Ho Medical ANAESTHESIA

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Clinical Measurement

Physiol-06B12 Explain the difference between viscosity and density. Outline the effects of changes in viscosity and density on the flow of gases and liquids.

1. Viscosity (η): the property of a gas or fluid's internal resistance to flow to the friction forces between sliding layers of fluid. This is more properly called the dynamic viscosity.
    a. Equation: $\eta = (F/A)/(dv/ds)$
    b. Units: $N.sec.m^{-2}$
    c. Temperature: ↑ gas viscosity, ↓ liquid viscosity

2. Density (ρ): relates the mass of a substance to its volume
    a. Units: kg/m^3
    b. Temperature: ↓ gas density, ↓ liquid density

These properties are independent for gases.

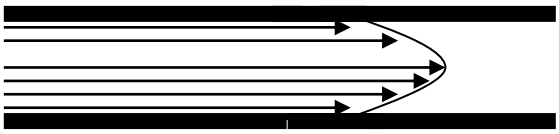
	Viscosity	**Density**
O_2	1.11	1.11
Entonox (70%N_2O, 30% O_2)	0.89	1.41
Heliox (80% He, 20% O_2)	1.08	0.33

3. Flow: describes the quantity of fluid/gas passing through a point per unit time. In clinical anaesthesia, this can be either laminar or turbulent. The density and viscosity of gas/fluid influences whether flow is laminar or turbulent, and also the quantity of each type of flow. Type of flow given by Reynold's number:

$$\mathbf{Re} = \frac{\mathbf{2rv\rho}}{\boldsymbol{\eta}}$$

Re > 2000 turbulent flow likely
Re < 2000 laminar flow likely

    a. Laminar flow: describes flow of a fluid/gas in smooth, parallel layers with no turbulence, eddies or branches. This occurs such that flow at the centre is twice flow at the walls.



        i. Equation – Pouiselle Hagan: linear relationship between pressure and flow

$$\mathbf{Q} = \frac{\mathbf{\Delta P \times \pi r^4}}{\mathbf{8\eta L}}$$

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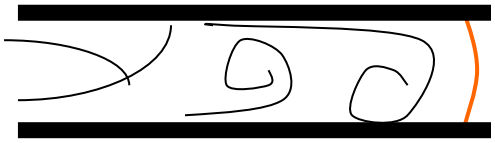
ii. Viscosity has an inverse relationship with flow. Density does not affect laminar flow. ↑η → ↑ R → ↓ Q
iii. Clinically:
    1. Laminar flow in smaller airways – entonox will tend to ↓ pressure gradients and ↑ flow (↓ viscosity), but it will make turbulent flow more likely (↑ density)



b. Turbulent flow: describes disorganised flow consisting of swirls, eddies and large scale lateral movements creating a square wavefront.

i. Equation: Pouiselle-Hagan formula no longer applicable. Instead:

$$\mathbf{Q = \frac{k\, r^2 \sqrt{\Delta P}}{\rho L}}$$

ii. Density has an inverse relationship to turbulent flow. Viscosity has no effect.
iii. Clinically:
    1. Turbulent flow in upper airways – heliox given in exacerbation of COPD due to ↓ density in turbulent flow → ↓ P and ↑ flow. Also, helium ↓ Re number → ↑ laminar flow.

Laminar	**Turbulent**
$\Delta P \alpha Q$	$\Delta P \alpha Q^2$
$\Delta P \alpha \eta$	$\Delta P \alpha \rho$
$\Delta P \alpha L$	$\Delta P \alpha L$
$\Delta P \alpha 1/r^4$	$\Delta P \alpha 1/r^5$

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Physiol-04A14/97B6 Briefly describe the differences between laminar and turbulent flow. List the factors that increase the probability of turbulent flow.

1. Flow is the measurement of amount of substance moving through a point (usually a tube) per unit time.

2. Laminar flow: describes flow of a fluid/gas in smooth, parallel layers with no turbulence, eddies or branches. This occurs such that flow at the centre is twice flow at the walls. This is due to the frictional forces between layers of moving fluid.
    a. Equation: Poiseuille Hagan: linear relationship between pressure and flow

$$\mathbf{Q = \frac{\Delta P \, x \, \pi r^4}{8 \eta L}}$$

    b. Linear relationship between pressure vs. flow

3. Turbulent flow: describes disorganised flow consisting of swirls, eddies and large scale lateral movements creating a square wavefront.
    a. Equation: Poiseuille-Hagan formula no longer applicable. Instead Fanning equation can be used –

$$\mathbf{\Delta P = \frac{Q^2 \rho L}{4 \pi^2 r^5}}$$

$$\mathbf{Q = \frac{\sqrt{4 \pi^2 r^5 \Delta P}}{\rho L}}$$

    b. Exponential relationship between pressure and flow (↑ WOB at higher flows)

4. Factors determining type of flow: the probability of flow can be determined by the Reynold number:

$$\mathbf{Re = \frac{2 r v \rho}{\eta}}$$

Re > 2000 turbulent flow likely
Re < 2000 laminar flow likely
Branching – turbulence at branch points
Velocity – critical velocity exists beyond which only turbulent flow occurs

    a. Clinical:
        a. Laminar flow: small cylinders, lower density, velocity, high viscosity –
            i. Small airways, heliox
            ii. Small vessels veins > arteries
            iii. Fluid through cannulas

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b. Turbulent flow: large cylinders, multiple branching, high velocity and density, low viscosity.
    i. Larger airways, trachea, COPD
    ii. Large vessels (aorta), anaemia (↓η)

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MAKE-UP: Briefly discuss the different methods used in blood pressure measurement

Method	Principle	Equipment	Assessment
Pressure gauges			
Liquid manometer	Pressure on mass of liquid changes height of a column of liquid.	Glass column Water (upward) or mercury (downward meniscus)	
Anaeroid gauge	High pressure causes a tube to uncoil → moves a pointer	Bourdon gauge Bellow	
Strain gauge	Movement of flexible diaphragm causes change in resistance. Calibrated to measure pressure change	Wire strain gauge Silicon strain gauge Optical Capacitance Inductance	
Non-invasive Manual			
Riva-Rocci cuff + manometer + aneroid gauge + detector	Cuff exerts external pressure (Starling resistor) which alters blood flow through an artery at various landmarks – SBP, DBP. Korotkoff sounds: I – sound appears → SBP II – sound quieter III – rise volume IV – muffling V – loss of sound → DBP	Riva-Rocci cuff Tubing + bulb Mercury manometer OR Anaeroid gauge Detector – stethoscope, microphone, Doppler	Accuracy: SBP slightly lower than direct measurement; DBP poor correlation. Problems: leaks from cuff, wrong size Anaeroid gauge needs calibration. Patient: AF, obesity, profound hypotension, arteriosclerosis.
Von Recklinghausen oscillotonometer	2 overlapping cuffs are connected by 2 tubes to 2 aneroid bellows. Bellow connected to lever system → pointer. One cuff controls pressure One cuff senses SBP → needle sings to make abrupt ↑ amplitude MAP → maximal oscillation of pointer DBP → sudden ↓ amplitude	2 cuffs 2 tubes 2 aneroid bellows Pointer display	Difficult to use Inter-observer error SBP, MAP reasonably accurate DBP inaccurate
Non-invasive Automated			
Automated oscillometric – DINAMAP	Single cuff occludes arterial flow, then deflated. SBP – sudden ↑ oscillations MAP – maximal oscillations DBP – abrupt ↓ oscillations	Cuff Transducer Display module	SBP accurate MAP, DBP less accurate Intermitted readings, no monitoring possible Affected by obesity, AF, ↓BP.
Penaz technique	Pulsatile change in blood volume of finger is detected by a photoplethysmograph. This varies pressure to maintain constant volume in finger.	Photoplethysmograph	Continuous BP monitoring. Reasonable accuracy. Underestimation in ↓BP. Clamping is painful,

