REVIEW ARTICLE

Electrical Bioimpedance Cardiography: An Old Technology With New Hopes for the Future

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THE POSITIVE IMPACT of early goal-directed hemodynamic therapy on postoperative outcome increasingly has been investigated over the last few years in high-risk patients undergoing noncardiac and cardiac surgeries.[1–4] However, these preemptive strategies require advanced hemodynamic monitoring to assess cardiac output and stroke volume. The classic available tools (intermittent pulmonary arterial or transpulmonary thermodilution or esophageal Doppler), either invasive or operator-dependent and necessitating a learning curve, are not convenient for routine practice. Therefore, they remain insufficiently used among North American and European anesthesiologists.[5] Besides, new mini-invasive cardiac output devices have been developed commercially over the last decade.[6] Less accurate but more convenient and easy to use, they potentially could help the practitioners in promoting advanced hemodynamic monitoring and early goal-directed therapy at the bedside in high-risk patients in an attempt to further improve postoperative outcome. Among these mini-invasive technologies, thoracic electrical bioimpedance (TEB) has major theoretical advantages and could be of great clinical utility in the settings of anesthesiology, cardiology, and perioperative medicine. Despite extensive literature published over the last 50 years, TEB remains scarcely used by practitioners.

This review first describes the principles and limitations of the TEB before addressing the crucial problem of its clinical validation. Endotracheal electrical bioimpedance is a new approach in mechanically ventilated patients that could bring a decisive advantage in the coming years and allow a wide dissemination of the method in the operating room and intensive care units (ICUs). This new approach is detailed in the final section. In contrast, the bioreactance technology has been well-described in a recent review[6] and will not be discussed further.

PRINCIPLES OF THORACIC ELECTRICAL BIOIMPEDANCE

TEB is based on old principles of physics established in Russia in the 1940s and applied to the measurement of cardiac output. Revived first by NASA in the 1960s to measure the cardiac output of astronauts in the space program, since the mid-1990s there has been renewed interest in TEB in the medical field with the emergence of new and ever-more-efficient monitors. The main monitors available today are BioZ.com (CardioDynamics, San Diego, CA), Physioflow (Manatec, Ebersviller Petit, France), and Niccomo (Medis, Ilmenau, Germany). The measurement principle is to apply an alternating current of low intensity (completely painless for the patient) and high frequency at the base of the thorax from a set of skin electrodes and collect the same alternating current at the base of the neck from another set of skin electrodes (Fig 1A). The electric current flowing preferentially through the liquid media (large intrathoracic blood vessels and heart chambers), continuous recording of the electrical impedance (ie, the resistances applied to an alternating current) of the thorax, and its variations during the cardiac cycle allow calculation of the stroke volume and cardiac output. The decrease in intrathoracic blood volume during systole is indeed responsible for a transient increase in the impedance while diastole is accompanied by a cyclic reduction of the electrical impedance of the thorax (Fig 1B). Different formulae for calculating the stroke volume were proposed in the mid-1960s and revised several times thereafter. Similarly, different models of the human thorax (cylinder or truncated cone) are used by software calculations. The oldest is the equation of Kubicek described in 1966.[7] More recently, Sramek and Bernstein proposed a simplified equation,[8,9] now integrated into the calculation software of multiple monitors on the market. This equation can be written as follows: $SV = LVET.k.[(dZ/dt)max/Z0]$, where SV is the stroke volume, LVET is the left ventricular ejection time, k is a constant estimated from a patient normogram incorporating the main morphologic characteristics (height, sex, age), Z0 represents the baseline impedance of the thorax, and (dZ/dt)max is the maximum impedance change during the cardiac cycle (Fig 2). It seems that the calculation of the stroke volume is even more reliable (better correlation and greater accuracy) when Z0 is greater than 15 ohms and (dZ/dt)max greater than 0.3.[10] This reflects the difficulties associated with the presence of pulmonary edema or large pleural effusions increasing the electrical conductivity of the thorax (and thus reducing the impedance) and small changes in stroke volume in patients with severe hypovolemia or left ventricular failure. Finally, some algorithms remain the property of the manufacturers and actually are not disclosed. All monitors provide the ability to measure or

