Cardiac output in 1998

M Singer

Over 100 years ago Karl Ludwig stated that:

"The fundamental problems in the circulation derive from the fact that the supply of adequate amounts of blood to the organs of the body is the main purpose of the circulation while the pressures that are necessary to achieve it are of secondary importance; but the measurement of flow is difficult while that of pressure is easy so that our knowledge of flow is usually derivatory."

Are we, in 1998, any nearer to the routine monitoring of flow? The more salient question may be whether flow measurement is actually useful in terms of clinical management or patient outcome. The wherewithal to monitor flow exists. Techniques for cardiac output measurement, albeit of varying accuracy, invasiveness and complexity, have been available commercially for the past 25 years, although their use in the UK is relatively sparse, both in intensive and coronary care units and operating theatres. The national confidential enquiry into perioperative deaths covering the years 1993–94 reviewed 1802 deaths occurring within 30 days of an operation. Three quarters of these patients were deemed moderate to very high risk, yet only 4.2% had a Swan-Ganz (pulmonary artery) catheter in situ during surgery.

**The Swan-Ganz catheter: friend or foe?**

Several studies have shown outcome benefit from flow directed haemodynamic manipulation in the high risk surgical patient using either invasive or non-invasive monitoring techniques. Only sporadic studies have demonstrated an advantage for the critically ill ICU patient. However, a recent retrospective study by Connors and colleagues suggested that patients receiving a Swan-Ganz catheter on day 1 of their ICU admission were 39% more likely to die compared with patients matched for disease and illness severity by complex statistical manipulations who did not receive the catheter. The accompanying editorial advocated an immediate moratorium on catheter use, a situation parallelling an earlier study by Gore et al, who found an increase in mortality in patients with acute myocardial infarction, the only perceived change in management over historical controls being the increased use of Swan-Ganz catheters.

The study by Connors et al has been heavily criticised; nevertheless, it served as the catalyst for a recent US consensus meeting, which acknowledged the lack of conclusive data showing benefit or harm, yet reaffirmed its likely worth. A prospective, randomised trial rather than an immediate ban was recommended, a view supported by the US Food and Drug Administration. It is more likely that fault, if any, lies with how the catheter is used rather than from any intrinsic damage caused by the catheter itself. To contemplate a study comparing management using the Swan-Ganz catheter against bedside clinical acumen alone undermines Ludwig's maxim and is, in my opinion, badly misdirected. A number of studies in both intensive care and coronary care unit populations has shown the unreliability of clinical and radiological evaluation of haemodynamic status with experienced specialists faring no better than junior staff and medical students. A first priority in evaluating the Swan-Ganz catheter should be to ensure adequate training. A recent European questionnaire examining proper use and interpretation of data mirrored an earlier US study showing that competency was highly variable, with only 70% of questions being answered correctly. Second, how the catheter is used must be addressed. At the time of Connors et al's study, many ICUs had adopted the supranormalised oxygen delivery philosophy advocated by Shoemaker whereby the circulation was driven with fluid loading followed by increasing doses of dobutamine to obtain predetermined raised values in cardiac index, oxygen delivery, and consumption. This approach proved highly successful in high risk non-cardiac surgical patients and was subsequently adopted by many ICUs. However, it took several years before—at best—no benefit and—at worst—harm was demonstrated in such critically ill patients in prospective, randomised, controlled studies.

**Non-invasive techniques**

Several non-invasive techniques exist for flow monitoring but none has yet penetrated clinical practice to any great extent. The major issues are reliability and familiarity. Unfortunately, many commercial devices have been launched without proper validation and often with obvious design flaws. Furthermore, thermodilution, an imperfect gold standard, which is often used imperfectly, is often used as the comparator technique. These problems have served to undermine confidence in the various technologies, which upgraded equipment and newer models have yet to fully overcome.

The two best described techniques are Doppler ultrasound and thoracic bioimpedance. Doppler technology has enjoyed a renaissance since the advent of combined Doppler echocar-
Table 1  Formulae used for stroke volume calculation by thoracic bioimpedance

<table>
<thead>
<tr>
<th>Formula</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>( \rho \cdot \frac{L^2}{(dZ/dt)<em>{\text{max}}} \cdot \frac{(dZ/dt)</em>{\text{max}}}{Z_0} )</td>
<td>Kubicek 1966</td>
</tr>
<tr>
<td>( \delta \cdot \frac{L^2}{(dZ/dt)<em>{\text{max}}} \cdot \frac{(dZ/dt)</em>{\text{max}}}{Z_0} )</td>
<td>Sramek 1983</td>
</tr>
<tr>
<td>( \delta \cdot 0.17H \cdot \frac{(dZ/dt)_{\text{max}}}{Z_0} )</td>
<td>Sramek-Bernstein 1986</td>
</tr>
<tr>
<td>( \rho \cdot \frac{(0.17H)^2}{(dZ/dt)<em>{\text{max}}} \cdot \frac{(dZ/dt)</em>{\text{max}}}{Z_0} )</td>
<td>Adjusted Kubicek 1997</td>
</tr>
</tbody>
</table>

\( (dZ/dt)_{\text{max}} \), maximum of 1st derivative of impedance signal; \( \rho \), electrical resistivity of blood; \( L \), distance between two levels of electrodes; \( \delta \), correction factor depending on weight; \( LVET \), left ventricular ejection time; \( H \), height; \( Z_0 \), basic thoracic impedance.

