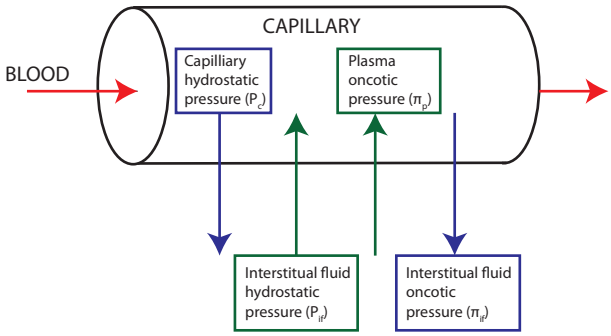
CARDIOVASCULAR PHYSICS AND MEASUREMENT

Starling forces determine to net movement of fluid across the capillary wall. The capillary wall is semi permiable to water and solutes but not to large molecules such as albumin. A plasma ultrafiltrate, free of these large molecules (mostly protiens) is filtered through the capillary wall by the action of opposing hydrostatic and oncotic pressures. Starling forces refer to the opposing oncotic and hydrostatic pressures. The sum of these values determine whether there is a net movement into, or out of the capilliary.



$$\text{Net Filtration Pressure} = (\text{Force inward}) - (\text{Force outward})$$
$$= (P_{if} + \pi_p) - (P_c + \pi_{if})$$

If the value is positive, then there is a net inward movement, if the value is negative then there is outward movement. This may be used to explain oedema due to increased pressure (eg right heart failure) or decreased oncotic pressure (hypoalbuminaemia). Some texts also discuss a gradient along the capillary from higher pressure on the arterial side (NFP positive) to lower pressures on the venous side (NFP negative). Most filtrate is returned to the circulating volume via lymphatics (3 litres / day).

The physics of blood flow Flow is defined as the quantity of fluid passing a point per unit time. Flow may be either laminar or turbulent. Laminar is similar to a fast running stream without rapids, the water in the middle moves the fastest and that on the edges barely moves at all. Turbulent flow is chaotic and all water in the river is moving forward in a front. Reynolds number predicts whether flow will be turbulent or laminar it is calculated using velocity.diameter.density/viscosity and a number greater than 2000 suggests turbulent flow. Therefore increased viscosity, or decreased velocity, density or diameter is more likely to be laminar.

Poiseuille measured laminar flow of homogenous (Newtonian) fluid and described the mathematical relationship between flow, pressure, vessel length, vessel radius and viscosity. From this he derived resistance to be equal to $8nL/\pi r^4$. Where n = viscosity, $\pi = 3.14$, r = radius and L = length

Remember that flow = pressure change/resistance.

Therefore Poiseuille's equation is

$$\text{flow} = \frac{(\text{pressure change})\pi r^4}{8nL}$$

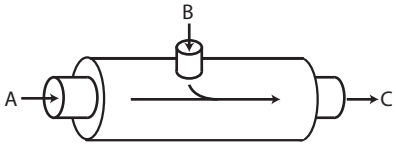
This is an experimental result and is useful for describing flow in the cardiovascular system, however it is very difficult to use this formula empirically because of several reasons. Firstly blood vessels are not rigid tubes but have features of distensibility and contractility which alters the relationship between pressure and flow. Furthermore myogenic stretch mechanisms involved in autoregulation mean the radius may vary counterintuitively with increased pressure. Secondly, Poiseuille measured constant flow, the CVS however is characterised by pulsatile flow. Thirdly blood is not a Newtonian fluid and is often heterogenous, with viscosity varying according to both its contents and the ambient temperature. Finally blood flow is often not laminar but turbulent.

Non invasive blood pressure measurement is performed most simply with an inflatable cuff (20% greater than diameter of the arm) and a manometer to measure pressure. Using a stethoscope over the brachial artery pressure is increased to a point inexcess of systolic pressure where there is no sounds. It is then reduced by 2-3mmHg until the onset of a pulsitile bruit, this is turbulent flow commencing and indicates systole. This point is the first Korotkoff sound. This is followed by a brief muffling (K2) then an increase in noise (K3) then a reduction in sound (K4). Finally sound is completely lost (Korotkoff 5) which indicates diastolic pressure whereby the flow is no longer turbulent enough to produce sound. Non invasive measurement is also possible using a single cuff automated oscillometric technique, which is set up similar to the manual technique however a signal transducer measures both the pressure and onset of oscillations (systole), the maximal oscillation (mean pressure) and estimates the diastolic pressure. Other methods include; Von Recklinghausen technique which uses two cuffs (one for pressure and one for oscillations), doppler ultrasound and the Penaz technique (volumetric clamp method). Non invasive methods are effective if the correct cuff size is utilised, but their utility is decreased if there is an arrythmia or the pressure is very low.