	Systole → ↑ volume → ↑ pressure → ↑ absorption IR light		causes venostatis and ↑ risk pressure sores.
Arterial tonometry	Sensor placed on skin over radial artery → pressure causes flattening of artery → detect transmitted pressure change through skin.		Constant monitoring with pressure waveforms.
Invasive			
Invasive pressure monitor	Blood pressure changes pressure of a saline column → diaphragm converts pressure into electrical signals via strain gauge.	Intra-arterial catheter tip Transducer with diaphragm Strain gauge Wheatstone bridge Bag pressurised heparinised saline	Static accuracy requires zeroing, calibration, gain. Dynamic accuracy requires consideration of damping, resonance.

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Physiol-07A15 Describe the effects of resonance and damping on an invasive arterial blood pressure tracing.

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1. Invasive arterial blood pressure monitoring requires accurate dynamic calibration. This is dependent on 2 parameters:
    a. Resonant frequency
    b. Damping co-efficient

2. Resonance frequency (f_0): frequency at which a system oscillates when disturbed (similar to its natural frequency) → if resonant frequency = natural frequency → amplification of disturbance signal.

    a. Principle: Normal values for BP system 1-3Hz (60-180bpm). The BP wave consists of a fundamental frequency wave (the pulse wave), as well as larger frequency waves (harmonics – Fourier principle). If the oscillation of the transducer system at the same frequency as the harmonic component of the arterial waveform, resonance will occur → system disturbance → excessive amplification → reading distortion.
    ↑ *resonance frequency* → ↑ *accuracy*
    b. Factors:
        i. Resonance frequency ↑:
            1. ↓ length
            2. ↓ compliance of tubing and diaphragm,
            3. ↓ density of fluid
    c. Correct measurement:
        i. Maximal frequency response is 2/3 resonant frequency → 10th harmonic 2/3 f_0 → calculated by PR / 4 Hz.

3. Damping: the tendency of a system to extinguish oscillations via viscous and frictional forces within the system.
    a. Principle: the ratio of magnitudes of consecutive oscillations (damping coefficient).
        i. 0 – no ↓ oscillations over time
        ii. 1 – falls to baseline → no overshoot (critical dampening), time delay
        iii. 0.64 – optimal dampening with balance to minimised overshoot, and preserve speed of response.
    b. Factors and effect:
            1. Damping ↓ by: ↓length, compliance, viscosity, volume displacement and ↑ diameter, ↑ fluid density.
    c. Effects:
        i. Over-damping –
            1. Results:
                a. As frequency ↑ → amplitude underestimated → SBP underestimated, DBP overestimated
                b. MAP unaffected
                c. ↓ nature frequency of system → ↑ likelihood resonance
            2. Causes: bubbles in fluid, clot cannula, excess tubing, kinks

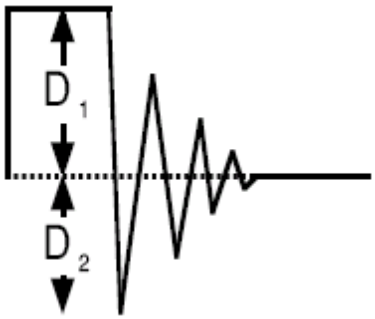
ii. Under-damping –
    1. Results:
        a. As frequency ↑ towards resonant frequency → amplification and distortion of waveforms → SBP overestimated, DBP underestimated.
        b. MAP unaffected

iii. Optimal damping – D = 0.64
    1. Tubing is short, non-compliant, kink-free, with a low density fluid (heparinised saline, free of clots and bubbles)
    2. Results:
        a. Optimal frequency response – all harmonics up to 2/3 of f_0 reproduced within 2% of original amplitude.
        b. Minimal amplitude distortion - <2% up to 2/3 resonance frequency
        c. Minimal phase distortion – describes time delay occurring from occurrence of pressure wave, and display on monitor. At D = 0.64 → phase delay proportional to frequency.

4. Dynamic accuracy:
    a. Measured by Fast flush device
    b. Damping ratio:

$$\beta = \sqrt{\frac{(\ln \frac{D_2}{D_1})^2}{\pi^2 + (\ln \frac{D_2}{D_1})^2}}$$

    c. Optimal dampening – β = 0.64
    minimises distortion of wave form at up to 2/3 resonance frequency



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Physiol-03A13/00B2/96/92 Briefly describe the principles and sources of error in the measurement of systemic arterial blood pressure using an automated oscillometric non-invasive monitor.

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1. The automated oscillometric non-invasive monitor is the standard non-invasive technique for monitoring arterial blood pressure in anaesthetic practice.

2. Principles of operation:
    a. Components:
        i. Cuff with inflatable bladder
        ii. Air pump for inflation and valve for deflation
        iii. Pressure transducer in control box
        iv. Results display
        v. Tubing connecting above components
    b. Method:
        i. Attach appropriate size cuff to patient upper arm with middle over the brachial artery
        ii. Inflate cuff to pressure > estimated SBP
        iii. SBP: onset of oscillations (usually 25-50% maximum)
        iv. MAP: maximal amplitude of oscillations
        v. DBP: plateau of oscillations OR derived value where DBP = 4SBP-3MAP

3. Sources of error:
    a. Machine error:
        i. DBP cannot be accurately assessed (plateau of oscillations, which may continue for a significant time < DBP) and is often derived.
        ii. Intermittent readings: unable to follow rapid changes in BP
    b. Cuff error: ideally cuff width should be 20% arm length
        i. Too large → artificially low reading
        ii. Too small → artificially high reading
        iii. Obese patients:
        iv. Leak: unable to maintain pressure → slow, inaccurate reading
    c. User error: maximum frequency every 2 min
        i. If shorter → blood flow impedance → ↓ vessel compliance → artificially ↑ SBP, ↓DBP
    d. Patient factors:
        i. Dysrhythmias: AF has beat-beat variation in BP → ↓ accuracy
        ii. Hypotension: over-reading at low BP, failure to read SBP < 50mmHg

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1991 Write short notes on the ideal properties of a pressure transducer .

1. A pressure transducer is an instrument which detects changes in pressure and converts this to an equivalent electrical signal.

