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Transthoracic electrical bioimpedance versus thermodilution technique for cardiac output measurement during mechanical ventilation

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Abstract. To study the possible influence of mechanical ventilation on the accurracy of thoracic electrical bioimpedance (TEI) in the measurement of cardiac output, we determined cardiac output concurrently by TEI using Kubicek's equation and by thermodilution in 8 acutely ill patients who were mechanically ventilated (assist/control mode) but who had no underlying respiratory failure. Cardiac outputs were lower with TEI than with thermodilution (3.97 ± 0.80 vs 4.83 ± 1.16 l/min $p = 0.004$) and there was poor correlation between the values ($r = 0.41$). Although there is a need to develop non-invasive techniques to measure cardiac output, the present study indicates that TEI is not reliable in mechanically ventilated patients.

Key words: Cardiac output determination – Bioimpedance – Thermodilution – Mechanical ventilation

Thoracic electrical bioimpedance (TEI) is a method used to measure the stroke volume non-invasively [3, 6, 7, 8]. The principle depends on the constant application along the thorax of an electrical current of low intensity and high frequency: pulsatile variations in aortic blood flow induce an opposite change in TEI, which is derived electronically.

Although earlier studies expressed doubts about the precision of the technique [6, 8], more recent studies using Kubricek's equation [7] showed a better correlation between cardiac output values measured by TEI and by thermodilution [1, 2, 3, 10]. A recent upsurge of interest is also related to the availability of a digital, on-line computer connected to spot electrodes rather than the cumbersome circumferential electrodes placed around the neck and the lower thorax. The accuracy of the TEI technique may be affected by many factors including the use of mechanical ventilation. Donovan et al. [5] recently found that the TEI technique was less accurate in mechanically ventilated patients, but the possible influence of the underlying pulmonary problem was not clearly defined. We therefore compared stroke volume measurements obtained by TEI and by thermodilution in a series of critically ill patients who were mechanically ventilated but who did not have evidence of respiratory failure.

Patients and methods

Patients were selected if they fulfilled two criteria: Firstly they had a Swan-Ganz catheter in place because of previous haemodynamic instability or perioperative invasive monitoring. Secondly they were mechanically ventilated (assist/control mode) for other reasons than respiratory failure. In particular, there were no signs of pulmonary oedema or pulmonary infection on the basis of current clinical, radiological, bacteriological or haemodynamic critieria.

Eight patients were studied (6 men, 2 women) ranging in age from 32 to 69 years (median age 62 years). Five patients were studied postoperatively: three after cardiac surgery (aortic valve replacement in 1, coronary artery bypass graft in 1, and both valve replacement and bypass graft in 1), and two after oesophagogastrectomy. Two patients had neurological disease (1 had meningitis and the other a subarachnoid hemorrhage) and one patient had myocardial infarction with recent circulatory failure. Each patient was mechanically ventilated on assist/control mode with tidal volumes of 10–15 ml/kg and zero end-expiratory pressure. No patient had a history of chronic respiratory failure. In each case, the haemodynamic status was stable and there was no evidence of hypovolaemia. Each patient had an haematocrit between 30 and 40%. A pulmonary artery catheter (Swan-Ganz model 93A–131H–7F, Edwards Laboratories) had previously been inserted and cardiac output was measured by the thermodilution technique (COM-1, Edwards Lab) using cold (< 8 °C) water and a closed system (Co-set system, Edwards Lab). The bolus injection was started at end-inspiration to reduce the variability of the measurement [4, 9]. Water injections were performed manually.

TEI was measured after placement of 8 voltage-sensing electrodes. Four electrodes were located on each side of the thorax: two at the xyphoid level and two 5 cm lower. Four electrodes were located on each side of the neck: two at the level of the carotid artery and two 5 cm higher. The electrodes were connected to the TEI computer (NCCOM-3, BoMed Medical Manufacturing Ltd, Irvine, CA). The patient's characteristics (height, weight and sex) were introduced in the computer's keyboard in order to calculate TEI cardiac output [3].

Thermodilution and TEI cardiac output measurements were made concurrently. For the thermodilution cardiac output, three to five measurements were averaged. For the TEI cardiac output, data (automatically updated every twelve beats) were averaged over one minute. Comparison of measurements was repeated within 24 h if the mean thermodilution cardiac output value had varied by more than 5% (The differences were then considered as significant). So, four measurements were obtained in 2 patients, two in 2 patients and one in 4 patients.

Results were analyzed by Student's t test for paired data. Data are presented as mean ±SD.

Results

Cardiac output values measured by TEI averaged 3.97±0.80 l/min (range 3.00–6.00 l/min) and by thermodilution 4.83±1.16 l/min (range 3.57–7.82 l/min). These differences were statistically significant ($p = 0.004$).

The correlation between cardiac output values obtained by TEI and by thermodilution is shown in Fig. 1. The equation was $Y = 0.28\,X + 2.61$ ($r = 0.41$). One patient had a cardiac output value falling clearly outside the range of other values but this measurement was felt appropriate. Even after exclusion of this value, the correlation was still relatively poor $Y = 0.31\,X + 2.35$ ($r = 0.60$).

When more than one value was obtained, serial analysis of cardiac output determinations did not yield a consistent relationship.

