Accuracy and Reliability of Non-invasive Cardiac Output: The Future in Cardiology?

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Abstract

A new generation of non-invasive cardiac output monitors provides an alternative to using conventional invasive methods such as thermodilution and direct Fick. The Bioz.com measures changes in thoracic electrical bioimpedance (TEB) of the descending aorta. The Innocor uses the principle of inert gas rebreathing. Simultaneous TEB and thermodilution cardiac output measurements were taken from 27 patients undergoing right heart catheterisation. Linear regression analysis showed good correlation between thermodilution and TEB about the line $y=0.85x + 0.63$ ($r=0.91$, $P<0.0001$). Preliminary data from the Innocor suggest comparable accuracy, continuous monitoring, portability, ease of use and low cost for a variety of applications in cardiology.

1. Introduction

This presentation relates the St. Vincent's Hospital experience with a diverse new generation of non-invasive cardiac output monitors, the Bioz.com and Innocor monitors. The Bioz.com measures changes in the baseline thoracic electrical bioimpedance (TEB) of the thoracic aorta (i.e. resistance to flow) to calculate cardiac output. The Innocor uses the principle of inert gas rebreathing, which involves rebreathing an inert, blood soluble gas that is absorbed via the lungs and is cleared exponentially at a rate proportional to the lung perfusion (i.e. cardiac output). Both techniques are possible because of powerful and refined technological advances in mathematical modelling, physiological software and instrumentation technology. Subject to validation and acceptance, both instruments have the potential to revolutionise patient monitoring and clinical evaluation. This would be possible without recourse to other more commonly used invasive and potentially dangerous means of determining cardiac output, such as the Fick Method and thermodilution, both of which require right heart catheterisation.

2. Background

Cardiac output is a useful variable in the diagnosis and management of acute and chronic cardiac conditions. For example, cardiac output is routinely measured during surgery and can be useful in monitoring critically ill patients in the operating theatre, intensive care, or emergency department. Current methods of determining cardiac output invasively are hampered by their potential for complications, including the possibility of infection and sepsis, plus increased risk of morbidity and mortality [1]. Clearly, there is considerable interest in devising a safe, effective and accurate non-invasive method of determining cardiac output as an alternative to existing invasive techniques such as cardiac catheterisation.

Thoracic electrical bioimpedance (TEB) is a non-invasive method of cardiac output estimation that measures changes in the baseline impedance of the thorax as blood flows along the descending aorta [2]. The BioZ.com (CardioDynamics, San Diego, USA) employs this technology for estimation of cardiac output along with a range of other haemodynamic parameters. The principal advantages of TEB are that it is non-invasive, provides continuous cardiac output measurements, can be easily used by a non-medical operator and is relatively inexpensive to perform.

The BioZ.com has been shown to be effective in a wide variety of clinical applications [3]. This study was conducted to validate the clinical accuracy of this instrument by comparison with cardiac output measurements obtained simultaneously by the thermodilution technique.

3. Methods

3.1. Patients

Twenty-seven patients from a population scheduled to undergo right heart catheterisation were enrolled in this study. Simultaneous TEB and thermodilution cardiac output measurements were compared in a linear

regression model. Patients with pacemakers or implantable defibrillators, aortic valve regurgitation and intra-aortic balloon pump operation were excluded from analysis, leaving 24 paired sets of 48 individual cardiac outputs. TEB and thermodilution cardiac output measurements were obtained independently by two technicians. Neither technician was aware of the other's results until after the case was completed. Owing to the nature of the study, double-blind randomised data collection was not feasible.

3.2. Statistical methods

Comparisons of group means and differences between paired observations were performed using Prism version 2.01 (GraphPad Software Inc, San Diego, CA). A paired t- test was used to test the hypothesis that there were no differences between paired observations and to calculate the mean bias. Multiple regression analysis was performed using SAS version 6.12 (SAS Institute, Cary, NC). A P value less than or equal to 0.05 was considered statistically significant.

4. Results

We present data obtained from 48 simultaneous TEB and thermodilution cardiac output measurements from 27 patients undergoing right heart catheterisation (Figures 1 and 2). Linear regression analysis showed good correlation between thermodilution and TEB about the line $y=0.85x + 0.63$ ($r=0.91$, $P<0.0001$).

