Measurement of flow and volume of blood

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Reasons

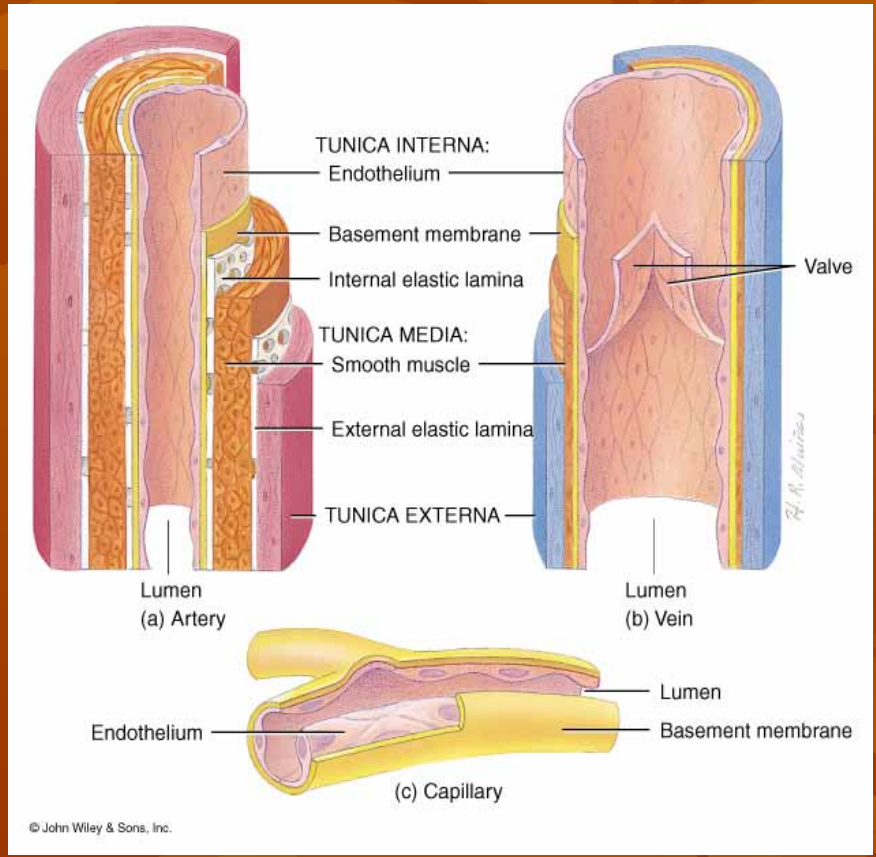
- Reasons:
  - Measurement of concentration of Oxygen and other nutrients in the cell too difficult
    - using measurement blood flow and change in blood volume
      - If blood flow difficult to measure => use blood pressure
        - If blood pressure is difficult => ECG measurement
  - The aim of finding some diseases in human body (do not know exactly which the diseases are)
  - All steps above are related to each other through different levels.
  - Working mainly with blood vessels

Blood vessel structure

- Five types of blood vessels:
  - Arteries
  - Arterioles
  - Capillaries
  - Venules
  - Veins
- Larger blood vessels served by own blood vessels located within their walls
  - Vasa vasorum

