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Review

Impedance Cardiography: The Next Technology in Obstetrics?

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REZUMAT

Impedanța cardiacă: următoarea tehnologie în obstetrică?

Cardiografia de impedanță a fost studiată în ultimele decenii ca fiind o tehnică nonivazivă, cost eficientă pentru a monitoriza parametrii hemodinamici. Pentru a i se stabili validitatea, impedanța cardiacă a fost comparată intens cu diferite alte metode atât în studii umane sau pe animale.
Până astăzi, metoda impedanței cardiace a fost supusă unor numeroase schimbări. Cu toate acestea, tehnica nu a fost acceptată în lumea întreagă pentru monitorizarea debitului cardiac. În această expunere prezentăm aspectele actuale ale impedanței cardiace, principiile acestei metode, aplicațiile în medicină și rolul nou atribuit în obstetrică.

Cuvinte cheie: impedanța cardiacă, hemodinamică, obstetrică-ginecologie

ABSTRACT

Impedance cardiography has been studied in the last decades as a noninvasive, harmless and cost-effective method of monitoring hemodynamic parameters. In order to establish its validity, impedance cardiography has been extensively compared with several other methods which measure those parameters in both human and animal studies. Until today, the method of impedance cardiography has been subjected to various refinements and alterations. However, the technique has not yet been accepted worldwide as reliable for assessing cardiac output. In the present review we show the current status of various aspects of impedance principles, its medical application and its new role in the field of obstetrics.

Key words: impedance cardiography, hemodynamics, obstetrics-gynecology

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INTRODUCTION

Impedance cardiography (ICG) is a noninvasive modality to assess hemodynamic parameters. It uses changes in impedance across the thorax. It can evaluate the thorax fluid capacity which includes extravascular, intravascular and chest water content and, indirectly, represents the degree of heart failure.

This technique allows the assessment of cardiac output (CO), cardiac index (CI), stroke volume (SV), stroke index (SI), systemic vascular resistance (SVR), systemic vascular resistance index (SVRI), left ventricular ejection fraction (LVEF), left ventricular ejection time (LVET). CO, CI, SV and SI can reflect the myocardial blood flow; SVR and SVRI can reflect systemic vascular resistance and cardiac afterload; PEP, LVEF, LVET and STR can reflect myocardial contraction (prolonged PEP, LVET shortening, increase of STR and decrease of LVEF represent the compromised cardiac function). (1, 2)

It is proved that with the alteration of heart function, resulting heart failure, the blood volume increases, resulting the expansion of the cardiac preload and TFC. A recent study showed that before and after cardiac rehabilitation in heart failure patients, impedance cardiography revealed a significant change in STR, LVEF, TFC and PEP. (3,4) Another study indicated that in hospitalized patients with advanced heart failure, ICG provided some information about CO, but not left-sided filling pressures. (5)

There are studies in which is evaluated the ability of impedance cardiography to reflect the cardiac functions in acute myocardial infarction patients. It is proved that ICG data can reflect the early cardiac functions of these patients, but the accuracy of ICG in evaluating cardiac functions should be enhanced with detection of blood NT-proBNP, BNP and cTnT and echocardiography. (6)

A recent study shows a new applicability of impedance cardiography. It includes echo planar MRI scans, simultaneously recorded ECG and thoracic impedance using carbon fiber ICG/ECG signals collected during MRI, and shows that it performs comparably with the signals collected outside the MRI environment. These results indicate that ICG can be used during MRI to measure stroke volume, cardiac output, pre-ejection period, and left ventricular ejection time. (7)

Principles of impedance cardiography

Impedance cardiography is based on Ohm's law: R=V/I, where R is resistance (Ohm), V is Voltage (volt) and I is current (Ampere). Resistance in an alternative current called impedance (Z) can also be calculated as Z=V/I in impedance cardio-graphy. In the human body this law is applied to an electrical model: the parallel conductor model. The principle is that the impedance of thoracic tissue is parallel to that of blood and the validity of this method has been proved by many investigators.

It is known that the fluctuations caused by respiration tissue impedance are constant and blood-related impedance changes are the same with each cardiac cycle. (8)

Electrode configuration and ICG waves

At the beginning, Kubicek used a tetrapolar band electrode configuration. Nowadays, this band is no more used being difficult to place, uncomfortable and expensive; instead many investigators are using spot electrodes. Since this method, was invented, the waves obtained by ICG and the correlation with electrocardiogram have been intensively studied.

Kubicek showed that stroke volume can be measured in a noninvasive way with this instrument. So, the impedance signal (dZ) marks the systolic time interval. (9)

Labadidi compared dZ/dT signal with phonocardiography and proved that:

A wave follows P wave on the ECG being linked with the contraction of atria. The exact contribution of the left atria to the A wave is not known.

