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Bioimpedance and bioreactance methods for monitoring cardiac output

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Noninvasive continuous cardiac output monitoring may have wide clinical applications in anaesthesiology, emergency care and cardiology. It can improve outcomes, establish diagnosis, guide therapy and help risk stratification. The present article describes the theory behind the two noninvasive continuous monitoring methods for cardiac output assessment such as bioimpedance and bioreactance. The review discusses the advantages and disadvantages of these methods and highlights the recent method comparison studies. The use of bioimpedance and bioreactance to estimate cardiac output under haemodynamic challenges is also discussed. In particular, the article focuses on performance of the two methods in the assessment of fluid responsiveness using passive leg raising test and cardiac output response to exercise stress testing.

Introduction

Cardiac output is a fundamental physiological measure used for diagnosis and guiding therapy in many clinical conditions. Monitoring of cardiac output has wide clinical applications in

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anaesthesiology, emergency care and cardiology [1]. Measurement of cardiac output is essential in critically ill, injured and unstable patients as it provides an indication of systemic oxygen delivery and global tissue perfusion [2]. Cardiac output monitoring during surgery is associated with reduced length of hospital stay and postoperative complications [3–5]. Measurement of cardiac output under pharmacological and physiological stimulations defines overall function and performance of the heart and is an excellent predictor of prognosis in heart failure [6–8].

The first method for estimation of cardiac output was described in 1870 by Adolf Fick [9]. This method was the reference standard by which all other methods of determining cardiac output were evaluated until the introduction of the pulmonary artery catheter (PAC) in the 1970s [10]. Cardiac output measurement with a PAC using the bolus thermodilution method has become the gold standard and reference method used to compare novel technologies [11,12]. These methods are however invasive, expensive, require specialist expertise and are associated with inherent risks and complications such as catheter-related infections, arrhythmias and bleeding [13]. These limitations preclude the use of invasive cardiac output monitoring in large number of patients limiting the application of this useful diagnostic and prognostic marker.

The development of minimally invasive and noninvasive, sensitive, operator-independent and cost-effective techniques for cardiac output monitoring has been the focus of attention for several decades [2]. Minimally invasive methods frequently used and described are trans-oesophageal Doppler, transpulmonary thermodilution, pulse counter and pulse power analysis, and noninvasive techniques such as CO_2 and inert gas rebreathing, transthoracic Doppler, thoracic bioimpedance cardiography, electrical velocimetry (modified bioimpedance) and bioreactance [2,12,14,15]. The aim of the present review is threefold: (1) to describe the theory behind bioimpedance, electrical velocimetry and bioreactance as methods for noninvasive continuous cardiac output monitoring; (2) to discuss the advantages and disadvantages of these methods and review the recent method comparison studies; and (3) to introduce the reader to modern uses of these devices (e.g., fluid responsiveness/passive leg raising (PLR) and physiological stress).

Bioimpedance method for measuring cardiac output

Thoracic bioimpedance cardiography for measuring stroke volume (SV), cardiac output and other cardiovascular variables was first described by Kubicek and associates in the 1960s [16]. Its initial testing and application was performed in aerospace programmes when central haemodynamic measurements and cardiac function were evaluated in astronauts [17]. The basis for its use was later pioneered by Lababidi and colleagues in 1970 [18], with significant software refinements and technical improvements over the following decades based on animal and human research. In the 1980s, Sramek et al. [19] developed a less cumbersome impedance cardiography device with a new SV equation that substituted the cylindrical model of the chest used by Kubicek et al. [16] with that of a truncated cone. In 1986, Bernstein [20] modified the equation of Sramek et al. [19] by introducing into the formulae the actual in addition to ideal weight, thus accounting for deviations from ideal body weight. The purpose was to determine more accurately the volume of the thorax [4].

The technique finally became popularized in the 1990s when its use in clinical settings was evaluated by several multicentre studies reporting improvement in determination of left ventricular ejection time (VET), change in impedance with systole and other markers of systole and diastole providing greater accuracy of noninvasive haemodynamic data [21,22].

The underlying theory behind the bioimpedance cardiography is that thorax is considered as a cylinder perfused with fluid (blood) which has a specific resistivity. The technique is based on the measurements of impedance (or resistance) to transmission of a small electrical current throughout the body (whole-body bioimpedance) or chest area (thoracic bioimpedance). Bioimpedance is therefore the electrical resistance to a high-frequency low-amplitude current (e.g., 1.4–1.8 mA at 30–75 kHz) transmitted from electrodes placed on the upper and lower thorax [23]. Conduits of low impedance (lowest resistance, equals high conductance) are blood and plasma (150 and 63 ohm/cm). Resistance of electrical current is higher (lower conductance) for cardiac muscle, lungs (reflecting air) and fat (750, 1275, and 2500 ohm/cm) [23]. When alternating low-level electrical