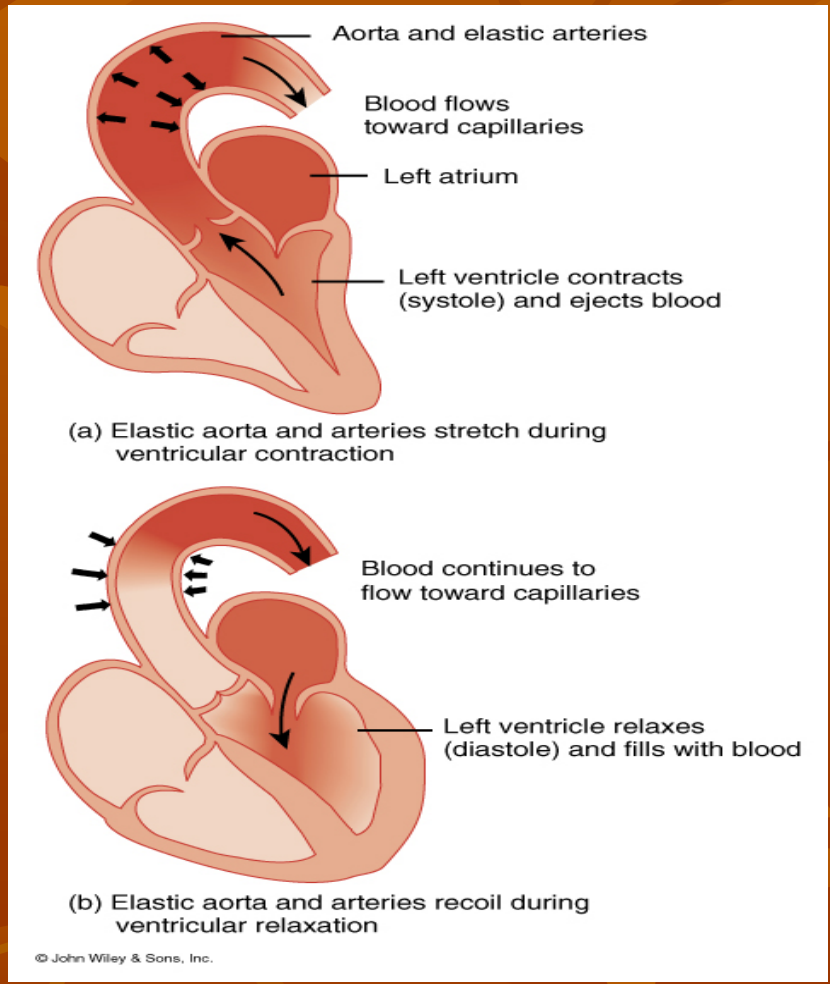
Vessel structure

- Arterial walls have 3 tunics
  - tunica interna
    - Endothelium
    - Basement membrane
    - Internal elastic lamina
  - tunica media
    - Thickest layer
    - Elastic fibres
    - Smooth muscle
    - External elastic lamina (only in muscular arteries)
  - tunica externa
    - Elastic and collagen fibres



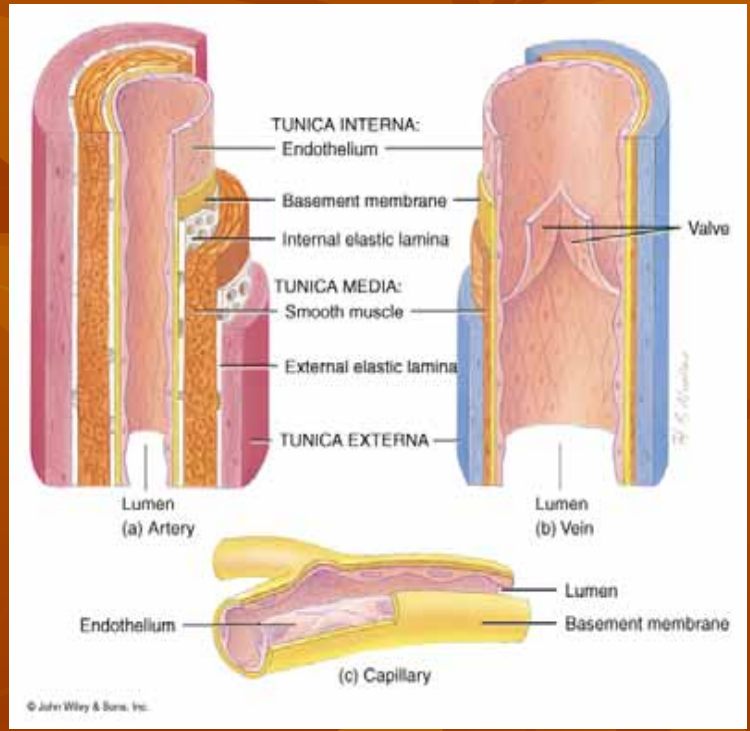
Arteries

- Elastic (conducting) arteries
  - Largest diameter arteries
  - Tunica media contains high proportion of elastic fibres
    - Store elastic energy
      - Helps keep blood moving during diastole
  - “conduct” blood from heart to smaller muscular arteries