2. Components:

    a. Strain gauge: connected to a pressure bag of a sterile solution that is continuously flushing the circuit to prevent clots collecting on the catheter.
        i. Diaphragm alters shape when a force is applied to it
        ii. A wire which is stretched (becomes thinner and longer) → ↑ resistance in proportion to stretch of the wire.
    b. Wheatstone bridge: consists of a parallel resistor arrangement in which current flows equally across both circuits.

        i. Resistance$_1$ = $R_1 + R_2$
        ii. Resistance$_2$ = $R_3 + R_4$

$$\frac{\mathbf{R_1}}{\mathbf{R_2}} = \frac{\mathbf{R_3}}{\mathbf{R_4}}$$

        iii. R_3 is a variable resistor
        iv. R_4 is the strain gauge transducer. When resistance ↑ at R4 because of ↑ blood pressure, current then flows through the galvanometer because it goes through a pathway of least resistance. A deflection in the galvanometer then occurs and readings can be taken.
        v. Most transducers contain 4 strain gauges which forms the resistance in the Wheatstone Bridge. It is designed so that the resistance on one of the side of the Wheatstone Bridge increases with blood pressure, while the other side declines. The output is then amplified and connected to a recorder.
    c. External power supply provides current for the circuit
    d. Micro-computer to calculate pressure results
    e. Monitor to display results

3. Ideal properties:
    a. Can be zeroed
    b. Maintain reasonable calibration.
    c. Instantaneous pressure results.
    d. Cheap
    e. Sterile and non toxic
    f. Pressure waves are conducted through saline.
    g. Static Accuracy
    h. Dynamic Accuracy
        i. Ability to faithfully record rapidly changing events.
        ii. Accounts for Natural Frequency of the system and appropriately dampens the recording.

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Physiol-04B11 Briefly explain how oximetry can be used to estimate the partial pressure of oxygen in a blood sample.
1993 Briefly discuss the factors which influence the measurement of oxygen saturation using a pulse oximetry

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1. Pulse oximetry: is a spectrophotometric technique used to measure O_2 saturation in arterial blood.

2. Principle:
    a. Beer-Lambert Law: states that the intensity of light transmitted through a solution of known concentration ↓ exponentially with ↑ distance and concentration.

$$\mathbf{I_t = I_o e^{-ecd}}$$

    I_t = intensity transmitted light
    I_o = intensity incidental light
    c = concentration solution
    d = distance through medium
    E = extinction coefficient
    b. Oxy-Hb absorbs more infra-red and less red light compared to deoxy-Hb.

3. Setup:
    a. 2 x LEDs: emitting specific wavelengths light → red light (λ = 660nm) and infrared light (940nm). This transmits rapidly alternating light at 100Hz alternately → I_t.
        i. 660nm
        ii. 940nm
        iii. Both LEDs off

    b. Photocell detection on opposite side of finger to read light intensity (I_o)
        i. AC/DC – the photocell reads I_o which has a fixed absorption (DC) and a variable absorption due to arterial blood pulse (AC). A ratio between the wavelengths is calculated:

$$\mathbf{R = \frac{ac_{660}/dc_{660}}{ac_{940}/dc_{940}}}$$

        ii. R then gives saturation from an intrinsic calibration curve which is derived from experimental data from volunteers.
            1. R = 3.4, sats = 0%
            2. R = 1, sats = 85%
            3. R = 0.4 sats = 100%

4. Error:
    a. Sensor:
        i. Inadequate light transmission (nail polish)

   ii. Varying length of light path
   iii. Extraneous light flickering at same frequency (fluorescent, infrared heaters)
   iv. Movement (shivering) → background noise
b. Processing:
   i. Human calibration: ±2% > 70%, ±3% 50-70%
   ii. Inaccurate ++ low SaO_2 readings due to lack calibration points.
c. Haemoglobin: oximeter only measures functional Hb (not fractional)
   i. High concentrations of abnormal Hb:
      1. MetHb – same absorption at 660 and 940nm, thus R → 1 and sats read 85%
      2. CO-Hb – absorbs identical to Hb-O_2 660nm → photocell reads the sum HbO_2 and COHb → overestimation of sats.
   ii. Other light-absorbing substances – dyes
      1. Methylene blue and indocyanine green absorb 660nm → underestimate
d. Blood flow:
   i. Poor perfusion - ↓ac/dc ratio → R will approximate unity → 1 → readings come to 85%. Inaccuracy compounded by amplification of signal which ↑ background noise.
   ii. Pulsatile venous flow (TR) → involve venous blood in calculation

5. Measure O_2 tension:
   a. O_2-Hb dissociation curve:

Sats (%)	**pO_2 (mmHg)**
99	150
97	100
91	60
75	40
50	27
10	10
0	0

   b. Error:
      i. Shifts in the curve: CO_2, pH, 2,3 DPG
      ii. Flat upper portion: saturations above 98% mean pO_2 > 100mmHg, but can't quantitate this.
      iii. Sample: delayed sampling ↓pO_2 → ↓SaO_2

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Physiol-99B7 Describe how the partial pressure of oxygen in a blood sample is measured using a Clark electrode.

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1. The Clarke electrode is the key component for the measurement of O_2 tension in a blood gas analyser. It is otherwise known as the oxygen polarographic electrode.

2. Components:
    a. DC voltage source 0.6V
    b. Ammeter
    c. Platinum cathode (wire)
    d. Silver/chloride anode
    e. KCl electrolyte solution
    f. O_2 permeable membrane

3. Principle: a voltage is applied to the anode and cathode which promotes redox reaction through the electrolytic cell.
    a. Anode: oxidation
    $4Ag \rightarrow 4Ag^+ + 4e^-$
    b. Cathode: reduction
    $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
    c. $\uparrow O_2 \rightarrow \uparrow$ reaction rate $\rightarrow \uparrow$ production of electrons $\rightarrow \uparrow$ current. Usually, for an electrical circuit, I α V. However, for the Clarke electrode, the graph of I vs. V shows a plateau at 0.6V (plateau voltage) where current produced is not altered by change in voltage. This allows accurate current vs. O_2 tension to be analysed without needing to control V.

4. Advantages:
    a. Reasonably accurate ±2mmHg
    b. Faster than fuel cells
    c. Lasts longer

5. Disadvantages:
    a. Temperature must be kept constant 37
    b. Cathode/membrane must be kept clean. Typically protein deposits
    c. Calibration with standard gases must be regularly performed
    d. Delay in analysis → cannot measure breath-breath
    e. Sample must be analysed immediately → O_2 consumption by cells will give false $\downarrow pO_2$ (therefore, use ice)
    f. Interference: halothane, microorganisms consume O_2 on electrode
    g. Battery required needing replacement

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1992/90 Write short notes on principles of measurement of end tidal carbon dioxide tension.

1. End tidal CO_2 is measured continuously in anaesthesia by capnography and gives useful information about patient acid-base status and gas exchange.

