ROHINI
COLLEGE OF ENGINEERING AND TECHNOLOGY
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DEPARTMENT OF BIOMEDICAL ENGINEERING

BM3491 Biomedical Instrumentation

UNIT-IV MEASUREMENT OF BIO SIGNALS

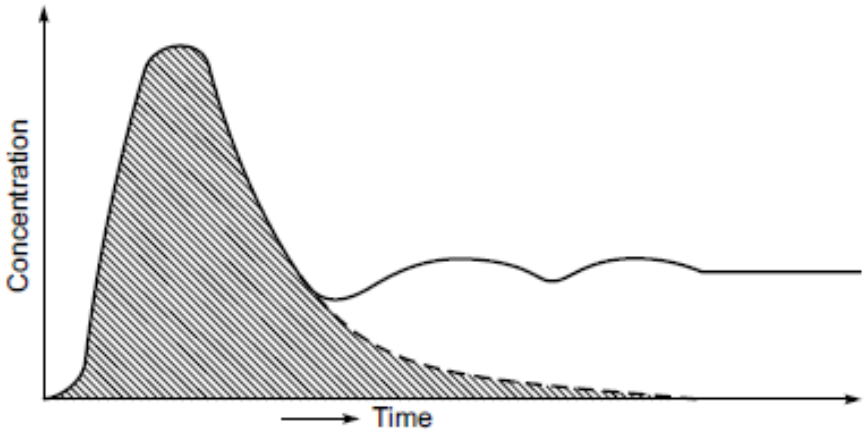
4.4 Cardiac output measurement

- Cardiac output is the ***quantity of blood delivered by the heart*** to the aorta per minute.
- It is a major determinant of ***oxygen delivery*** to the tissues.
- Obviously, problems occur when the supply of blood from the heart is unable to meet the demand.
- ***A fall in cardiac output*** may result in low blood pressure, reduced tissue oxygenation, acidosis, poor renal function and shock.
- *It reflects* the ***myocardial function*** and when taken with other measurements such as blood pressure and central venous pressure, the rational treatment of cardiac disorders becomes clearer.
- ***Stroke volume of blood*** pumped from the heart with each beat at rest varies among adults between 70 and 100 ml, while the cardiac output is 4 to 6 l/min.
- The direct method of estimating the cardiac output consists in measuring the stroke volume by the use of an ***electromagnetic flow probe*** placed on the aorta and multiplying it by the heart rate.
- The method involves surgery and, therefore, is not preferred in routine applications.
- Another well-known method for measuring cardiac output is the ***Fick's method***, which, consists in determining the cardiac output by the analysis of the gas-keeping of the organism.
- Even this method is rather complicated, difficult to repeat, necessitates catheterization and, therefore, cannot be considered as a solution to the problem, though it is practiced at many places even now.

- The most popular method group is the one applying the principle of ***indicator dilution.***

Indicator Dilution Method:

- Indicator dilution principle states that if we introduce into or remove from a stream of fluid a known amount of indicator and measure the concentration difference upstream and downstream of the injection (or withdrawal) site, we can estimate the volume flow of the fluid.
- The method employs several different types of indicators. Two methods are generally employed for introducing the indicator in the blood stream, viz it may be injected at a constant rate or as a bolus.
- The method of continuous infusion suffers from the disadvantage that most indicators re-circulate, and this prevents a maximum from being achieved. In the bolus injection method, a small but known quantity of an indicator such as a ***dye or radioisotope*** is administered into the circulation.
- It is ***injected*** into a ***large vein*** or preferably into the right heart itself. After passing through the right heart, lungs and the left heart, the indicator appears in the arterial circulation.
- The presence of an indicator in the ***peripheral artery*** is detected by a suitable (photoelectric) transducer and is displayed on a chart recorder.
- This way we get the cardiac output curve shown in figure. This is also called the ***dilution curve***.



- The run of the dilution curve is self-explanatory. During the first circulation period, the indicator would mix up with the blood and will dilute just a bit. When

passing before the transducer, it would reveal a big and rapid change of concentration.