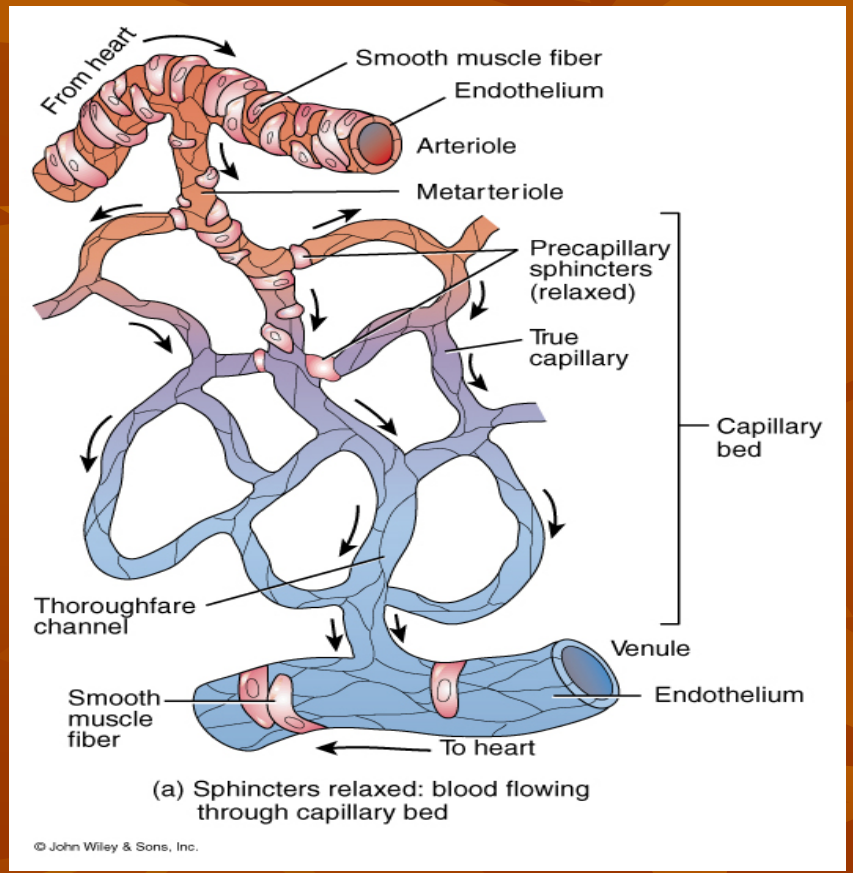
Arteries

- Muscular (distributing) arteries
  - Medium sized arteries
    - Tunica media contains
      - High proportion of smooth muscle
        - Very active in vasoconstriction and vasodilation
  - Distribute blood to various parts of body