2. Components: mainstream (sapphire chamber over breathing apparatus with analyser on top) or sidestream (Teflon drain aspirates gas from breathing circuit to analyser, returned afterwards to circuit)
    a. Infrared source (heated wire)
    b. Filter to specify IR wavelength
    c. Sapphire gas chambers (glass not used as it absorbs IR light) → sample chamber and reference chamber (used to correct for background and calibration inaccuracy). This chamber must have no CO_2 and calibrated to zero regularly.
    d. Detector unit:
        i. Photodetector
        ii. Luft type

3. Principle: using infrared spectrophotometry
    a. Gases with two or more different atoms absorb infra-red light at unique wavelengths.
    b. Wavelengths of expired gases (O_2, CO_2, N_2, N_2O, volatiles)
        i. CO_2 = 4.28µm
        ii. N_2O = 4.5µm
    c. Beer's and Lambert's law state that the amount of transmitted light through a solution exponentially decreases with ↑ concentration and distance:

$$\mathbf{I_t = I_o e^{-ecd}}$$

    d. The detector can measure the amount of IR light absorbed and hence give an accurate CO_2 concentration of the gas sample

4. Assessment:

	Advantage	**Disadvantage**
Sidestream	Convenient, easy to transport Cheap interface No interference with breathing apparatus Multiple IR wavelengths can be used to measure different gases	Longer lag time (up to 2sec) FGF loss (50-500mL/min) and scavenging required. Extra-tubing can leak Blockage by water vapour Tubing contributes to dead space
Mainstream	Less lag time No tubing complications No loss FGF No reference cell required	Expensive sapphire, cumbersome Requires heating to 41 C Only measures single gas agents Injury and burns risk to patient

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a. Other errors:
    i. Collision broadening – the presence of other gases (O_2, CO_2, N_2, N_2O, volatiles) widens spectrum of absorption by CO_2 due to kinetic interactions → ↑ absorption 10% with 50% N_2O.

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1996 Explain briefly the causes of differences between measured end tidal and arterial partial pressures of carbon dioxide.

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1. Introduction:
    a. End tidal CO_2 is measured in expired gas at the mouth by capnograph (infrared absorption spectrophotometry) and displayed on a capnograph.
    b. Arterial CO_2 is measured by a CO_2 sensitive (Severinghaus) electrode which measures pH after CO_2 reacts with water.
    c. It is normally assumed that $ETCO_2 = PACO_2 = PaCO_2$ which is approximately the case in correctly measured healthy individuals.
    d. Normal value $PaCO_2$ = 38.3 +/- 7.5mmHg with measured $ETCO_2$ usually 4-6mmHg lower. Usually, $ETCO_2 < P_ACO_2 < PaCO_2$.
    e. $ETCO_2$ is different from mixed expired which is much lower due to dilution from anatomical dead space.

2. $ETCO_2 < P_ACO_2$. This is due to:
    a. Patient factors:
        i. Alveolar dead space – ventilated alveoli which do not participate in gas exchange (not perfused) and hence do NOT contain CO_2. This space is small/none in normal lungs but occurs in West zone 1 lungs (positive pressure ventilation, COPD, PE). Mixing of this CO_2-free gas with better perfused units dilutes CO_2 and lowers $ETCO_2$. In healthy individuals this may account for lower $ETCO_2$ by 4-6mmHg.
        ii. Phase III capnography – the presence of slow alveoli (COPD) with delayed emptying causes a slow rise in expired Co_2 can failure to reach plateau.
    b. Sampling factors:
        i. Machine –
            1. Leaks, Occlusions in sampling lines
            2. Water entrapment
            3. Collision broadening – interference from other gases (N_20) which artificially raises $ETCO_2$.
        ii. Sampling site
            1. Error increased by length of line and distance from trachea
            2. Pa CO_2 - venous gas sample increases pCO_2 by 5mmHg

3. $P_ACO_2 < PaCO_2$. This is due to:
    a. Patient factors:
        i. V/Q mismatch where blood flowing through poorly ventilated alveoli ↑$PaCO_2$.

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Physiol-06A15/01A3/91 Briefly describe the measurement of pH in a blood sample using a pH electrode.

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1. $pH = -\log_{10}[H^+]$
    a. Norma value blood = 7.4 ±0.05
    b. Measured by pH electrode is blood gas machines

2. Components: 2 half-cells connected by blood sample to make a complete circuit

    a. 2 x half-cells (ion-specific electrodes): a metal in its metal-salt solution.
        i. Glass electrode – Ag/AgCl in buffer solution
        ii. Reference electrode – Ag/AgCl bathed in KCl salt bridge constant pH. Salt bridge is saturated solution than maintains electrical contact between sample and electrode.
        iii. Sample tubing – blood sample separated by glass membrane
    b. Specialised capillary tube glass membrane, permeable to H^+, pH sensitive
    c. Surrounding water jacket 37 degrees
    d. Galvanometer to measure voltage

3. Principle: potentiometry → electric potential generated across a H^+ sensitive membrane is proportional to pH difference across the membrane.

    a. Half-cells - a metal in its metal-salt solution will dissolve into its ions, leaving negative charge on the electrode → generation of EMF. Two half-cells with different EMFs are connected to make an electrical circuit with a constant EMF.
    b. Blood sample passes by both electrodes, separated by H^+ membrane → H^+ ions attracted to glass (by negative charge of electrodes).
        i. Glass electrode H^+ unchanged due to buffering
        ii. Reference electrode → EMF difference by movement of H^+ (no buffer)
        iii. There is a change in EMF proportional to the concentration of H^+ movement (related to $[H^+]$ blood sample) → 61.5mV per pH unit
    c. Requires:
        i. Constant temperature 37: ↑ temp → dissociation of acids/bases → ↓pH
            1. Correction for variations on temp with Rosenthal equation:

ΔpH = ΔT x -0.015

        ii. Regular calibration with buffers of known pH (phosphate buffers)

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MAKEUP Describe how the partial pressure of CO_2 in a blood sample is measured using a Severinghaus electrode.

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1. The Severinghaus electrode is the key component for the measurement of CO_2 tension in a blood gas analyser.
    a. Normal CO_2 = 40mmHg

2. Components: essentially a modified pH glass electrode held in a solution of $NaHCO_3$ by a porous cellophane membrane.

    a. 2 half-cell electrodes:
        i. Reference - Ag/AgCl + salt bridge
        ii. pH electrode – Ag/AgCl + buffer (HCl)
    b. closed cylinder of pH sensitive glass in the centre
    c. Sodium bicarbonate solution surrounding pH electrode
    d. Thin film of bicarbonate impregnated nylon mesh covering the end of the cylinder
    e. CO_2 permeable membrane covering the end of the electrode

3. Principle: potentiometry → CO_2 dissolves to give out H^+ → change in voltage of circuit in proportion to pH change.

    a. Half-cells - a metal in its metal-salt solution will dissolve into its ions, leaving negative charge on the electrode → generation of EMF. Two half-cells with different EMFs are connected to make an electrical circuit with a constant EMF.
    b. Blood sample passed between the two electrodes:
        i. CO_2 traverses through the CO_2 permeable silicone membrane
        ii. CO_2 dissolves in bicarbonate mesh solution: $CO_2 + H_2O \Leftrightarrow H^+ + HCO_3^-$
        iii. H^+ traverses pH sensitive glass which changes EMF and is detected by galvanometer
        iv. Change in pH proportional to $[CO_2]$ → calibrated
        v. $[CO_2]$ converted to partial pressure according to CO_2 dissociation curve