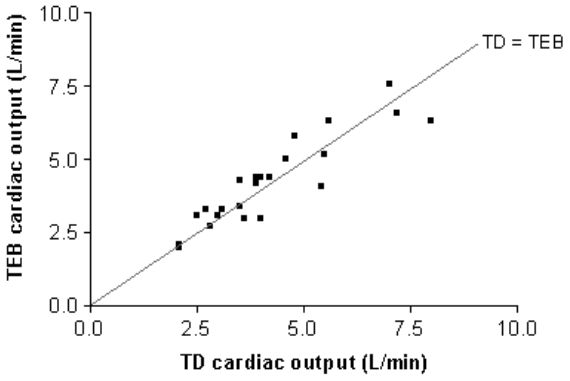

Figure 1. Linear regression of thermodilution and TEB cardiac output measurements.

Limited preliminary data from the Innocor rebreathing device (Innovision, Odense, Denmark) promise comparable accuracy, continuous monitoring, portability, ease of use and low cost. We consider both methods an important advancement in patient safety and cost-effective health care.

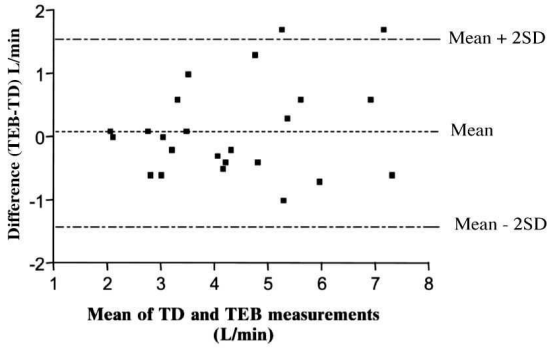

Figure 2. Bland Altman analysis of data in Fig.1, showing little systemic difference between the two sets of values.

5. Discussion

5.1. Clinical implications

Accurate determination of cardiac output is one of the single most valuable diagnostic parameters in clinical cardiology. Yet, despite several innovative new techniques, the original Fick Method remains the gold standard by which all other methods are assessed. The thermodilution technique, which is probably the most commonly used method of determining cardiac output, also involves insertion of a right heart catheter into the pulmonary circulation, with similar attendant risks. Routine measurement of cardiac output using these two techniques is consequently hampered by its invasive nature, which has the potential for serious complications.

The non-invasive nature of TEB, like the Innocor instrument, means that these new techniques can be available to a wider selection of patients without the potential complications of other invasive methods, and can be applied quickly with a minimum of training. Most other methods of cardiac output determination either require a team of highly skilled specialists, are invasive procedures, or involve complex equipment and high cost.

In the cardiac catheterisation laboratory, left and right heart catheters are routinely inserted to facilitate pressure measurement and to permit Fick or thermodilution cardiac output measurements. In other settings such as the intensive care or coronary care units, pulmonary artery catheters need to be especially

inserted to determine cardiac output. TEB and inert gas rebreathing are two new techniques that permit determination of cardiac output without invasive catheterisation, and allow continuous measurement of cardiac output, which is not possible by direct Fick or thermodilution methods. It is expected that TEB cardiac output modules will be available for various haemodynamic monitoring systems in the near future, which will facilitate monitoring of cardiac output in greater numbers and in a much wider selection of patients than is currently available [2]. Our data are consistent with other published findings on the accuracy of bioimpedance cardiography and its equivalence with other thermodilution techniques [4]. The newer Innocor device is still subject to independent clinical evaluation and is expected to find a similar niche in monitoring patients.

Hence, non-invasive techniques have valuable potential for use in a variety of clinical settings. Patients receiving cardioactive therapies can be monitored, and changes in cardiac output and other haemodynamic parameters can be followed with the trend capabilities of the BioZ.com, as potential invasive hazards have been eliminated.

5.2. Study Limitations

Previous studies have shown that the thermodilution method has little bias compared to the Fick method [5,6] while others show that thermodilution measurement can overestimate cardiac output by as much as 2.3L/min compared to the Fick technique [7]. Our results show that the accuracy of the new TEB technology is at least comparable to that of thermodilution techniques. However, limitations such as the effect of shifting fluid volumes on conduction (as with tricuspid or aortic valve incompetence), or the potential for electrical interference (as with pacemakers or patient movement) suggest that its application may be limited in certain clinical areas. Despite these restrictions, its benefits considerably outweigh its limitations. Ultimately, a clinician's choice of non-invasive methodology will depend on its benefits relative to the degree of accuracy required for individual applications.

5.3. Implications for Further Research

The Bioz.com has great potential for use in research. Heart responses during coronary interventions could be assessed through cardiac output and the other parameters available on the unit. Assessment of patients with acute coronary syndromes may help to define subgroups of patients in whom different therapies are appropriate, while short and long-term effects of new drugs for a variety of cardiac conditions can also be assessed.

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