- This is shown by the rising portion of the dilution curve. Had the circulation system been an open one, the maximum concentration would have been followed by an exponentially decreasing portion so as to cut the time axis as shown by the dotted line. The circulation system being a closed one, a fraction of the injected indicator would once again pass through the heart and enter the arterial circulation.
- A second peak would then appear. When the indicator is completely mixed up with blood, the curve becomes parallel with the time axis. The amplitude of this portion depends upon the quantity of the injected indicator and on the total quantity of the circulating blood.
- For calculating the cardiac output from the dilution curve, assume that

  M = quantity of the injected indicator in mg

  Q = cardiac output

$$Q = \frac{M}{\text{average concentration of indicator per litre of blood for duration of curve} \times \text{curve duration in seconds}} \cdot 1/s$$

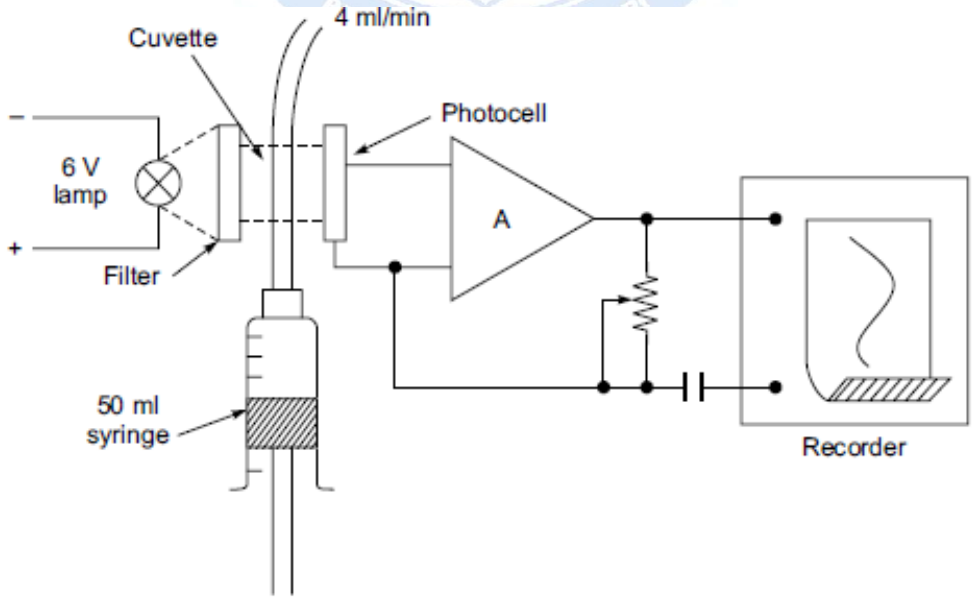
$$= \frac{M \times 60}{\text{area under the curve}} 1/\min$$

- The area under the primary curve obtained by the prolongation of the down slope exponential curve to cut the time axis, encloses an area showing the time concentration relationship of the indicator on its first passage round the circulation.
- The decreasing exponential portion of the curve appears as a straight line, which is projected downwards to cut the time axis. The area under the replotted primary dilution curve is then measured either with a mechanical planimeter or by counting the square units under the curve.

Dye Dilution Method:

- The most commonly used indicator substance is a dye.
- Indocyanine green (cardiogreen) dye is usually employed for recording the dilution curve.

- This dye is preferred because of its property of absorbing light in the 800 nm region of the spectrum where both reduced and oxygenated haemoglobin have the same optical absorption.
- While using some of the blue dyes, it was necessary to have the patient breathe oxygen. The concentration of cardiogreen can be measured with the help of infra-red photocell transducer.
- Dye cuvettes of volume as small as 0.01 ml are available.
- The procedure consists in injecting the dye into the right atrium by means of a venous catheter.
- Usually 5 mg of cardiogreen dye is injected in a 1 ml volume. The quantity used may be 2.5 mg in the case of children. A motor driven syringe constantly draws blood from the radial or femoral artery through a cuvette.
- The curve is traced by a recorder attached to the densitometer.
- After the curve is drawn, an injection of saline is given to flush out the dye from the circulating blood. There are problems relating to the use of the indicator indocyanine green.
- It has been experimentally determined that above a dye concentration of approximately 20 mg/ml of blood, the optical density rises less with an increase in dye concentration than below this level.



