Proc. Workshop on Instrumentation for Cardio-vascular Monitoring & Therapy.
~~Bombay~~ Cardiological Society of India, Bombay, 9th July, 1995
Ed. Subir Kar

Non-invasive Cardiac Output Monitoring

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Cardiac output, the quantity of blood delivered by heart to aorta per minute, is the major determinant of oxygen supply to tissues. It can be obtained by multiplying the stroke volume and the heart rate. Stroke volume can be directly estimated by using an electromagnetic flowmeter probe placed on the aorta. Semi-invasive methods include (i) Fick's method, (ii) indicator dilution method, (iii) dye dilution method, (iv) aortic pressure waveform method. All these techniques require catheterization and the presence of well trained operators [1].

Impedence cardiography offers a method for monitoring cardiac stroke volume and output non-invasively and continuously [2-4]. The stroke volume (SV) is calculated from changes in the thoracic impedence "Z" caused by the varying amount of blood in the lungs during a cardiac cycle. As the blood resistivity "ρ" is for less than other body tissues, the changes in Z are mainly due to changing blood volume in the thorax. Using the "two components model" of Kubicek, the stroke volume is given as

$$SV = \rho \left(\frac{L^2}{Z_o^2}\right) \Delta Z$$

where Z_o is the base impedence, L is the separation between electrodes used for sensing thorax impedence, and ΔZ is the change in impedence due to blood flow into the thorax. The sensed impedence Z at any given instant depends on both influx and outflux of blood. Several models have been proposed for estimating ΔZ from Z. In the "forward slope extraction" procedure proposed by Patterson, ΔZ can be estimated as

$$\Delta Z = \left(\frac{dZ}{dt}\right)_{max} LVET$$

where LVET is the left ventricular ejection time.

Several instrumentation systems for impedence cardiography have been proposed [2-6]. All these systems have two main functional blocks (i) sensing *Z* waveform (ii) estimation of SV and cardiac output from *Z* waveform. Impedence *Z* is sensed by feeding sinusoidal excitation current at 100 KHz, 5 mA into a pair of electrodes and picking up the voltage on another pair of electrodes. The main issues involved are the choice of electrode configurations, and electrode type (band, spot, or combination). The main instrumentation challanges are removal of breathing artefacts from *Z* waveform.

The estimation of Z_0 does not pose any severe problem, but estimation of LVET is a difficult task, and several signal processing techniques have been employed to tackle this problem [5-7]. The blood resistivity "ρ" can be assumed to be 150 Ω - cm in normal cases, but it is related to the patient's hematocrit, and therefore should preferably be estimated for the individual patient.

So far, the correlation between cardiac output monitored by impedence cardiograph and other "standard" techniques has not been fully satisfactory. But this is a problem in inter-correlation of the values obtained by using the different "standard" methods also.

It is hoped that with development of appropriate signal processing techniques for reliable estimation of "left ventricular ejection time" and appropriate modification in Patterson's method to account for non-uniform rate blood flow into the aorta during the ejection phase, impedence cardiography will become a reliable technique for cardiac output monitoring.

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