MEASUREMENT OF CARDIAC OUTPUT

BY THERMAL DILUTION IN MAN

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Float catheterisation of the pulmonary artery was described in The Lancet by Dr R D Bradley (as he then was) in 1964 at a time when invasive circulatory monitoring was almost non-existent outside cardiac surgical units, and ‘intensive care’ was a term barely in use. Cardiac catheterisation was laboratory based and required radiological control: management of acute circulatory crises relied on clinical assessment alone. Dr Bradley recognised the diagnostic and therapeutic value which might accrue from knowledge of central circulatory variables, and used the flow of the circulation itself to direct a fine nylon tube (ID 0.5mm) through the heart and into the pulmonary artery. The catheter was introduced through a short nylon cannula inserted most often in an antecubital vein using the Seldinger technique. A similar cannula in the brachial artery provided not only far more reliable measurement of low arterial pressure than can be achieved with a sphygmomanometer but also permitted display of the arterial waveform, itself of value in interpreting circulatory dynamics.

I had the great good fortune to join Dr Bradley during the 1960s first as a Research Fellow and subsequently Senior Registrar, and we provided a mobile investigative service to patients at St Thomas’ Hospital, trundling around a large trolley which incorporated not only the catheterisation and associated recording equipment but also arterial pH and blood gas analysers – information not otherwise available on the general wards. The pathophysiology of many acute cardio-respiratory disturbances suddenly became so much clearer and treatment could be tailored to need rather than given empirically. Inevitably the mortality amongst such patients was still high and for a while we were known within the hospital as ‘The Death Watch Beetles’.

But two circulatory variables still eluded measurement – left atrial pressure and cardiac output. An attempt to develop a transeptal method for measuring left atrial pressure, using an intracardiac ECG rather than radiology to identify the mid-septum, was rejected in favour of the greater ease and safety of reliance on the end-diastolic pressure in the pulmonary artery as an indirect but reasonably reliable index of left atrial pressure in all but patients with sustained pulmonary hypertension. The final piece in the circulatory jigsaw came from the chance reading of a paper describing measurement of cardiac output by thermal dilution in rabbits and the realisation that it could be adapted for use in man. Laboratory based measurement of cardiac output at the time depended on either the Fick technique or dye dilution. The former is neither accurate nor practical in the acutely ill and conventional dye dilution is unreliable when cardiac output is low because of recirculation. But if the indicator is heat – or negative heat - it is dissipated within one circulation and the measurement is reliable.
So, the original 0.5mm ID nylon catheters were modified to house a bead thermistor mounted on two insulated copper wires which were drawn through the 110 cm catheter and then hand-soldered to the thermistor, the junction being insulated with teflon spray and then pulled back until the thermistor was in the tip of the catheter where it was held by injecting a silicone sealant. Finally a side-hole proximal to the thermistor was created with a heated wire so that pressure measurements and samples could still be obtained. The good eye sight of youth was necessary for this manufacturing process! The proximal end of the wires was brought out through the hub of the catheter and the signal detected on a simple Wheatstone bridge and recorded on graph paper. The indicator was a bolus of 10 ml of 5% dextrose at room temperature, injected through a catheter introduced percutaneously into the jugular vein. This technique was another of Dr Bradley’s innovations, explored and refined by experiment on each other, although subsequently superseded by an easier approach developed by Dr Ian English at the Brompton Hospital.

Measurements of cardiac output were made in triplicate over a period of a few minutes and were surprisingly consistent. But initially the calculation was time-consuming because it involved ‘counting the squares’ on the graph paper to determine the area under the thermal dilution curve. Subsequently the department of medical electronics collaborated in the design of an automated system which not only counted the squares but also completed the calculation and displayed the result.

The technique was validated by comparison with the Fick technique on a series of stable patients requiring intensive care after cardiac surgery. Expired air was collected via a valve assembly incorporated onto the expiratory limb of the breathing circuit, arterial blood was readily available from the routine indwelling arterial cannula and mixed venous blood was sampled – very slowly - through the tiny port of the thermistor catheter. Three measurements of cardiac output by thermal dilution were made both before, and after the samples were collected for the Fick analysis. The entire procedure – including the manual analysis of the thermal dilution curves and lengthy measurement of oxygen content – was usually undertaken on the first post-operative night and took two people the whole of a night shift to complete.

Unexpected developments followed. Dr Jeremy Swan, an English trained cardiologist then working in the US visited St Thomas’ to discuss float catheterisation and thermal dilution. His subsequent request for detail was answered in a personal letter - typed manually on an elderly machine with a fading ribbon - which presumably arrived but was never acknowledged. Some months later, adverts appeared for the Swan-Ganz catheter – a balloon tipped device for float catheterisation of the pulmonary artery which could incorporate a thermistor for measuring cardiac output by thermal dilution. No acknowledgement of the pioneering work at St Thomas was ever made and, far more importantly, two features of the Swan-Ganz catheter made it much more hazardous: it was much larger in diameter than ‘Bradley catheters’ and
the balloon could, if inflated in the wedge position, rupture pulmonary vessels. Since then, and for a variety of reasons, there has been a waning of enthusiasm for float catheterisation of the pulmonary artery. But in its day it provided invaluable diagnostic and therapeutic information which in turn formed the basis for an instructive monograph ‘Studies in Acute Heart Failure’ authored by the innovator – by now Professor Bradley – and a treasured source of guidance to generations of ICU house officers.

With the wisdom of hindsight, there are some obvious ethical concerns and, if today’s standards had applied, the technique would never have developed. We experimented on each other. We re-used the equipment, cleaning it immediately after use and resterilising it, in the early days in a domestic pressure cooker. Measurements were made on patients, in many cases without their informed consent, and in a few cases where the clinical indication was doubtful. It was widely accepted at the time that patients could be involved non-consensually in research to enhance medical knowledge and so improve the welfare of others....how times have changed!

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