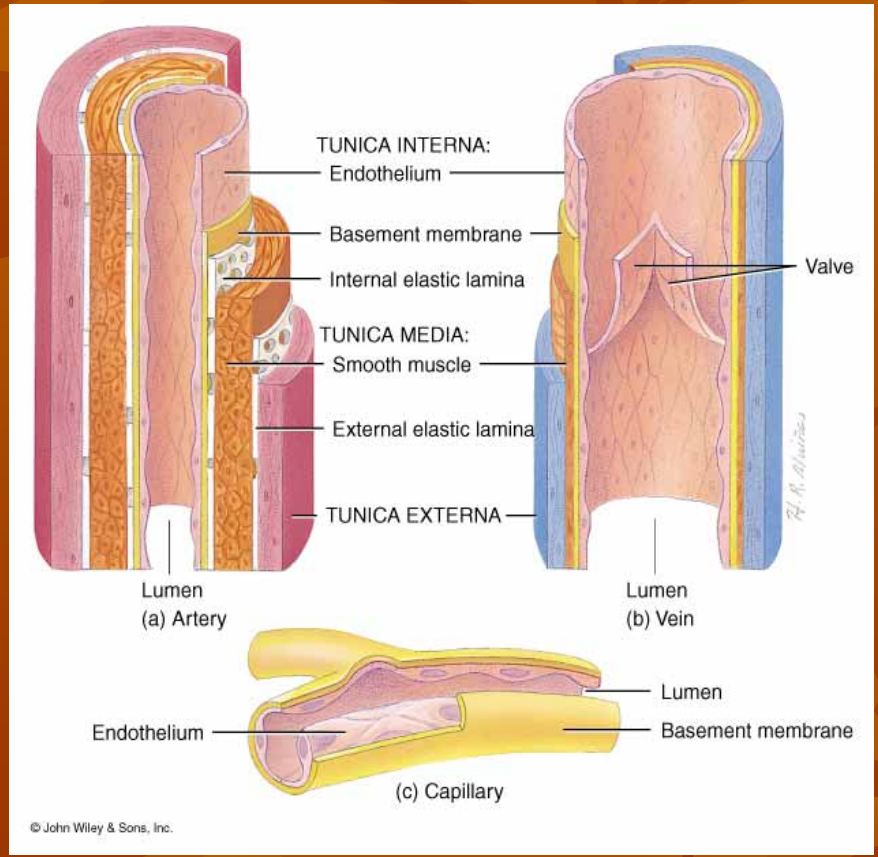
Arterioles

- Arterioles
  - small, almost microscopic arteries
    - deliver blood to capillaries
  - key regulators of systemic vascular resistance
- Metarterioles
  - Emerge from arterioles
    - Supply capillary beds
    - Distal end has no smooth muscle
      - thoroughfare channel



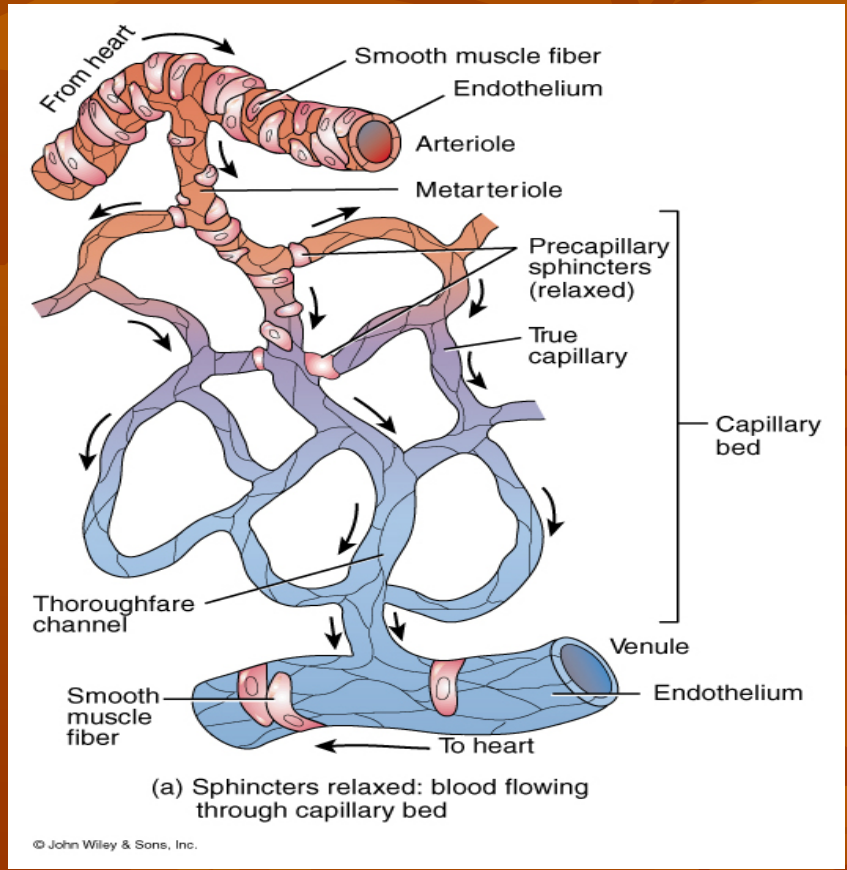
Capillaries

- Microscopic vessels (microcirculation)
  - Distribution varies with metabolic activity of tissue
  - Prime function is exchange of nutrients and wastes via interstitial fluid
    - Walls consist of only endothelium and basement membrane