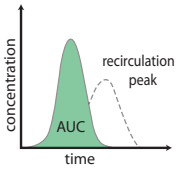
Invasive blood pressure measurement the indications for invasive blood pressure management have been covered previously and include; Continuous, real-time blood pressure monitoring, planned pharmacologic or mechanical cardiovascular manipulation, repeated blood sampling, failure of indirect arterial blood pressure measurement, supplementary diagnostic information from the arterial waveform. Complications include distal ischemia, pseudoaneurysm, arteriovenous fistula, hemorrhage, arterial embolization, infection, peripheral neuropathy, misinterpretation of data, misuse of equipment. The standard set up for invasive arterial measurement is a plastic cannula in a peripheral artery (preferably the radial) where there is good collateral flow. The tubing is pressurised with a heparised saline mixture at 300mmHg. A column of saline is continuos with a diaphram which fluctuates as pressures change. The diaphram is connected to transducer with either a pizoelectric crystal or a strain gauge which converts the movement of the diaphram into an electrical voltage or a change in resistance respectively. The signal is then reproduced following Fourier decomposition (which reduces the signal into sine or cosine waves, with the fundamental frequency measured in Hz being heart rate/60), and amplified.

Measurement of Cardiac Output Cardiac output is the amount of blood ejected from the left ventricle per minute. It is calculated by the formula stroke volume x heart rate. Because stroke volume is difficult to directly measure there is a number of methods employed to achieve accurate measurements of CO. Methods may be classified according to the underlying principles used in their calcuation. Fick's principle is an application of the conservation of mass and is the underlying principle used for the thermo and dye dilution techniques, PiCCO (Pulse induced contour cardiac output) and oxygen consumption methods. Doppler ultrasound assessment of stroke volume using TOE or TTE is another method employed. Electrical impedence is another principle used to assess stroke volume and thus CO.

Fick's Principle is an expression of the conservation of mass, A+B=C. Dye dilution methods applies this method but inserting a known amount dye into B. The amount at A is 0 and therefore amount = flow(concentration). Measuring the concentration at C (using a denistometer) enables the equation to be solved for flow. As this is over a time period the concentration is the area under the curve. It should be noted that following one complete circulation there will be a second peak which represents A no longer being 0. Thermodilation uses similar principles with more complex calculations. An injectate of normal saline of known temp and volume is introduced to the RA and a thermistor (metal device which converts temp changes to an electrical signal) measures the temperature change in the pulmonary artery. PiCCO uses the same principles but the measurements are made at a peripheral artery and the cool saline is injected via a central line which removes the requirement for a pulmonary catheter. The same principles are used in Oxygen uptake assessments of CO. In this setting A=(mixed venous O_2 concentration)flow, B= oxygen uptake (usually 250ml/min) and C=arterial O_2 concentration)flow. CO_2 elimination is another application, but in this setting becuase it is elimination A = B + C.



$A + B = C$



Measurement of regional blood flows The same principles underlie the assessment of regional blood flows to those that measure CO. The clearance of PAH is used to determine renal blood flow, also using an application of the Fick principle. PAH is not utilised or excreted by any other organ apart from the kidney, and once filtered by the kidney it is not reabsorbed. It has an excretetion ration close to 1.0 therefore the amount excreted is a direct fraction of the plasma filtered which if the haematocrit is known it can be used to assess renal blood flow. The Kety-Schmidt method is an experimental method applying Fick's principle to cerebral blood flow usually using N2O, it measures the amount taken up by the brain divided by the arterial-venous concentration difference. PET scanning may be used to assess uptake by a radioactive substance or tagged glucose in another method in assessing different regional circulations.

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