4. Advantages:
    a. Reasonably accurate

5. Disadvantages:
    a. Slow response time 2-3min
    b. Requires calibration with set CO_2 values
    c. Constant temperature required

6. Derived Measurements: Astrup interpolation uses Siggaard-Anderson nomogram to extrapolate base-excess and buffer. 2 samples of patient blood are taken with different CO_2/O_2 gas mixtures and a CO_2 titration line drawn. pH is read off the X-axis graph, and BE is read off the lower curve.

    a. Bicarbonate – calculated according to Henderson-Hasselbach:

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$$\mathbf{pH} = \mathbf{pKa} + \log_{10}\frac{\mathbf{A^-}}{\mathbf{AH}}$$

$$\mathbf{pH} = \mathbf{6.1} + \log_{10}\frac{[\mathbf{HCO_3^-}]}{\mathbf{0.03PCO_2}}$$

$$[\mathbf{HCO_3^-}] = \mathbf{0.03\ PCO_2 . 10^{pH-6.1}}$$

b. Base excess – amount of strong acid or alkali required to titrate 1L blood back to pH 7.4 at 37 degrees.
c. Buffer base – sum of all buffer anions in blood (Hb, bicarbonate, protein, phosphate), normally 41.7 +(0.42 x Hb)
d. CO_2 titration line:
    i. Slope – related to Hb (buffering capacity)
    ii. Position – metabolic component of buffer. Left shift in metabolic acidosis.

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Physiol-99B1/98A6 How does a fall in temperature influence blood gas solubility and acid base values?

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1. Blood gas solubility
    a. Definition – the amount of gas dissolved in blood.
    b. Fall in temperature → ↑ solubility of gases
    c. Mechanism:
        i. ↓ temp → ↓ kinetic energy of gas particles → ↓ partial pressure of gas in solution → ↑ amount of gas dissolved in liquid (total CO_2 content unchanged) → ↑ solubility
    d. Principles
        i. Henry's Law: concentration of gas in solution at constant temperature is proportional to partial pressure –

[Gas] = solubility x gas tension

        ii. Ostwald solubility coefficient: measure of volume of gas dissolved in unit liquid at temperature and pressure of the gas in equilibrium with liquid. Temperature dependent.
        iii. Bunsen solubility coefficient: measure of volume of gas dissolved in unit volume of liquid at STP where partial pressure of gas is 1atm.
    e. Specific gases:
        i. ↓temp → ↑CO_2 solubility → ↓pCO_2
        ii. ↓temp → ↑O_2 solubility, Shift O_2 dissociation curve left → ↓pO_2

2. Acid-base values:
    a. ↓ temp → ↓ionic dissociation → ↓H^+ → ↑pH

$$\boldsymbol{pH = -log_{10}[H^+]}$$

        i. Measured by Rosenthal correction factor: ΔpH = ΔT x -0.015

3. Extra: Managing gas tensions during hypotension
    a. α-stat hypothesis: aim to maintain normal total CO_2. This preserves the ratio of ionised:unionised α-imidazole ring on histidine → preserves buffering system.
        i. Degree of ionization of imidazole groups constant despite change in temperature despite change in temperature:
        $H_2O \Leftrightarrow H^+ + OH^-$
        ii. ↓temp:
            1. ↓ ionisation → **↑pH** (equal H^+/OH^- ratio)
            2. ↑CO_2 solubility → ↑dissolved CO_2 ↓pCO_2 → overall **constant CO_2** in system
        iii. Blood gas machine: no correction required for temperature difference
        iv. Examples:
            1. arterial blood from heart; temp 37°C; pH 7.4
            2. skin: temp 25°C; pH 7.6
            3. exercising muscle: temp 40°C; pH 7.35

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b. pH-stat hypothesis: aims to have patient at normal pH even at hypothermia
    i. ↓ temp:
        1. Constant pH
        2. CO_2 added into system to maintain pCO_2 40mmHg and pH 7.4 → total CO_2 stores elevated
        3. Ratio OH^- : H^+ changed
    ii. Blood sample measured against normalised values 37 degrees. Rosenthal correction factor applied for differences in temperature.

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Physiol-99A5/95B7 Differentiate between the terms 'heat' and 'temperature'. Explain briefly the principles of a mercury thermometer, indicating its advantages and disadvantages.

1. Heat is a form of energy, being the amount of kinetic energy contained within molecules of a substance.
    a. Units: Joules (Nm^{-1})
    b. Transferred as energy by:
        i. Conduction through a substance
        ii. Convection by a substance (movement of air/fluid medium)
        iii. Radiation as EM radiation waves

2. Temperature is the thermal state of a substance which determines the direction of heat transfer with another substance. Heat is transferred from high temperature → low temperature
    a. Units:
        i. Kelvin – absolute temperature = 1/273.16 x triple point water (equilibrium of ice, water, and water vapour)
        ii. Kelvin = Celsius + 273.15
        iii. Fahrenheit
    b. Specific heat capacity: amount of heat energy applied to 1kg of substance in order to ↑ temp by 1^0C.
        i. Links heat and temperature
        ii. Units $kJ/kg/^0C$

3. Measuring temperature:

Property	**Mercury monometer**	**Thermistor**
Components	Mercury reservoir Evacuated glass capillary tube: • small, thin and uniform to allow sensitivity and linear calibration. • Curved with focal point at back of mirror for ease of reading Constriction at bottom of tube: maintains position of column after removal from measurement site	Heavy metal oxide solids (cobalt, Nickel, Zinc) Electrical circuit
Diagram		
Principle	Heat → ↑ temperature mercury → expansion of fluid → movement up column Linear expansion with temperature Scale calibration	Resistance of thermistor changes with temperature in non-linear relationship. Most metals negative temperature coefficient: ↑ temp → ↓ resistance. Platinum has positive coefficient. Calibration and zeroing required as relationship exponential. Accuracy can be improved with Wheatstone bridge.

Advantages	Accurate – Gold standard Reliable Cheap Easy to use Able to be sterilised Large range: freezing point low -40, boiling point high 357 C. No calibration required (closed system)	Small size Incorporation into display monitors Continuous readings Can be inserted into body orifices Rapid response
Disadvantages	Fragile Slow response time 2 min Cannot be put in orifices – toxicity if break Column is fixed length → not able to shrink size or make more compact Reading intermittent not continuous Reading cannot be processed	Non-linear response (↓ accuracy) Variation in manufacture (alloy) Hysteresis Expensive

EXTRA NOTES

4. Other methods of temperature measurement
    a. Volume expansion:
        i. Liquid filled manometer: mercury, alcohol
        ii. Dial:
            1. bimetallic strip – coiled strip of 2 metals turn a pointer as the metals expands at different rates with heat. Slow to equilibrate, low accuracy, prone to corrosion
            2. Bourdon gauge – hollow metal tube in a spring, filled with volatile liquid which expands with ↑ temperature → ↑ pressure. Rapid response, small temperature range, moderate accuracy 0.3° C.

    b. Chemical:
        i. liquid crystal thermometer

    c. Electrical
        i. Thermistor – as above
        ii. Platinum wire thermometer: resistance of platinum wire ↑ with temperature. Linear relationship. Accuracy improved with Wheatstone bridge. Small range, accurate, bulky.
        iii. Thermocouple: 2 different metals generate a current when in contact → proportional to temperature. (Seebeck effect). Usually copper and constantan (60% Cu, 40% Ni) are used giving a linear response of 40µV per ° C. Rapid response, small and accurate.
        iv. Infrared: focus infrared detector onto a body point, usually tympanic membrane. IR radiation emitted α (Body-thermometer temp)^4 → electrical signal voltage → calibrated to temperature recording. Fast, non-invasive, less accurate.

