C 8. Measurement of CVS function

a. Outline the physics of blood flow.

b. Give a detailed account of the various methods of measuring blood pressure.

in Physics and Measurement (1.R).

c. Explain the various methods of measuring cardiac output as well as their limitations.

Fick principle (Adolph Fick)

pulmonary venous oxygen flux (q_3) equals pulmonary arterial oxygen flux (q_1) plus alveolar oxygen uptake (q_2)

$$q_1 + q_2 = q_3$$
$$q_1 = Q\,[O_2]_{pa}$$
$$q_3 = Q\,[O_2]_{pv}$$
$$\Rightarrow Q = q_2 \div ([O_2]_{pv} - [O_2]_{pa})$$

so cardiac output (Q) can be calculated from pulmonary O_2 uptake, and mixed venous and pulmonary venous oxygen concentrations.

Mixed venous oxygen concentration can be measured using a Swan-Ganz catheter and pulmonary venous oxygen concentration approximated with a systemic arterial sample.

This method requires determination of oxygen uptake over several minutes and so requires either a completely closed breathing circuit in anaesthesia or an approximation using mixed expired and inspired oxygen concentrations or a laboratory setting.

Indicator dilution

A known amount of an indicator is introduced into the circulation at a point where the entire cardiac output is passing.

The concentration of the marker is measured downstream before any of the flow is diverted to other vessels and its value is plotted over time. For example, the indicator might be injected in the right atrium and the sampling done from the pulmonary outflow tract.

The amount of indicator (n) is related to its mean concentration ($\bar{c}$), cardiac output (Q) and the time for which it is detected (t_2 - t_1):

$$n = \bar{c}\dot{Q}(t_2 - t_1)$$
$$\bar{c} = \frac{\int c\ dt}{t_2 - t_1}$$
$$\Rightarrow \dot{Q} = \frac{n}{\int c\ dt}$$

The conventional expression is in the Stewart-Hamilton equation:

$$\dot{Q} = \frac{n}{\int c\ dt} = \frac{k(T_{core} - T_{indicator})V_{indicator}}{\int_{t_1}^{t_2} -\Delta T\ dt}$$

This can be done using a dye indicator (which requires a semi-log plot to determine t_2 when recirculation occurs) or more commonly using cold saline with temperature being the “indicator”. There is an inherent inaccuracy in thermodilution when thermal exchange occurs between the blood and the vessel and structures surrounding it and when cool fluids may be being infused peripherally in a variable fashion.

Echocardiography

Cardiac output ($\dot{Q}$) can be calculated using the TOE probe to measure cross-sectional area (A) and flow velocity (V) over the duration of one cardiac cycle (t) at a point where the entire cardiac output is passing (e.g. pulmonary outflow tract).

$$\overline{V} = \frac{\int V \ dt}{t}$$

$$\dot{Q} = A \times V$$

This method assumes equal flow over the whole area and it is technically difficult to perform.

d. Outline methods and principles used to measure regional blood flow.

hepatic

Fick principle with indocyanine green

cerebral

Kety-Schmidt technique

renal

PAH clearance