The Effect of a Progressive Decrease in the Circulating Blood Volume of the Dog on the Transthoracic Impedance

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Abstract. The correlations between the haemodynamic and transthoracic electrical impedance changes resulting from a progressive reduction in the circulating blood volume were studied in four intact mongrel dogs artificially ventilated with a mixture of halothane in nitrous oxide-oxygen. The cardiac output of the dogs was measured by both the electrical impedance and the fibre optic dye dilution techniques. It was found that significant correlations existed between the blood loss and the arterial blood pressure, the maximum first derivative of the transthoracic impedance, the Heather Index, the transthoracic impedance, the maximum rate of change of aortic pressure and the cardiac stroke work. There was also a good correlation between the dye and impedance cardiac output values, the impedance value always being higher than the corresponding dye value. The correlation between the Heather Index and the PEP/LVET ratio and 1/PEP² varied markedly from dog to dog.

Key words: Thoracic impedance, Haemorrhage, Systolic time intervals.

Introduction

The availability of a fibre optic densitometer (Polanyi, 1975) led us to investigate the changes in cardiac output in the dog as a result of a progressive reduction in the circulating blood volume using both the dye dilution and the electrical impedance method of Kubicek et al., (1966) and to compare the changes observed in the transthoracic impedance waveforms with the corresponding changes seen in as many haemodynamic variables as possible. The following measurements were performed: heart rate; aortic blood pressure; stroke volume and cardiac output by the dye dilution and electrical impedance methods; left ventricular stroke work; maximum rate of rise of the aortic blood pressure; the area under the aortic pressure curve during active systole; the maximum rate of change of the transthoracic impedance (dZ/dt)max; the transthoracic impedance Z₀; the ratio of the pre-ejection period to left ventricular ejection time PEP/LVET; the reciprocal of the pre-ejection period squared 1/PEP²; the diastolic interval and the Heather Index.

Methods

Four unselected mongrel dogs of either sex and weighing 19.7–27 kg were premedicated with acepromazine (0.2–0.4 mg per kg) intramuscularly. They were anaesthetised 30 to 60 minutes later with thiopentone sodium (25 mg per ml, 0.5 ml per kg) intravenously. The trachea was intubated with a 9–11 mm cuffed endotracheal tube and anaesthesia maintained with 1.0–1.5% halothane in nitrous oxide/oxygen (60/40). Intermittent positive pressure ventilation was provided by a Manley ventilator (Hutchinson Blease Ltd.) with a non-rebreathing system, at an inflation pressure of 20–25 cm water. The minute volume of ventilation was adjusted in each case to maintain the arterial carbon dioxide tension within physiological limits. The body temperature was maintained at 37 °C ± 1.5 °C.

Following the induction of anaesthesia, a polyethylene cannula (Bardic, 18) was introduced into the left femoral artery for the withdrawal of blood. A catheter-tip micropressure transducer (Millar Instruments Inc. Model PC-350) was introduced into the ascending aorta via the right femoral artery for the measurement of the aortic pressure. An atmospheric pressure reference was obtained during the previous calibration of the transducer in water at 37 °C. A thermistor temperature probe (Light Laboratories Ltd., size 5F) was placed in the right femoral vein to monitor body temperature. Two catheters were advanced into the ascending aorta via the right carotid artery and placed approximately 20 mm from the aortic valve. One was a fluid-filled nylon catheter (5F, Portex
The output signal from the densitometer was taken to an analogue cardiac output computer (Waters Instruments Inc., Model DCR-702). A fluid-filled nylon catheter (5F, Portex Ltd.) was placed in the left ventricle via the left carotid artery for dye injection. This was connected to a powered injector (Contraves AG) set to deliver a dose of indocyanine green dye and 5 ml of saline wash. It was triggered by the preceding R-wave of the lead II ECG after a delay of approximately 300 ms. A similar catheter was placed in the right ventricle via the left jugular vein for pressure measurements and connected to an external pressure transducer (Bell and Howell Ltd., Type 4-327-L221). The position of each catheter was verified by pressure tracings and re-checked at autopsy.