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Physiol-08B9/94 What is humidity and how can it be measured?

1. Humidity is a measure of the amount of water vapour in a gas – usually air.
    a. Absolute humidity: the mass of water vapour present per unit volume of gas or air at given temperature.
        i. Units – g H_2O/m^3
        ii. Typical values:

Environment	Humidity (g H_2O/m^3)
Saturated air 20°C	17
Saturated air in trachea 34°C	34
Saturated air in lung 37°C	44

        iii. Independent of temperature

    b. Relative humidity: the amount of water vapour in air as a percentage of amount in saturated air at that temperature and pressure.

$$\textbf{Relative humidity} = \frac{\textbf{Absolute humidity x 100\%}}{\textbf{Absolute humidty (saturated air at} \frac{\textbf{temp}}{\textbf{pressure}})}$$

        i. Relative humidity 100% when air saturation with water vapour → number of molecules leaving liquid = number molecules enter liquid (no net evaporation).
            1. Saturated vapour pressure (SVP) = pressure of vapour at which 100% relative humidity (saturated air)

$$\textbf{Relative humidity} = \frac{\textbf{Actual VP}}{\textbf{Saturated VP}}$$

            SVP water vapour in lungs = 47mmHg
        ii. Dependent on temperature : ↑ temperature → ↑ SVP → ↓ relative humidity

2. Measuring humidity – hygrometers

Method	Equipment	Principle	Assessment
Hair hygrometer	Hair fibres Needle gauge	↑ humidity → ↑ length Accuracy maximum 20-90% relative humidity	Slow response Difficulty coupling to electrical circuit Inaccurate ±2%
Wet/dry bulb hygrometer	Dry thermometer – ambient temperature Wet thermometer Calibration scale	Wet thermometer is cooled by evaporation of water from a wet wick. ↑ humidity → ↓ evaporation → ↓ cooling → ↓ temperature difference between thermometers	Used for climactic humidity Requires sufficient air movements in vicinity of wet bulb to prevent local rise in humidity.
Regnault's	Silver tube	Air blown through tube	↑ accuracy

hygrometer	Diethyl ether gas in tube Thermometer Air source	→ cooling due to ether vaporisation. Air outside tube is cooled → ↓ temp → ↓SVP air → condensation. Temperature at which condensation first occurs → dew point. Read off calibration to give absolute humidity **Relative humidity = $SVP_{dew}/SVP_{ambient\ temp}$**	
Humidity transducers	Conducting substance for circuit	↑ humidity → ↓ resistance ↑ humidity → ↑ capacitance ↑ humidity → ↑ thermal capacity	
Mass spectrometry	Sample gas Ionising beam Magnetic field Detector	Water vapour mass in air measured by deflection through magnetic field.	
UV/IR absorption	UV/IR Light source Filter Sample and reference gas chamber Detector	Water absorbs UV and IR light according to Beer and Lambert's law.	

EXTRA NOTES -

3. Importance of humidification:
    a. Insulates patient
    b. Hydration
    c. Ciliary function: ↓ humidity causes
        i. ↑ post-op pulmonary complications
        ii. Mucosal degeneration
        iii. Squamous metaplasia
        iv. Infection, mucous plugging
    d. Comfort in theatre

4. Methods of humidification:
        i. Natural: Nose, Nasopharynx, Oropharynx
    b. Humidifier: produce water vapour – problem is that administered vapour at 100% humidity room temperature will ↓ relative humidity when introduced into body temperature respiratory system due to ↑ temp → ↑SVP.
    c. Nebuliser: produces aerosol water droplets – super-saturation with water droplets which vaporise when inhaled into respiratory system as ↑SVP.
        i. Cold water bubble
        ii. Condenser

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iii. Hot water bath
iv. Heated Bernoulli nebuliser
v. Ultrasonic nebuliser

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Physiol-02A7/95A5 Outline the principles of a pneumotachograph. What factors affect the accuracy of this device?

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1. Pneumotachographs are used to measure respiratory airflow. Integrating these calculations, gas volumes can also be derived.

2. Components:
    a. Input from patient breathing circuit (mask)
    b. Flow measuring:
        i. Fixed orifice gauze screen which creates fixed resistance, with sufficiently large diameter to allow laminar flow
        ii. Transducer with Wheatstone bridge – measures pressure and converts pressure change into electrical signal
        iii. Display monitor

3. Principle:
    a. Resistance to airflow by gauze screen causes ↓ pressure according to Ohm's and Pouiselle's laws: flow α ΔP

$$\mathbf{\Delta P = Q\ x\ R}$$

$$\mathbf{Q = \frac{\Delta P\ x\ \pi r^4}{8 \eta L}}$$

    b. Pressure drop usually 1-2cmH_2O

4. Factors affecting accuracy: factors affecting laminar flow
    a. Viscosity gas: ↑ viscosity → ↑ resistance
        i. Calibration used for specific gases
    b. Temperature: affects humidity and viscosity, ↑ temperature → ↑ viscosity
        i. Heater incorporated to maintain constant temperature
    c. Obstruction of gauze (vapour, mucous) → ↑ resistance, ↑ turbulence
    d. Turbulent flow: ↑↑ flows, ↑ density of gas, appropriate diameter for subject (adult vs. paediatric)
        i. Range of sizes available
        ii. Turbulence: $flow \propto \sqrt{\Delta P}$

$$\boldsymbol{Re = \frac{2rv\rho}{\eta}}$$

5. Advantages:
    a. Easy to use
    b. Can be incorporated into breathing circuit
    c. Breath by breath analysis
    d. Minimal resistance to breathing

6. Disadvantages:
    a. Requires flow range for accuracy:
        i. Insufficient flow – pressure values too small to measure
        ii. ↑ flow – turbulence

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MAKE-UP: How does a rotameter work?

1. Rotameter is a gas-flow measuring device otherwise known as a rotating bobbin flowmeter.

2. Components:
    a. Inverted cone-shaped gas tube
    b. Matched calibrated bobbin
    c. Vertical scale
    d. Safety features:
        i. Coloured knobs
        ii. Numbering system to match bobbin and tube
        iii. Non-interchangeable

3. Principle: variable orifice, constant pressure flowmeter
    a. Gas flows up through the vertical tube, causing upward pressure on the bobbin and a subsequent rise in its position. As the bobbin rises, the space between it and the tube rises due to the cone-shaped tube → ↓ resistance of air flow → maintain constant pressure (=gravity).
    b. The bobbin spins/moves until it comes to rest at equilibrium when downward gravity pressure = upward gas flow pressure.
    c. A vertical scale on the side of the tube is calibrated to particular gas flows.
    d. Cone-shaped scale allows variable orifice with which to measure unique flow rates.

