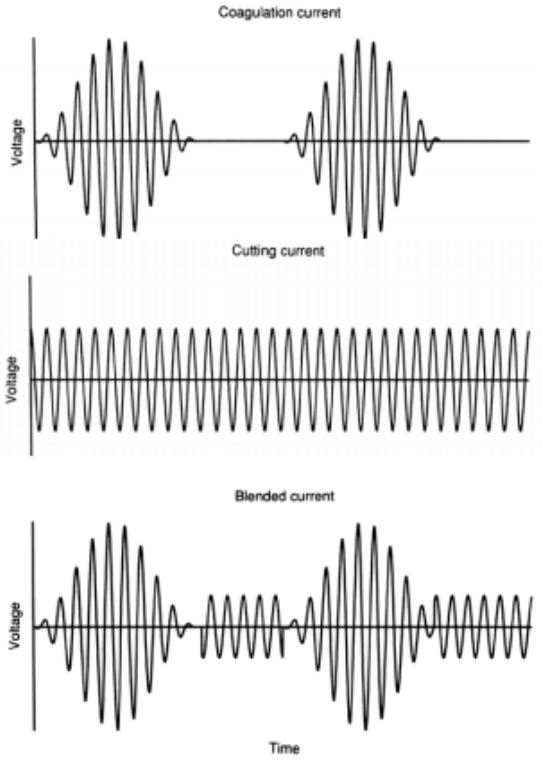
Discuss the principles of surgical diathermy, its safe use and the potential hazards

Diathermy

- use of an electrical current to cut tissue + coagulate blood via localised heating

Principles

- When voltage applied across body → current flows either producing heat or effects depending on current + frequency
    - Low frequency + low current → heat
    - Low frequency + high current → muscle contraction, arrhythmias, electrocution
    - High frequency + low/ high current → heat
    - Diathermy: uses high frequency, alternating current passing between 2 electrodes
- heat produced ∝ to electrical power dissipated (I^2R)
    - relies on principle of current density
        - current density = current per unit area
        - high current density at electrode → tissue damage
        - low current density e.g. at plate of unipolar electrode → heating without damage
    - Heating power = I^2xR



Diathermy types

- unipolar
    - consists of probs containing 1 electrode + large plate (placed on patient) containing other probe
- bipolar
    - consists of pair of forceps with each point containing a separate electrode
    - ↓current passing between probes
    - used when diathermy on electrically sensitive tissues e.g. brain

Modes

- cutting: low voltage mode producing high current in shape of continuous sine wave
- coagulate: high voltage mode producing damped sine wave response
- blended: mix of cutting and coagulate in different tissues

Risks

- burns / electrocution
    - Diathermy burn: accidental activation of diathermy, break in cables/ circuit → prevent by storing diathermy electrode in insulated quiver when not in use
    - Poor contact with neutral patient plate → stray capacitance → allows electrical circuit to be completed via other pathways (operating table, floor, equipment) → burn
    - Alcoholic skin prep + other flammable agents → ignition/ explosion
    - Chanelling effect → organ being diathermied has attachment or pedicle → concentrates current → ↑current density in pedicle → potential damage to blood vessels
- electrical interference:
    - frequencies can interfere with monitors e.g. ECG (overcome by low pass electrical filters)
    - may interfere with PPM/ AICD function → inappropriate firing/ pacing (overcome by appropriate positioning of neutral patient plate; bilpolar safe than monopolar
- smoke production: resp irritant
- tissue dissemination: potential source of metastatic seeding
- tissue damage: excessive necrotic tissue; ischaemia; perforation of viscus

Describe the principles of surgical lasers, their safe use and the potential hazards

Laser

- device for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation
- laser light is:
    - non divergent/ collimated: all photons move in parallel
    - coherent: all photons are in phase
    - monochromatic: all photons have same wavelength
- Clinically used for:
    - Precise incisions: destruction of cells by localised vapourisation of water
    - Destruction of chemicals: tattoos, oncological drugs
    - Tissue destruction without heating: ophthalm

Principles

- method
    - energy source is passed through a lasing medium, housed in a resonator made of mirrors
    - as lasing medium is excited → electrons enter higher energy level → when >50% electrons are at higher energy level, population inversion has occurred
    - as electrons falls back to resting state → release photon
        - spontaneous emission occurs when an electron enters its resting state spontaneously
        - stimulated emission occurs when electron enter resting state after being struck by a photon released from spontaneous emission → result in amplification of light release
    - mirrors in the resonating chamber ensure most light is reflected back into the chamber → ↑stimulated emissions
    - the exit form the chamber can be adjusted so only certain polarities of light are emitted
    - lasers may be:
        - pulse wave: use short busts of laser light to ↓collateral damage
        - continuous wave: may lead to excessive heating

Pros

- precise surgery + haemostasis

cons

- require multiple safety precautions
    - laser safety officer
    - eye protection
    - warning signs on doors/ cover theatre windows
    - non combustible drapes
    - matte finish on equipment to ↓chance of relection
- additional risks in airway surgery
    - use lowest FiO2 possible

- avoid N2O
- consider use of heliox
- use specialised lasertubes: normal PBVC ETT are combustible

Outline the pharmacology of radiological contrast agents

Intravenous contrast divided into:

- **x-ray contrast**
  - based on tri-iodinated benzene ring which absorbs x-ray radiation
  - alterations to this ring alter toxicity, lipophilicity, and elimination
  - agents classified by these structural differences into:
    - ionic
      - strong acids; water soluble due to ionisation
      - further divided into: monomers; dimers
    - non ionic
      - water soluble due to hydrophilic side chains
      - lower MW than ionic
      - monomer: agent of choice for angio; water soluble at physiological pH
      - dimer: harder to inject 2o to ↑viscosity; typically used for urography
  - renally eliminated
- **gadolinium contrast**
  - Gd3+: 7 unpaired electrons → paramagnetic and alters magnetic field of MRI
  - Free gadolinium = nephrotoxic and must be chelated → ↑solubility + allows to be renally eliminated
  - Also attenuates xrays but not used as x-ray contrast as doses required would be toxic

Adverse reactions

- Adverse reactions to low somolarity agents = common (3%); severe reactions rare (0.04%) and fatal extremely rare (1:170 000)
- General adverse reactions
  - Chemotoxicity: platelet inhibition; ↑VA tone (-ve inotropy/ -ve chronotropy)
  - Ionic toxicity: cellular membrane dysfunction; may worsen MG
  - Oxmotoxicity: pain, emesis, ↑PAP, ↓PVR
  - Hypersensitivity reaction: <20mins of injection
- Risk factors:
  - Asthma/ atopy
  - Critically ill
  - Cardiac/ renal disease
- Contrast nephropathy
  - ↑Cr by 25% above baseline <3days of IV contrast administration
  - MoA: osmotic stress + direct tubular toxic effects → renal tubular injury → ATN
  - Typically benign; Cr usually to baseline <10-14d
  - Significant uncertainty as to whether contrast media does cause AKI
  - Rehydration + vol correction = effective in preventing ↑Cr