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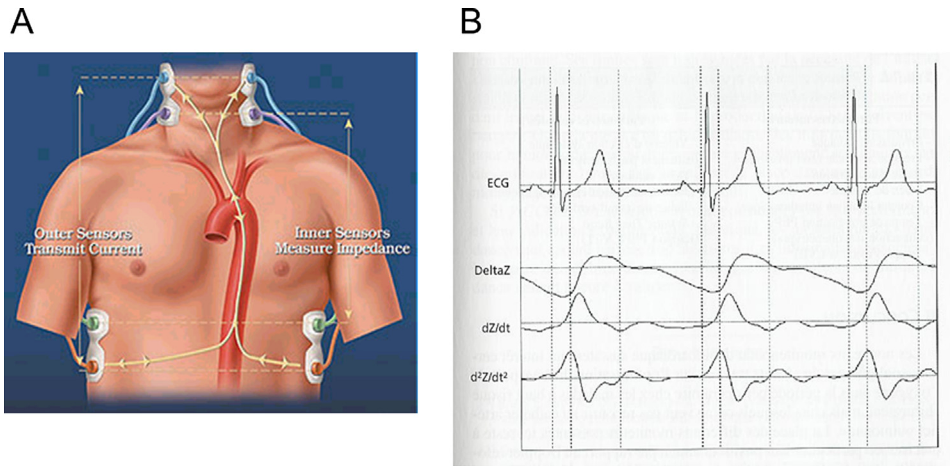

Fig 1. Measurement of changes in thoracic electrical bioimpedance during a cardiac cycle. A: Placement of skin electrodes at the base of the thorax (emitters) and at the base of the neck (detectors). B: Recording of thoracic electrical bioimpedance changes during systole and diastole (deltaZ) and its first (dZ/dt) and second (d^2Z/d^2t) derivatives over time.

calculate many other hemodynamic parameters and integrate into a modern concept of global noninvasive hemodynamic monitoring (Table 1). Thus, intrathoracic fluid content could be an interesting variable to guide fluid therapy. However, for routine clinical practice, interest in most of these parameters remains to be proven.

LIMITATIONS OF THORACIC ELECTRICAL BIOIMPEDANCE

There are many limitations to the validity of the calculation of cardiac output by the TEB. These limitations can be divided into two main categories: (1) The difficulty of acquiring the signal because of spontaneous movements of the patient, interferences with electrocautery in the operating room, disorders of heart rhythm, or mechanical ventilation; the newest monitors, such as the Niccomo, include a quality indicator signal to eliminate real-time misinformation; and (2) physiologic and pathophysiologic situations in which the physical modeling of the system is no longer valid, in particular during changes in the baseline thoracic impedance (pregnancy, obesity, gas or fluid pleural effusion, chronic congestive heart failure with pulmonary edema) or when there is severe aortic valve disease or modified mechanical properties of the arterial tree. These limitations must be kept in mind when using TEB at the bedside.

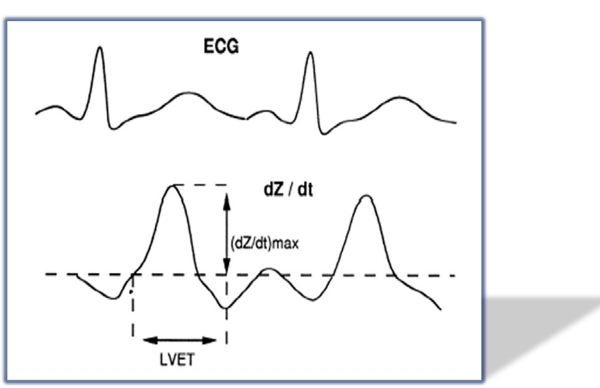

Fig 2. Stroke volume calculation by using the Sramek-Bernstein formula. (dZ/dt)max = maximal change in bioimpedance during the cardiac cycle. ECG, electrocardiogram; LVET, left ventricular ejection time.

CLINICAL VALIDATION OF THORACIC ELECTRICAL BIOIMPEDANCE

It is possible to define the theoretic characteristics that clinicians are entitled to demand in a modern method of cardiac output monitoring. These criteria are summarized in Table 2. To date, none of the techniques currently available meets these specifications, but TEB is probably the one that comes closest (Table 3). The main value of the TEB lies in its simplicity and speed of implementation and its completely noninvasive nature. The technique is learned easily, and there is good inter-and intraobserver reproducibility.[12–14] Current thinking about what is expected of a cardiac output monitoring tool tends to minimize the importance of accuracy and precision for the benefit of its noninvasive and continuous nature (capable of providing beat-to-beat information), its ease of use via a plug-and-play system, and its ability to detect fast, consistent, and reliable changes in cardiac output caused by different spontaneous hemodynamic conditions or different therapeutic maneuvers.[15,16] These latter qualities seem to offer the possibility to guide clinical decision-making at the bedside and control any hemodynamic optimization strategy with the ultimate goal of improving prognosis in the short- and long-term for high-risk patients.

More than 2,000 publications have focused on the TEB in the last 50 years. Overall, these studies reported conflicting results and are difficult to compare. Conducted with different generations of monitors, they use different physical models and equations. The reference method for the comparative analysis is also different from one study to another, although pulmonary arterial thermodilution is the most commonly used. The profiles of the patients studied vary widely, from healthy volunteers to heart failure patients, in medical or surgical settings. Finally, statistical tools used in these studies differed significantly, the