4. Advantages:
    a. Accurate ±2.5%

5. Disadvantages:
    a. Need calibration to specific gases:
        i. Density gas important at high flows (turbulent)
        ii. Viscosity gas important at low flows
    b. Need constant temperature (effects density and viscosity).
    c. Fragile and not mobile (ball flowmeters are used for mobile gas cylinders)
    d. Bobbin, and tube must be matched.

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MAKE-UP: Briefly describe the basic principles of vaporisers in current clinical use.

1. Vaporisers are used in anaesthesia to control input of volatile anaesthetic agents into the fresh gas flow.

2. Components:
    a. Anaesthetic machine delivers gas at positive pressure
    b. Vaporiser with chamber

3. Principle:
    a. Vaporisers receive total gas flow from rotameters and are split into two streams – bypass flow, and vaporiser flow.
    b. The bypass flow does not pass through the vaporiser
    c. The vaporiser flow passes into the vaporising chamber and picks up the vapour at it SVP (for that particular temperature).
    d. The two streams combine again to form the FGF.
    e. The volatile agent concentration is controlled by the:
        i. Degree of splitting of the gas flows – splitting ratio
        ii. Ambient temperature

4. Assessment:
    a. Each chamber is specific for a volatile agent (as they have unique SVP)
    b. Work only within specific temperature range and require insulating devices

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Physiol-10B11/07B11/02B14/98B4 Explain the physical principles of ultrasound imaging.

1. Ultrasonography is a method of imaging internal soft tissues within the body through the reflection and detection of transmitted ultrasound waves.
    a. Ultrasound is a sound wave with frequency > human ear detection, whereby pressure on a medium causes the molecules to compress and expand.
        i. Frequency ranges 2-15MHz (human ear 20Hz – 20kHz)
    b. Has same properties of other energy waves: Amplitude, Wavelength, Velocity

$$\mathbf{V = f\lambda}$$

2. Principles:
    a. Ultrasound Generation: a piezoelectric crystal within the transmitter probe is stimulated by an electrical current → contracts and expands → generations ultrasound wave.
    b. Ultrasound Detection: reflected waves of tissues are detected by the probe → cause crystal vibration → transduced back into electric signal (piezoelectric effect).
    c. Sound-tissue interactions:
        i. Absorption: tissue absorbs energy and is converted to heat → attenuation of signal.

$$\mathbf{Absorption \propto dis\ x\ freq}$$

1. Air/skin interface has ↑absorption → ↑ attenuation. Gel used to minimise attenuation.

        ii. Reflection: occurs where there is a change in density between two substances. This depends on difference in tissue impedance (z) –
        iii.

$$\mathbf{z = \rho\ x\ v}$$

$$\%\mathbf{reflection} = \left(\frac{\mathbf{z_1 - z_2}}{\mathbf{z_1 + z_1}}\right)^{\mathbf{2}}\mathbf{x\ 100}$$

        iv. Diffraction: reflection of wave at irregular interfaces smaller than λ.
    d. Ultrasound parameters:
        i. Depth – attenuation limits depth of reading due to absorption of ultrasound by tissues. Inversely proportional to frequency. Measured by time taken for ultrasound wave to return (assuming constant velocity through tissues → average 1540m/sec.
        ii. Brightness – proportional to amplitude of reflected wave. However, ↑ amplitude wave → ↑ artefact.
        iii. Resolution – proportional to frequency.
        Therefore must US use frequency = 2 – 7.5MHz allows 25cm penetration, 1mm object resolution
        → achieve ↑ penetration without ↓ resolution.
        → gain/amplitude ↑brightness/resolution without ↑artefact

3. Modes:

a. A – amplitude scan
    i. Amplitude of reflected waves displayed as single lines → provides information about tissue depth.
    ii. No longer used.
b. B – brightness scan
    i. Amplitude returns as single dots → amplitude = brightness
c. M – motion scan
    i. B-mode vs. time, single beam in one-dimensional view, 30 images/second
    ii. Rapidly repeated vibrations detect movement at tissue interfaces
d. 2D –
    i. B-mode across 90°
    ii. Requires an array of crystals
e. Doppler – measures the velocity of moving objects which reflect ultrasound waves.
    i. Doppler effect – changes in wavelength and frequency of reflected sound wave when the source moves with respect to the observer.

$$\mathbf{V} = \frac{\mathbf{C}.\Delta\mathbf{F}}{\mathbf{2F_0 cos\theta}}$$

C = speed sound in tissues (1540), F_0 = emitted sound frequency, V = velocity, θ = angle between beam and direction of movement

    ii. Types of Doppler:
        1. Pulsed wave
        2. Colour: superimposed on 2D ultrasound with red = towards, blue = away.

4. Components:
    a. Array of piezoelectric crystals → 2D imaging
    b. TCG – amplification ↑ amplitude
    c. Focus – lateral resolution
    d. Transducer – controls type of beam, divergence, linear.
    e. Display

5. Clinical use:
    a. Imaging anatomy – nerve blockade, epidural
    b. Cardiac output measurement
    c. Blood pressure measurement
    d. ECHO / TOE

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Physiol-05A16*/98A4 Briefly explain the principles of Doppler ultrasound used to measure cardiac output.*

1. Doppler ultrasound relies on the Doppler effect which states that there is a change in wavelength and frequency of reflected sound wave when the source moves with respect to the observer. Velocity is calculated by:

$$\mathbf{V = \frac{C.\Delta F}{2F_0 cos\theta}}$$

2. Ultrasound: high frequency sound waves undetectable by human ear, used with frequencies 2.5-15Hz.
    a. Generation of ultrasound: piezoelectric crystal is electrically stimulated to expand-contract at ultrasound-frequencies.
    b. Detection of ultrasound: ultrasound waves are reflected back to transducer which vibrate crystal and converted to electric signal by transducer.
    c. Tissue-sound relationship:
        i. Ultrasound waves directed along aorta
        ii. Travelling RBC reflects ultrasound waves → Doppler shift frequency
        iii. Frequency shift detected by transducer and RBC velocity calculated by Doppler equation.

3. Cardiac output measurement:

$$\mathbf{CO = Area_{AO}.V_{avg}.T_{ejec}.HR}$$

    a. Equipment:
        i. 2 proves placed beside aorta
            1. One probe → cross sectional area
            2. Doppler probe → velocity
    b. Equation components – time and HR account for the fact that cardiac flow is pulsatile.
        i. Area: cross sectional area of ascending aorta measured from 2D ECHO
        ii. Average velocity RBC: measured by Doppler effect
        iii. Time period for ejection: measured during 2D ECHO
        iv. Heart rate: measured during 2D ECHO
    c. Advantages:
        i. Less invasive
        ii. Easy
    d. Disadvantages:
        i. Blood flow pulsatile, so mean flow is used
        ii. Directed ultrasound is not parallel to flow → don't know θ
            1. $\theta = 90^o$ → no Doppler shift
            2. $\theta < 60^o$ → ↓ accuracy
        iii. Hard to accurately measure aortic cross-sectional area
        iv. Respiration artefact
        v. Less accurate than thermodilution

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Physiol-10A15/05B13/00A1 Explain how cardiac output is measured using a thermodilution technique.