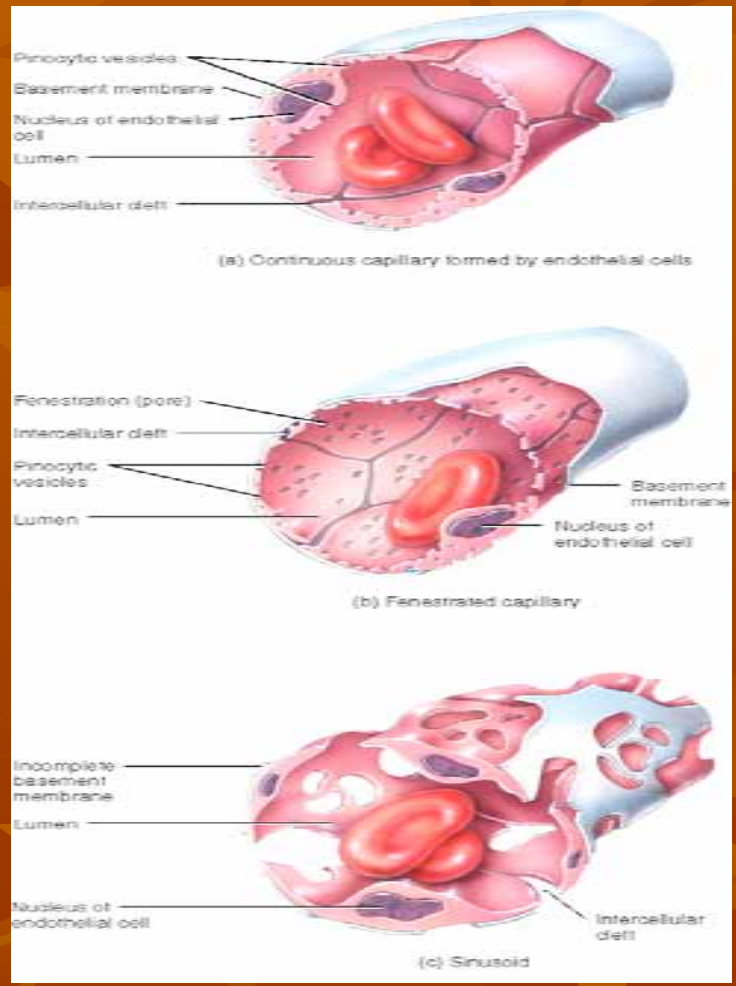
Capillaries

- True capillaries
  - Emerge from arterioles or metarterioles
  - flow regulated by precapillary sphincter
  - Flow intermittent (vasomotion)
    - Caused by alternating contraction/relaxation of metarterioles and pre-capillary sphincters
  - RBC move in single file



Capillary exchange

- Three different types of capillaries
  - Continuous capillaries
    - uninterrupted lining
  - Fenestrated capillaries
    - many fenestrations/pores
  - Sinusoidal capillaries
    - large fenestrations and intercellular clefts
    - incomplete basement membrane

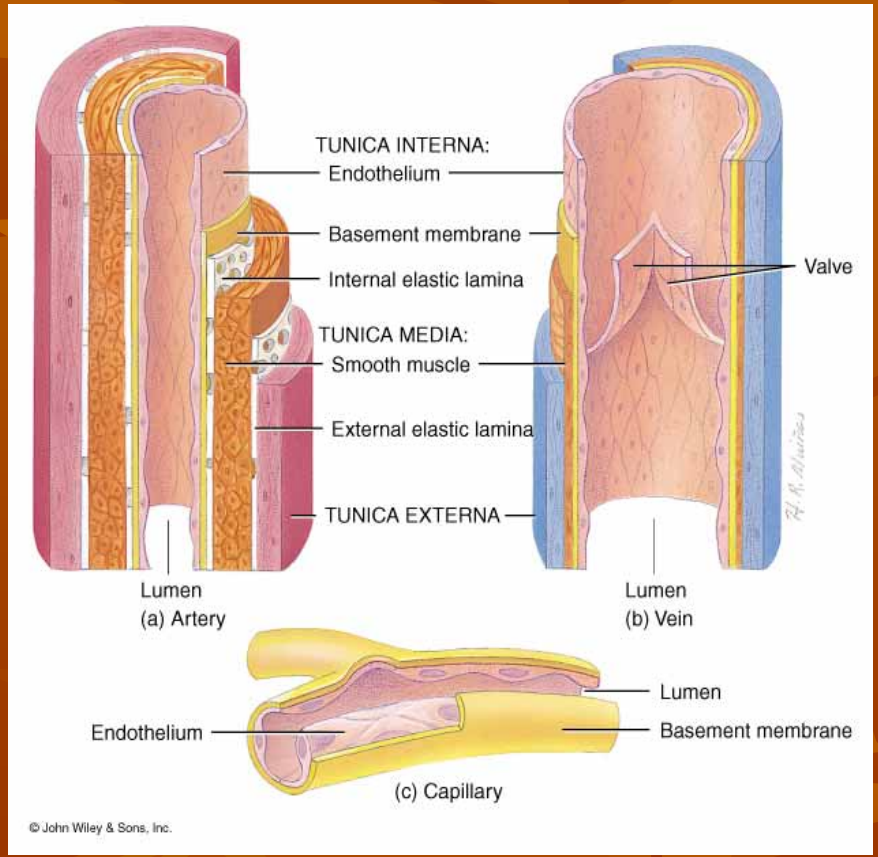


Venules

- Small veins formed from merging of several capillaries
- Venules merge to form veins