B point coincides with aortic valve opening.

E point represents the maximum speed of impedance changes.

X point coincides with aortic valve closure.

Y point coincides with pulmonary valve closure.

O wave upwards deflection during diastole.

Pre-Ejection Period (PEP) represents the interval from the onset of ventricular depolarization (Q wave on ICG) to the beginning of mechanical contraction (B point-first up slope of the impedance waveform).

LVET (Left Ventricular Ejection Time) - is the time from the aortic wave opening (B point on the impedance waveform) to the aortic valve closing (X point on the impedance waveform) (**Fig. 1**).

Bonjer et al. published the first article about that and made a study on anesthetized dogs and proved that the volume changes in the heart play a minor

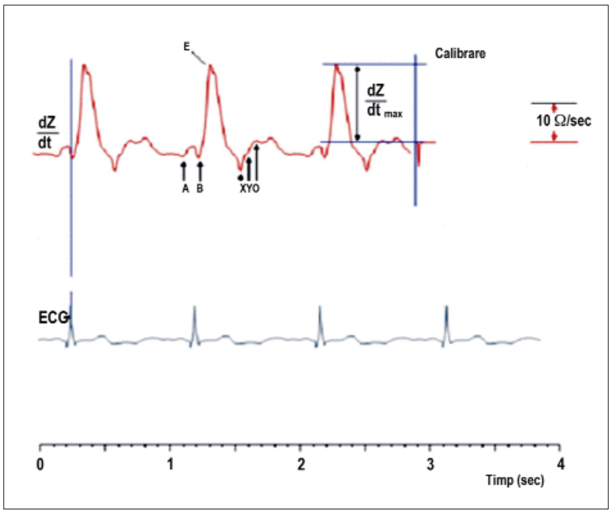

Figure 1.

role (10), whereas Geddes and Baker observed that the contraction of both ventricles can determine changes in thoracic impedance. In the same time, it was highlighted that impedance changes from the aorta are larger. (11) In other study performed on anesthetized dogs with the aorta and the pulmonary artery perfused with a controlled pulsatile flow, Ito concluded that less than 30% of thoracic impedance signal originates from the pulmonary artery. (12) It represents the inverse of baseline impedance measurement, baseline impedance being in direct ratio to conductive material (i.e.: blood, lung water) in the chest.

In the last decade, new refinements were applied to the impedance technique, including the use of the computer, which eliminates the effects of respiration on the impedance signal. Another problem was represented by the movement of artifacts, but Barros claimed that this aspect can be solved by adaptive filtering techniques and digital filtering techniques which are in research nowadays. (13)

Short review of clinical applications of impedance cardiography:

1. To asses baseline hemodynamic status of any patient.
2. Patients with suspected, known or in treatment cardiovascular disease.
3. Fluid management.
4. Dyspnea - differential diagnosis of cardiac or pulmonary causes.
5. Monitors medication titration.
6. Provides hemodynamics for patients where invasive procedures are contraindicated.
7. Pre-operative, peri-operative and post-operative hemodynamics.
8. Emergency care: unstable hemodynamics: trauma, early sepsis, shock, heart failure.
9. Pacemaker optimization (hemodynamics before device insertion)
10. Heart transplant: the first sign of early rejection is the decreased myocardial contractility.
11. Arterial hypertension: interaction between blood pressure, flow, resistance and dosing of therapy with: left ventricle contractility (beta-blockers), systemic vascular resistance (vasodilators) and fluid status (diuretics).
12. Dialysis – impedance cardiography prevents hemodynamic crisis. The ICG monitor should not be used for patients with pacemakers because it may cause a rate acceleration.

There are some measures that ensure accurate ICG results:

- sensors are in direct contact with the patient's skin;
- leads are properly connected to sensors and ICG monitor;
- patient should stay still to eliminate possible monitor artifacts. (14)

Impedance cardiography in pregnancy

In pregnancy the maternal cardiovascular system is characterized by several changes: the circulating blood volume, heart rate, cardiac output and oxygen consumption are increased (15) and the peripheral vascular resistance decreases, being also the first adaptive mechanism in early pregnancy. (16) This systemic decrease in tonicity during pregnancy is thought to be related to uteroplacental-induced vasoactive substances which interact with the inner layer of the blood vessel, the endothelium. (17) Systemic vascular resistance (SVR) increases during the third trimester of pregnancy. (18) It is also demonstrated that this fall in systemic vascular tonus affects both the arteries and the veins, and, in turn, will affect the systems of osmoreceptors', facilitating volume retention. (19) Due to this plasma volume expansion, a preload-induced reversible remodeling of the maternal heart, and left ventricular eccentric hypertrophy, occurs during normal pregnancy. (20) In this adaptation process, the role of the venous system is still rather underestimated. However, together with the observed plasma volume expansion, the increase in venous capacitance, due to enhanced venous distension, provides a larger buffer to control