Diagrammatic representation of a densitometer for quantitative measurement of dye concentration

- Figure shows a diagrammatic representation of a densitometer which can be used for the quantitative measurement of dye concentration. The photometric part consists of a source of radiation and a photocell and an arrangement for holding the disposable polyethylene tube constituting the cuvette.
- An ***interference filter*** with a peak transmission of **805 nm** is used to permit only infrared radiation to be transmitted. This wavelength is the isobestic wavelength for haemoglobin at various levels of oxygen saturation.
- In order to ***avoid the formation of bubbles***, the cuvette tubing should be flushed with a solution of ***silicone in ether***.
- flow rate of ***40 ml/min*** is preferred in order to get as short a response time as possible for the sampling catheter. The sampling syringe has a ***volume*** of ***50 ml/min.***
- The output of the photocell is connected to a ***low drift amplifier***. It has a high input impedance and low output impedance. The amplification is directly proportional to the resistance value of the potentiometer R.
- A potentiometric recorder records the amplifier signal on a 200 mm wide recording paper and a paper speed of 10 mm/s.

Thermal Dilution Techniques:

- A thermal indicator of known volume introduced into either the right or left atrium will produce a **resultant temperature change** in the pulmonary artery or in the aorta respectively, the integral of which is inversely proportional to the cardiac output.

$$\text{Cardiac output} = \frac{\text{"a constant"} \times (\text{blood temp.} - \text{injectate temp.})}{\text{area under dilution curve}}$$

- Fig.4.4.3 shows a typical cardiac output thermal dilution set up. A solution of ***5% Dextrose*** in water at room temperature is injected as a thermal indicator into the right atrium.
- It ***mixes*** in the right ventricle, and is ***detected*** in the pulmonary artery by means of a ***thermistor*** mounted at the tip of a miniature ***catheter probe.***

- The ***injectate temperature*** is also sensed by a thermistor and the temperature difference between the injectate and the blood circulating in the pulmonary artery is measured.

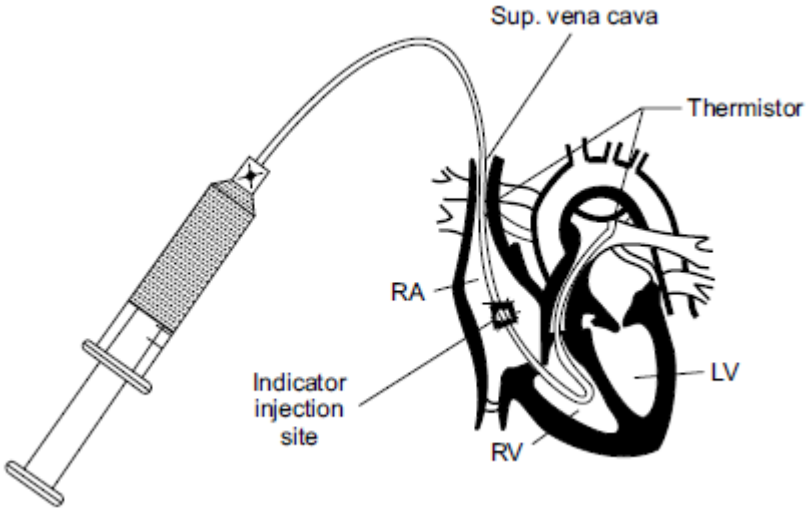


Fig. 4.4.3 Cardiac output thermal-dilution set-up

- The ***reduction in temperature*** in the pulmonary artery (due to the passage of the Dextrose) is integrated with respect to time and the blood flow in the pulmonary artery is then computed electronically by a computer which also applies correction factors.
- A meter provides a ***direct reading of cardiac output*** after being muted until integration is complete so as to avoid spurious indications during a determination.
- The electronic computation is relatively simple, because there is no significant recirculation of the indicator in man. The calculation rests upon the integral of the inscribed curve, the resting temperature in the pulmonary artery, the temperature of the injectate, and a number of constants.
- Absence of the need to subtract that part of the area under the curve due to recirculation, and the ease with which an unsatisfactory curve can be detected by failure to return to the original baseline value of temperature, contribute to the internal consistency of the results.
- The system calibration is based upon the use of an injection of 10 ml of 5% Dextrose solution at a temperature in the range of 18–28°C. Within this range, the injectate temperature is measured to an accuracy of ± 0.2°C, and is also displayed on a meter.