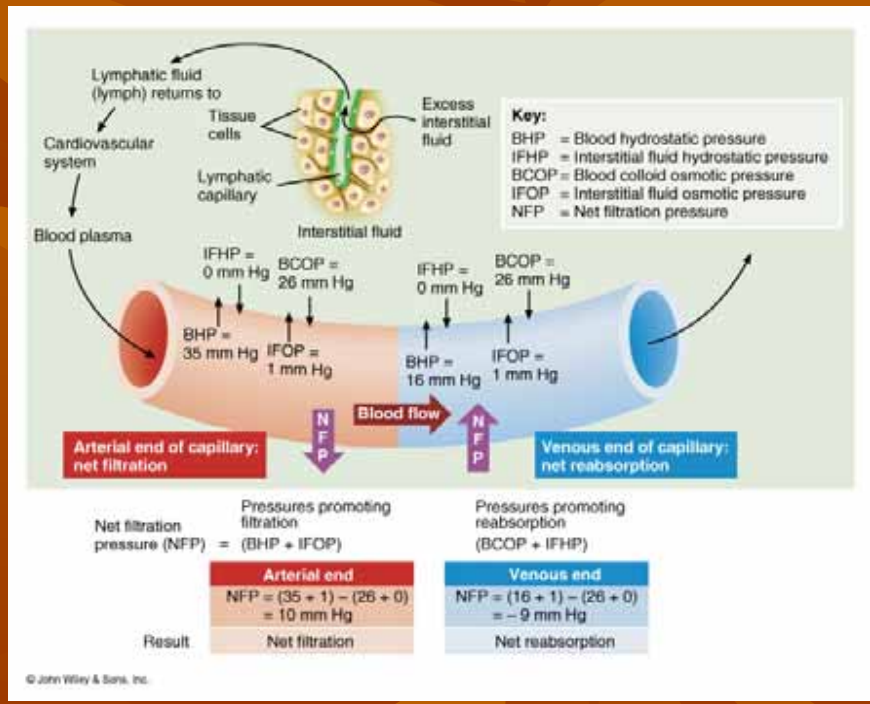
Veins

- Veins:
  - Composed of essentially same 3 tunics as arteries
    - Tunica interna thinner
    - Tunica media thinner
      - Less smooth muscle and elastic fibres
    - Tunica externa
      - Thickest layer - collagen and elastic fibres
      - Lack elastic lamina of arteries
  - Many contain valves to prevent backflow of blood.



Capillary exchange

- Substances enter and leave capillaries by three methods:
  - diffusion (most important)
  - transcytosis (vesicular transport)
  - bulk flow (filtration and absorption)
    - Important for regulation of relative volumes of blood and interstitial fluid
      - Driven by balance between hydrostatic and osmotic pressures (Net filtration pressure)
        - Volume of fluid and and solute reabsorbed normally almost same as volume filtered (Starling's Law of the Capillaries)



Dynamics of Blood Circulation

- Interrelationships between
  - Pressure
  - Flow
  - Resistance
  - Control mechanisms that regulate blood pressure
  - Blood flow through vessels

Laminar and Turbulent Flow

- Laminar flow
  - Streamlined
  - Outermost layer moving slowest and center moving fastest
- Turbulent flow
  - Interrupted
  - Rate of flow exceeds critical velocity
  - Fluid passes a constriction, sharp turn, rough surface

Indicator-dilution method that uses continuous infusion

- Concentration
  - Main parameter using to identify the disease.
  - Define by equation: $C = m_0 / V$
    - In which: m0 is a quantity of an indicator, V is the blood volume
  - When the quantity is increased so the flow can calculated from the equation below:

$$F = \frac{dV}{dt} = \frac{dm/dt}{\Delta C}$$

  - It means that the changing of quantity of indicator with changed volume per unit of time