Table 1. The parameters

Parameter	Normal value	Definition
Cardiac Output (CO)	4-8 L/min	The amount of blood pumped by the left ventricle in one minute in the systemic circulation.
Cardiac Index (CI)	2,5- 4.7 L/min/m^2	Cardiac Output normalized for body surface area.
Thoracic Fluid Content (TFC)	Males: 30-50 Ohm, Females: 21-37 Ohm	Total fluid volume in the chest including intravascular and extra-vascular fluid.
Stroke Volume (SV)	60-130 mL	The amount of blood pumped by the left ventricle in each heartbeat.
Stroke Index (SI)	SI: 35-65 mL/beat/m^2	Stroke Volume normalized for body surface area.
Systemic Vascular Resistance (SVR)	742-1378 dyne.sec.cm^5	The arterial system's resistance to the blood flow.
Systemic Vascular Resistance Index (SVRI)	SVRI: 1337-2483 dyne.sec.cm^5.m^2	The arterial system's resistance to the blood flow normalized for body surface area for body surface.
Velocity index (VI)	33-65/1000 sec (per 1000 seconds)	Peak velocity of blood flow in the aorta.
Mean Arterial Pressure	84-100 mmHg	Average pressure exerted by the blood on the arterial walls.
Acceleration Index (ACI)	Males: 70-150/100 sec^2 Females: 90-170 sec^2	Initial acceleration of blood flow in the aorta, which occurs within the first 10-20 milliseconds after the opening of the aortic valve.
Heart rate (HR)	60-99 beats/min	The number of heart beats per minute.

and regulate cardiac output in pregnancy. (21)

Cardiac morphological changes during pregnancy are characterized by reversible left ventricular hypertrophy and chamber enlargement (22), and studies on cardiac function report altered left ventricular systolic and diastolic performance (23). The cardiovascular system of the pregnant woman may respond differently to a variety of challenges. For example, it is well established that physiological response to angiotensin II is blunted in pregnancy (24). The baroreceptor reflex activity is attenuated during pregnancy, (25) and an improved tolerance to orthostatic stress has been reported in conditions associated with increased circulatory volume including pregnancy. (26) Orthostatic tolerance correlates positively with plasma volume and negatively with baroreceptor activity. (27)

A recent prospective cross-sectional study included 108 healthy pregnant women at 22-24 weeks of gestation and 54 non-pregnant women. Cardiac function and systemic hemodynamics were studied using non-invasive impedance cardiography. The hemodynamic parameters in both pregnant and non-pregnant women changed significantly during passive leg rising compared to baseline, but the magnitude and trend of change was similar in both groups. The stroke volume was increased both in pregnant and non-pregnant women, whereas the blood pressure and systemic vascular resistance decreased following passive leg rising in both groups. Static measurements of cardiovascular status are different between healthy pregnant and non-pregnant women, but the physiological response to passive leg rising is similar and not modified by pregnancy at 22-24 weeks of gestation. (28)

Another relevant recent study evaluated characteristics of venous hemodynamics, together with cardiac and arterial function, in uncomplicated pregnancies, non-proteinuric gestational hypertension and preeclampsia. In this observational cross-sectional study, venous hemodynamics was assessed using a standard protocol for combined electrocardiogram (ECG)-Doppler ultrasonography, together with a non-invasive standardized cardiovascular assessment using impedance cardiography in 13 women with uncomplicated pregnancies, 21 with gestational hypertension, 34 with late onset preeclampsia in 34 weeks and 22 with early onset preeclampsia. The results of this study confirm those of other publications that cardiac and arterial function is different between gestational hypertensive diseases and normal pregnancies. This research adds to this knowledge that venous hemodynamic dysfunction in preeclampsia is more pronounced than in gestational hypertension. (29)

The objective of another study was to report thoracic impedance cardiography measurements and compare them with echocardiography measurements throughout pregnancy and in varied maternal positions. A prospective cohort study involving 28 healthy parturients was performed using ICG and echo at three time points and in two maternal positions. ICG and echo demonstrate significant correlations in some, but not all, measurements of cardiac function. ICG has the ability to detect small changes in SV associated with maternal position change. ICG measurements reflected maximal cardiac contractility in the antepartum period yet reflected a decrease in contractility and an increase in TFC in the postpartum period. (30)

CONCLUSION

Impedance cardiography is a noninvasive technique which can provide hemodynamic parameters. It has a large usage in different medical domains. Lately, it started to be applied in the field of obstetrics, especially in gestational hypertension or pre-eclampsia.

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