Discussion

Measurement of cardiac output by TEI has many attractive aspects, it is non-invasive, simple and relatively inexpensive, and it provides a continuous on-line measurement of blood flow. In addition to stroke volume, ventricular ejection time and ejection velocity index and thoracic fluid index can be continuously evaluated. In essence, the method assumes that the thorax is a cylinder with homogeneous electrical conductive properties. If an electrical alterning current of low amplitude is applied, the pulsatile changes in thoracic aortic blood flow cause a negative change in impedance and the greatest magnitude of this change is proportional to the peak aortic blood flow.

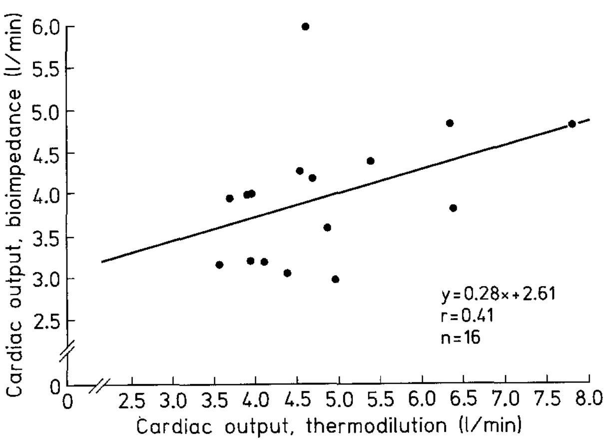

Fig. 1. Correlation between cardiac output values measured by bioimpedance and by thermodilution

There are several assumptions made in this equation; firstly, measurement of aortic blood flow depends on blood specific resistivity which can vary with haematocrit and other factors, secondly, the method regards the thorax as being a perfect cylinder and assumes a fixed relationship between the length and the radius of this cylinder, thirdly the method assumes that perfusion within the thorax is homogeneous and the distribution of blood flow is largely influenced by the cardiovascular status.

Despite the development of new equipment and algorithms, the accuracy of measurement of total blood flow by the TEI method is still open to controversy. During haemorrhagic shock induced in dogs, Tremper et al. [10] found TEI could reliably track changes in blood flow. Two recent studies compared measurements of cardiac output by TEI and by thermodilution in acutely ill patients. Bernstein et al. [2] made 94 comparisons in 17 patients and found a correlation coefficient of 0.88 while Appel et al. [1] made 391 measurements in 16 patients and found a correlation coefficient of 0.83. In both studies the correlations could be increased by the exclusion of some values before statistical analysis and by the large number of measurements obtained in each patient. The possible influence of mechanical ventilation on the accuracy of the measurements was also not defined in the two studies. More recently, Donovan et al. [5] made similar comparisons in 27 patients with one to eight cardiac output determinations performed in each patient. Using varying distances between electrodes and several different values for blood resistivity, their correlation coefficients did not exceed 0.70. The correlation was worse still in the 16 patients who were mechanically ventilated. The authors could not separate the effects of mechanical ventilation per se from those related to the underlying pulmonary problem necessitating the need for mechanical ventilation. Our present results indicate that in mechanically ventilated patients, cardiac output measurements by TEI are not very accurate even in the absence of recognized respiratory failure. Interestingly, cardiac output values were significantly lower by the TEI method and this is contrary to earlier observations [3]. It is possibile that this was due to the mechanical ventilation itself but this was not tested in our study. As our thermodilution measurements were cycled with the ventilator, it might be suggested that the thermodilution values were over-estimated, but this is not supported by data from previous studies [4].

Mechanical ventilation should probably be added to the list of factors which limit the use of the technique together with valvular regurgitation, intrathoracic shunts, sepsis, tachycardia or dysrhythmia, hypertension, pulmonary atelectasis or pleural effusions [1, 2, 3, 5, 10]. Our results support the view than non-invasive measurement of cardiac output by TEI lacks precision in acutely ill patients.

References

1. Appel PL, Kram HB, Mackabee J, Fleming AW, Shoemaker WC (1986) Comparison of measurements of cardiac output by bio-impedence and thermodilution in severely ill surgical patients. Crit Care Med 14:933
2. Bernstein DP (1986) Continuous non-invasive real time monitoring of stroke volume and cardiac output by thoracic electrical bioimpedance. Crit Care Med 14:898
3. Bernstein DP (1986) A new stroke volume equation for thoracic electrical bioimpedance: theory and rationale. Crit Care Med 14:904
4. Daper A, Parquier JN, Preiser JC, Contempré B, Vincent JL (1986) Timing of cardiac output measurements during mechanical ventilation. Acute Care 12:113
5. Donovan KD, Dobbs GJ, Woods WPD, Hockings BE (1986) Comparison of transthoracic electrical impedance and thermodilution methods for measuring cardiac output. Crit Care Med 14:1038
6. Keim HJ, Wallace JM, Thurston H (1976) Impedance cardiography for determinations of stroke index. J Appl Physiol 41:797
7. Kubicek WG, Karnegis JN, Patterson RP (1966) Development and evaluation of an impedance cardiac output system. Aerospace Med 37:1208
8. Myhrman P, Granerus G, Karlsson K (1982) Cardiac output in normal pregnancy measured by impedance cardiography. Scand J Clin Lab Invest 42:797
9. Stevens HJ, Thomas AR, Frederick GM (1985) Thermodilution cardiac output measurement. Effects of respiratory cycle in its reproducibility. JAMA 253:2240–2242
10. Tremper KK, Hufstedler SM, Barker SJ (1986) Continuous noninvasive estimation of cardiac output by electrical bioimpedance: an experimental study in dogs. Crit Care med 14:231

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