Indicator-dilution method that uses continuous infusion

- FICK technique
  - Using for measurement cardiac output
    - Definition: volume of blood pumped by the heart per min / measure volume displacement
    - “the total uptake or release of a substance by an organ is the product of the blood flow through that organ and the arteriovenous concentration difference of the substance”

$$CardiacOutput = \frac{\text{Consumtion of } O_2 \,(liters / \text{min})}{\text{different concentration of } O_2 \text{ per unit of time } (liters / \text{min})}$$

    - Limited by cumbersome equipment, sampling errors, need for invasive monitoring and steady-state haemodynamic and metabolic conditions

Indicator-dilution method that uses continuous infusion

- FICK technique
  - Equation:

$$F = \frac{dm/dt}{C_a - C_v}$$

    - F: blood flow, liters/min
    - dm/dt= consumption of oxygen, liters/min
    - Ca= arterial concentration of oxygen, liters/liter
    - Cv=venous concentration of oxygen, liters/liter
  - This technique is nontoxic and the presence of catheter causes a negligible change in cardiac output.

Indicator-dilution method that uses rapid injection

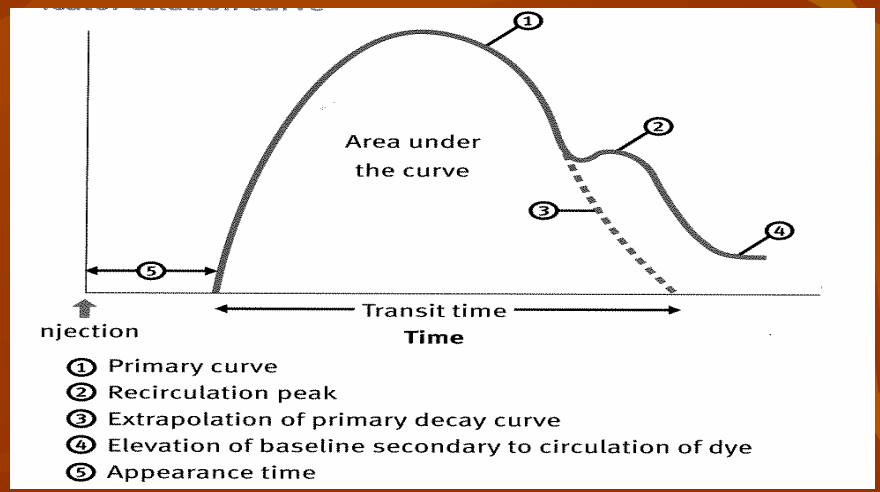
- Principle:
  - Bolus of indicator is rapidly injected into the vessel and the variation in downstream concentration of the indicator versus time is measured until the bolus has passed.
  - Equation:

$$F = \frac{m}{\int_0^{t_1} [\Delta C(t)] dt}$$

  - Still following the main definition.

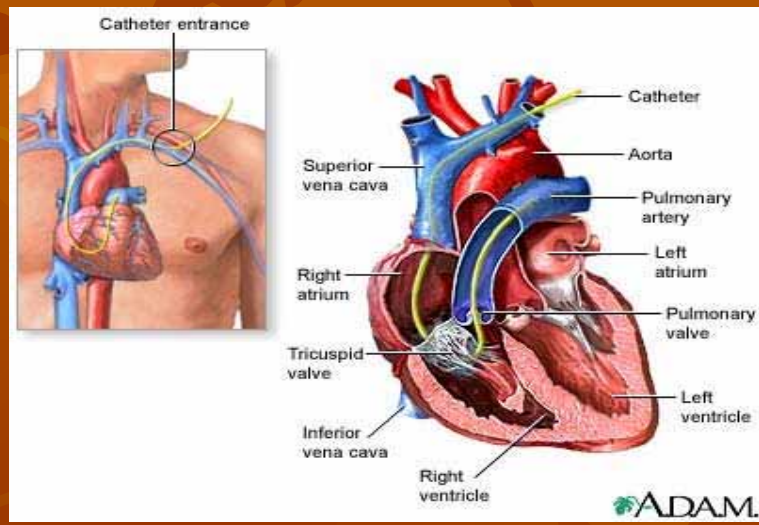
Indicator-dilution method that uses rapid injection

- Common method
  - Dye dilution
    - Injected thought catheter
    - 50% of the dye is excreted by the kidneys in the first 10 min so repeat determinations are possible.
    - Shape of measured curve can provide additional diagnostic information