- Blood temperature is measured over a range of 30 to 40°C to an accuracy of ±0.2°C.
- During a determination the incremental temperature is automatically derived, relative to a baseline value equal to the blood temperature, immediately before starting the determination.
- The incremental temperature is measured and displayed in the range 0-1°C full scale to an accuracy of ± 0.02°C.

Impedance Technique :

- The technique used for the measurement of cardiac output by the impedance method is illustrated in Fig. 4.4.4. If r is the resistivity, the resistance of the thorax between two sensing electrodes (2 and 3) is given by

$$R_0 = \frac{\rho L}{A}$$

where L is the separation between the electrodes and A is the cross-sectional area of the thorax.

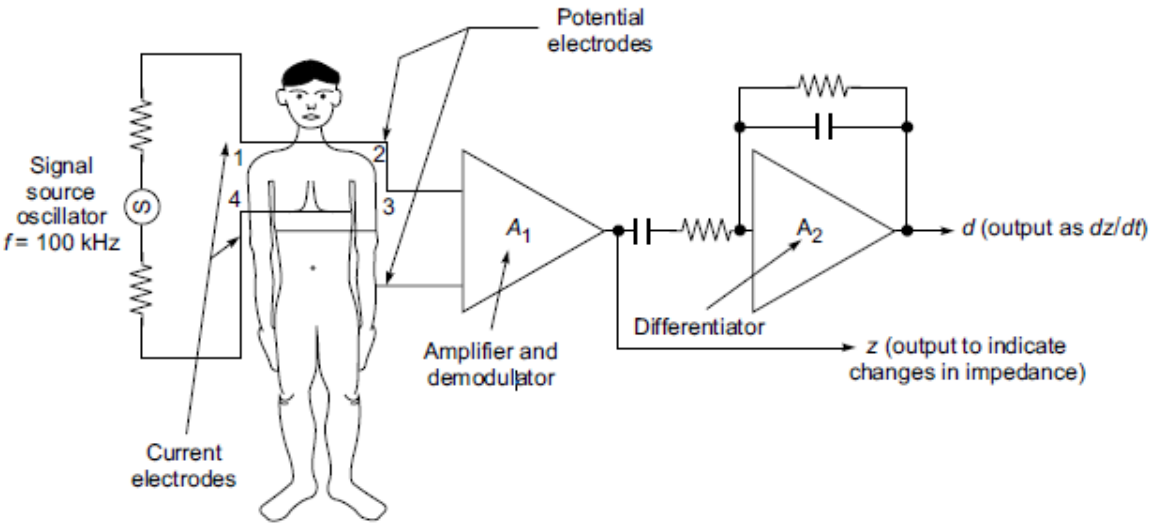


Fig. 4.4.4 Technique of measuring cardiac output by impedance changes

Assuming that with each ejection of stroke volume dV, the resistance decreases by dR, it can be derived that

$$dV = \left[\frac{L^2}{R_0^2}\right] dR$$

- R can be replaced by Z if an ac signal is used for transthoracic impedance measurement, thus giving

$$dV = \left[\frac{L^2}{R_0{}^2}\right] dR$$

- In this relationship, dV is the stroke volume in ml, r is the resistivity of the patient's blood in Ω.cm and dz is the decrease in Z_0 during a particular systolic ejection. The stroke volume is given by the product of the initial rate of change of impedance and the time the aortic and pulmonic valves open.

  i.e., dz = T(dz/dt)$_{max}$ where (dz/dt)$_{max}$ corresponds to the peak negative value of dz/dt found during systole and T is the interval between dz/dt =0 and the second heart sound.

- For experimentally calculating the stroke volume, a constant current at 100 kHz is applied between electrodes 1 and 4. The resulting voltage fluctuations occurring across the thorax coincident with cardiac activity are detected at the inner pair of electrodes 2 and 3.
- The basal impedance between these electrodes is found to be about 25Ω and this diminishes by about 0.1 Ω with each systole.
- The voltage signal due to changes in impedance is amplified and demodulated to obtain Z.
- The dz/dt is calculated using a differentiator.
- A two-channel recorder is used to record dz/dt and the phonocardiogram.
- The method of measuring cardiac output from transthoracic impedance plethysmograms has several advantages in clinical use, especially in monitoring each stroke volume non-invasively.
- For this reason, there have been many correlation studies of cardiac-output values between those measured by this method and those by other methods such as indicator dilution, Fick and pressure-gradient methods.

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