... like a truncated cone. Pulsatile thoracic aortic blood flow causes negative impedance changes with a maximum rate of change during systole between pairs of electrodes placed on the neck and upper abdomen. Various new correction factors and equations have been advanced (table 1) and incorporated into commercial systems using pairs of electrodes placed around neck, thorax, and upper abdomen. Unfortunately, validation studies have produced highly inconsistent results. Generally, the technique appears to be reasonably reliable in healthy volunteers but performs unpredictably in the critically ill. Thus, the paper by Spiering et al in this issue is rather surprising in view of the major discrepancy between bioimpedance and dye dilution in normal subjects. Despite the authors' assurances, I wonder if an unrecognised methodological problem affected the study outcome. If bioimpedance is to develop as a clinical tool it must address these reliability issues, alert the operator to erroneous readings, and regain user confidence.

Other techniques are also available for either intermittent or continuous monitoring of flow. Echocardiographic measurement of ventricular volumes at end systole and end diastole enables stroke volume to be measured with reasonable accuracy; however, at least six different methods have been described and user expertise is a significant factor. Recently developed technology allows three dimensional reconstruction of images of the left ventricle, although ventricular volumes are still generally calculated from cross sectional and M mode images, accepting assumptions about left ventricular shape.

Analysis of the contour of the aortic pulse wave allows monitoring of cardiac output, as the rate blood flows from arteries to veins is proportional to the rate of fall of arterial pressure. This can be performed non-invasively from the finger artery, or from an indwelling pressure transduced arterial cannula. There is not an extensive literature assessing its reliability in different conditions; furthermore, it cannot be used for measurement of cardiac output unless first calibrated against another technique.

Thermal dilution techniques can be performed without the need for pulmonary artery catheterisation, although validation data are scanty. A commercially available device using this technology (COLD; Pulsion, Munich, Germany) also claims to measure global end diastolic volume (the sum of the end diastolic volumes of both left and right atria and ventricles), intrathoracic blood volume (a possible indicator of cardiac preload), and extravascular lung water.
large discrepancies have been found in comparative studies in the critically ill. In theory, the Fick technique is the gold standard for cardiac output monitoring. However, it is invasive and methodological error is not uncommon, for example, when high inspired oxygen concentrations are being administered. Using the indirect Fick approach, the carbon dioxide rebreathing technique is a popular technique among sports physiologists as it is totally non-invasive and more reliable at exercise than at rest. Alternatively, a new approach using lithium chloride as the indicator with mixed venous PCO2 (PVCO2), which, combined techniques and it has yet to be applied at the bedside of the sick patient.

Finally, the dye dilution technique may enjoy renewed interest as a bedside cardiac output monitoring technique through online means of measuring plasma concentrations of indocyanine green, the standard indicator in use today. Alternatively, a new approach using lithium chloride as the indicator with plasma concentrations being measured by a lithium selective electrode in a flow through plasma concentrations being measured by a lithium selective electrode in a flow through arterial cannula, may also merit consideration.

Conclusion
There is sufficient evidence to show that flow monitoring leading to directed haemodynamic management is beneficial, at least in certain patient subgroups. Advantage is generally gained by those at risk of, rather than having, established organ failure, such as the high risk surgical patient. Few studies have demonstrated outcome benefit in critically ill patients in whom metabolic, inflammatory, and cellular processes are often too advanced for benefit to be gained from haemodynamic manipulations that prevent or reverse tissue hypoxia, a potent stimulus of various inflammatory pathways. Current use of flow monitoring generally precludes pre-emptive circulatory optimisation to prevent, or at least, minimise tissue hypoxia. This is equally applicable to the trauma patient or the patient in acute heart failure, where hypovolaemia often passes unrecognised and untreated until hypotension and organ failure have supervened. Invasive measurement of cardiac output is coming under increasing scrutiny and the place of non-invasive technology merits re-appraisal in the light of newer and more reliable equipment and techniques. This should provide impetus for further investigation, particularly in patients in the early stages of illness.

37 Young JD, McQuillan P. Comparison of thoracic electrical bioimpedance and thermodilution for the measurement of cardiac index in patients with severe sepsis. Br J Anaesth 1993;70:38-62.

**Hypertension**

The theme for the 1978 World Health Day was “Down with high blood pressure”. A number of countries issued stamps to promote this campaign. Four stamps and a miniature sheet (containing the complete set) were released by Uganda. Illustrated is the 2 shilling stamp which incorporates the campaign slogan and hypertensive retinal changes. (The other three stamps depicted a sphygmomanometer and a daily blood pressure chart, the heart in hypertension, and the kidneys and renal circulation.) Belgium issued a set of three charity stamps in 1978 for philanthropic works; the middle 6 franc value (carrying a 3 franc surcharge) contained the stamp for the World Health Day. The design incorporates the measurement of blood pressure, a stylised heart, brain, and kidney as well as the electrocardiogram. (The other two stamps in the set featured deserted children and the De Mick sanatorium (antituberculosis campaign issue).)

Hypertension and the measurement of blood pressure have appeared on a few stamps outside of the 1978 World Health Organisation theme. These include stamps from Czechoslovakia in 1952 for the National Health Service, the United Nations (Vienna headquarters) in 1988 for international volunteer day and in 1983 from the British Virgin Islands for nursing week.

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