Indicator-dilution method that uses rapid injection

- Thermodilution
  - CO derived from modification Stewart-Hamilton conservation of heat equation
  - $Q = \frac{V \times Di \times Si[Tb-Ti] \times 60}{dT \times t \times Db \times Sb \times 1000}$
    - V – volume of injectate
    - D – densities
    - S – specific heats
    - T – temp
    - dT – mean temp change
    - t – duration of temp change
    - 60/1000 = scaling factor convert CO into l/min



Indicator-dilution method that uses rapid injection

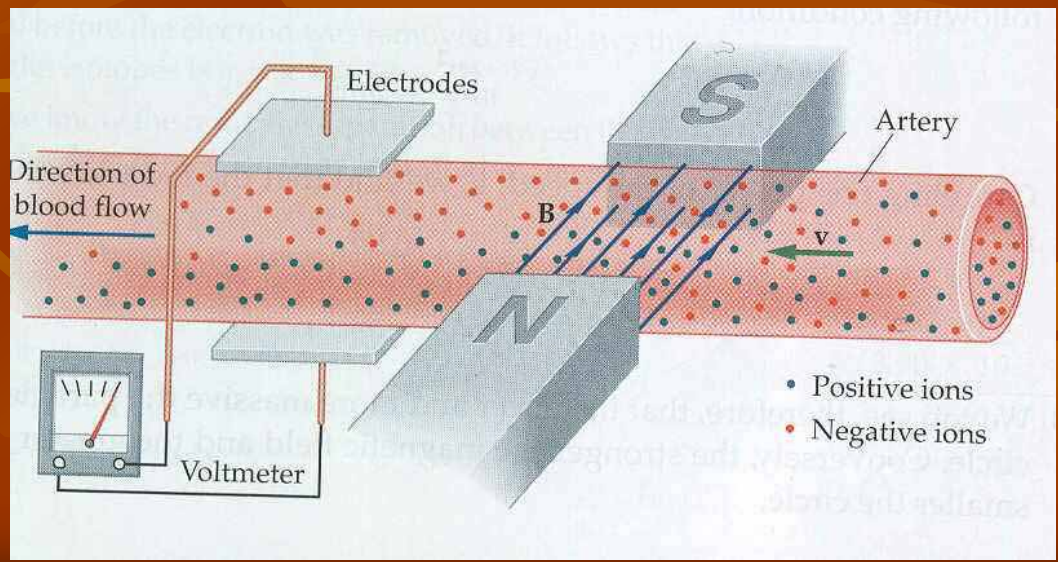
- Common method
  - Thermo dilution
    - Inject bolus of cold saline as an indicator.
    - Equation:

$$F = \frac{Q}{\rho_b c_b \int_0^{t_1} \Delta T_b(t)\,dt} \left(m^3/s\right)$$

    - Q= heat content of injectate, $J\left(=V_i \Delta T_i \rho_i c_i\right)$
    - ρ_b= density of blood, kg/m3
    - Cb= specific heat of blood, J/(kg.K)

Electromagnetic Flowmeters

- Principle:
  - Moving ions in the blood are deflected by magnetic force.
  - Positive ions are deflected down, negative ions are deflected up.
  - This separation of charge creates an electric field E pointing up.
  - There is therefore a potential difference V = Ed between the two electrodes.
  - The velocity of blood flow is measured by v = E/B.



Electromagnetic Flowmeters

- In details, the formula for induced electromagnetic field is given by Faraday's law of induction:

$$e = \int_0^{L_1} u \times B \cdot dL$$

  - B= magnetic flux density, T
  - L= length between electrodes, m
  - U= instantaneous velocity of blood, m/s
- Error factor:
  - The varying drops in resistance within the conductive blood and surrounding tissues.
  - Shunting effects of the wall cause variable error (physiology structure of vessels)
  - The effect of conductivity between in the wall and outside the wall.
  - The not uniform of magnetic-flux in transverse plan
  - The not uniform of magnetic-flux along the axis

Electromagnetic Flowmeters

- DC Flowmeter
  - Using dc magnetic field
  - Some disadvantages: 3 reasons
    - Noise have the same order as flow signal so can not remove
    - Content of ECG and waveform frequency are the same so interference
    - Noise at low freq is large so have poor SNR.
- AC Flowmeter
  - Using ac magnetic field though effect of transformers.
  - Some disadvantages but can solve by using different techniques.