1. Cardiac output is the volume of blood pumped from the heart per unit time into the systemic circulation.

CO = HR x SV = 72bpm x 70mLs = 5L/min

2. Fick Principle: Thermodilution is the gold standard for measuring cardiac output and is based on the Fick principle which states that the amount of a substance extracted from a circulation equals the flow x A-V concentration difference. In equation:
   Flow (to heart) = Rate of uptake/conc difference

   The most common use of this applies to O_2 whereby $VO_2 = CO \times (Ca_{O2} - C_{VO2})$. However, this is not commonly used to measure cardiac output because:

   - VO_2 difficult to measure consistently (spirometry, metabolic computer)
   - CO changes during sampling time and with different respiratory condition

3. Thermodilution:
   a. Theory – thermodilution relies on Fick's principle. When a known amount of substance is introduced into a system of unknown flow (assuming no substance is lost, and mixing complete),

$$\mathbf{Q} = \frac{\textbf{Amount substance}}{\textbf{Conc gradient}_{\textbf{Ave}}}$$

$$\mathbf{Q} = \frac{\textbf{Amount susbstance}}{\int \textbf{cdt}}$$

   b. Method:
      i. Equipment:
         1. SG catheter inserted into PA with 2 ports:
            a. Proximal – lies in SVC/RA for injection of saline/dextrose
            b. Distal – lies in PA for thermistor
         2. Temperature monitor and computer software
      ii. Process:
         1. 5mL Cold dextrose 5% injected into SVC
         2. Mixing occurs in RV
         3. Change in temp measured in PA
         4. Graphed (Draw)
      iii. Calculation:

$$\mathbf{CO} \propto \frac{\textbf{Volume injected}}{\textbf{AUC}}$$

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4. Assessment:
    a. Advantages: compared to indicator method

5. Non toxic (saline)
        i. Thermal load low → dissipation in one circulation → no recirculation hump → easier to repeat measurements
        ii. Does not require arterial blood sampling
    b. Disadvantages:
        i. Invasive → risk pneumothorax
        ii. Cold dextrose → arrhythmias
        iii. Accuracy limited – between 3-13%. This can be minimised by:
            1. Repeated measurements, discarding outliers
            2. Larger volumes used → greater reproducibility
            3. Smooth, rapid injections
        iv. Invalid in:
            1. TR
            2. R→L AV shunt
            3. Dialysis
            4. Equipment malfunction (misplaced catheter)

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Physiol-07B16 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?

1. The ECG (electrocardiogram) is a monitor which graphically records the potential difference across the skin surface caused by the current generated by cardiac myocytes.
    a. Speed 25mm/sec → 1 small square = 0.04s, large square = 0.2s
    b. Voltage calibration 10mm = 1mV

2. Lead II ECG:

Segment	**Description**	**Duration** (s)	**Cardiac volume cycle**
P	Atrial depolarisation	PR 0.12-0.2	Atrial systole
Q	Ventricular depolarisation		Ventricular systole (rapid ejection)
R	Ventricular depolarisation		
S	Ventricular depolarisation		
QRS	Ventricular depolarisation and atrial repolarisation	QRS < 0.12	Ventricular systole
T	Ventricular repolarisation	T wave 0.15	Ventricular systole (slow ejection) Ventricular diastole starts at end of T wave
QT	Ventricular depolarisation	QT < 0.4 $QTc = {QT}/{\sqrt{RR}}$	Duration of ventricular electrical systole

3. PR interval:
    a. Definition: the distance between the start of the P wave and the start of the QRS complex. It represents the time taken for conduction of the action potential from the atria → AV node → ventricles. Normal values are 3-5 small squares = 0.12-0.2 sec.
    b. Factors:
        i. Measurement factors: paper speed
        ii. Patient factors:

↑ PR interval	**↓ PR interval**
Vagal outflow (↓HR)	Tachycardia, sympathetic discharge
Hypothyroidism	Hyperthyroidism
Heart block – 1°, 2°, 3°	WPW
Electrolyte abnormalities – ↓K	
Hypothermia	
Drugs – digoxin, Ca-blockers, beta-blockers, adenosine	Drugs – atropine, sympathomimetics

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EXTRA-NOTES:

4. QT interval:
    a. Definition: the beginning of the QRS → end of T wave
    b. Measurement correction for ↑HR:

$$\mathbf{QTc} = {}^{\mathbf{QT}}\Big/_{\sqrt{\mathbf{RR}}}$$

    c. Normal values: male < 0.4, female < 0.44
    d. Factors: clinical importance as ↑ QT → ↑ risk Torsades.

↑ QT interval
Inherited Electrolyte - ↓Mg Drugs: class 1A, III anti-arrhythmics, TCAs, droperidol

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MAKE-UP: Briefly discuss the principles of EEG use for the monitoring of depth of anaesthesia and sedation.

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1. Definitions
    a. Anaesthesia is a reversible state of drug induced unconsciousness in which the patient neither perceives nor recalls noxious stimuli.
    b. Sedation is a reversible state of drug induced alteration of consciousness that includes reduction of anxiety, stress, irritability and excitement.

2. EEG – measures voltages of PSP of cortical dendrites
    a. Components: 20+ reference electrodes, 16 channels
    b. EEG waves:
        i. PSPs from cortex are asynchronous and random, summing to make a composite signal that the EEG reads. It cannot break these back down into original PSP signals, therefore unlike ECG, EEG is a random signal.
        ii. Generally-
            1. human conscious function → desynchronisation of neurons → ↓ magnitude, ↑ frequency of waves
            2. depressed consciousness → synchronisation of neurons → ↑ magnitude, ↓ frequency.
    c. Clinical use: EEG is processed and analysed statistically for the purposes of anaesthesia monitoring:
        i. BIS
        ii. Entropy
        iii. PSI (patient state index)
    d. Limitations:
        i. Equipment large and cumbersome
        ii. Massive paper production
        iii. Interference from movement, nose, power lines
        iv. Interpretation requires expertise
        v. Qualitative only

3. Bispectral index (BIS): index of hypnotic state which is scored using EEG processing and then comparison with in-built algorithms.
    a. Principle:
        i. EEG obtained from > 2000 patients using common anaesthetics
        ii. EEG analysed using –
            1. Time-domain analysis:
                a. burst-suppression: ↑ depth → ↑ burst suppression
                b. Power analysis(β-wave): ↑ depth → ↑β-wave frequency
            2. Frequency domain analysis:
                a. Fourier analysis: each complex waveform broken down into series of sine waves
                b. Epoch analysis: frequency/amplitude of waves within the packet.
                c. ↑ depth → move from low freq/high amp → high freq low amp

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3. Bi-spectral analysis:
    a. Phase relationship between different frequencies

b. Measurement: Variables ranked, scaled and then summed to give BIS number.

BIS	**Level of hypnosis**
100-85	Awake, alert
85-60	Sedation, general anaesthesia suitable for surgery
60-70	Low probability of consciousness
40-30	Deep anaesthesia
30-0	Burst suppression