Four disposable Mylar tape electrodes, each having an aluminium strip along its mid-line (3M type M 6001) were placed around the dog in order to measure its transthoracic impedance, the skin under the electrodes having been closely shaved and smeared with Cambridge electrode jelly. Two electrodes were placed around the neck and two around the thorax, the innermost at the level of the xiphisternum. The outermost pair of electrodes was fed with a constant sinusoidal current of level of the xiphisternum.

The impedance stroke volume was calculated from the equation of Kubicek et al. (1966): $SV_Z = p \left( \frac{L^2}{Z_o^2} \right) LVET \left( \frac{dZ}{dt} \right)_{\max}$, where $SV_Z$ is the impedance stroke volume in ml, $p$ is the specific resistance of the dog’s blood at 100 kHz in ohm-cm, $L$ is the shortest distance in cm between the innermost pair of band electrodes, $Z_o$ is the basal thoracic impedance in ohms, LVET is the left ventricular ejection time in seconds, and $(dZ/dt)_{\max}$ is the height of the systolic peak of the $dZ/dt$ tracing in ohms per second above the baseline. LVET was measured from the crossing of the baseline by the systolic upstroke of the $dZ/dt$ tracing to the incisura of the aortic pressure waveform. The impedance cardiac output was calculated as the product $SV_Z \times$ heart rate.

The cardiac output was also estimated by the dye dilution technique with the injection of 1 ml of indocyanine green dye (1.25 mg per ml) into the left ventricle. Sampling of the blood was performed simultaneously by withdrawing blood at a rate of 20 ml per minute from the aortic catheter through the densitometer cuvette. The cardiac output in litres per minute was automatically calculated on the associated analogue computer. Additionally, the arterial concentration of dye was measured with the fibre optic densitometer operating with a time constant of 0.2 s. The resulting dye dilution curve was plotted on a flat bed potentiometric chart recorder together with the lead II ECG on a second channel. The dye curve exhibited notches corresponding with each stroke ejection. This was confirmed from the position of the R-waves of the ECG. After each experiment had ended, the fibre optic densitometer was calibrated by immersing the tip of the fibre optic catheter in a sample of the dog’s blood containing a known amount of dye and magnetically stirred. The cardiac output values from the analogue computer were only used as a check on the cardiac output during the experiment and have not been included in the statistical analysis.

The following signals were displayed on an ink jet recorder (Mingograf Type 81) at a paper speed of 100 mm per second: the change in the thoracic impedance $\Delta Z$; the rate of change of the thoracic impedance $\frac{dZ}{dt}$; the aortic blood pressure; the right ventricular pressure and the lead II ECG. The value of the basal thoracic impedance $Z_o$ was read from the digital display of the impedance cardiograph.

A set of recordings was taken after each successive withdrawal of 50-80 ml of blood to a total of 375 to 755 ml. From the six waveforms the following variables were obtained: heart rate; systolic, diastolic, mean and pulse pressure in the aorta; $(dZ/dt)_{\max}$; the $R -(dZ/dt)_{\max}$ interval; the Heathcote Index, i.e. $(dZ/dt)_{\max}$ divided by the $(R-(dZ/dt)_{\max})$ interval; the left ventricular ejection time LVET; the pre-ejection period PEP (Q-wave to notch interval minus LVET); $1/PEP^2$; diastolic interval (notch to the following Q-wave, Weisdorf and Spodick, 1976); $R$-R interval; systolic area (area under the aortic pressure waveform during systole and above end-diastolic pressure); cardiac output and stroke volume from planimetry of the fibre optic dye dilution curve, $Q_{dyne}$ and $SV_{dyne}$; cardiac output and stroke volume by the impedance technique, $Q$ and $SV$; stroke work ($SV_{dyne} \times$ mean aortic pressure, Kappagoda and Linden, 1976) and the total systemic resistance (mean aortic pressure/$Q_{dyne}$).

A multiple cross-correlation computer program was used to determine the correlation between the individual pairs of variables and the level of significance of the correlation coefficients. Fisher’s Z-transform was em-