

IMPEDANCE CARDIOGRAPHY – OLD METHOD, NEW OPPORTUNITIES. PART I. CLINICAL APPLICATIONS

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Abstract

Monitoring of cardiovascular hemodynamic changes requires a very expensive and highly specialized equipment and skilled medical personnel. Up to the present time, an inexpensive, non-invasive and easy-to-use method which, like Doppler echocardiography, magnetic resonance angiography or radionuclide imaging, would assess hemodynamics of the cardiovascular system was not available. A method known as impedance cardiography (ICG) or thoracic electrical bioimpedance cardiography (TEBC) meets those criteria. It is non-invasive, which is of a particular advantage over the conventional methods that require catheterization. As a result, the patient is not at risk of possible complications and the procedure is less expensive and easier. Impedance cardiography, despite its non-invasive character, has not been so far extensively used for monitoring of hemodynamic parameters in hospitalized patients. Various authors report that attempts have been continued to compare the results from ICG and those obtained by other diagnostic methods. This paper presents the use of impedance cardiography in diagnosis of hypertension, cardiac insufficiency, differentiating the causes of acute dyspnea, as well as in assessing the effects of cardiac rehabilitation in patients with heart failure.

Key words:

Impedance cardiography, Hypertension, Heart failure, Dyspnea, Cardiac rehabilitation

INTRODUCTION

Monitoring of cardiovascular hemodynamic changes requires a very expensive and highly specialized equipment and skilled medical personnel. Up to the present time, an inexpensive, non-invasive and easy-to-use method which, like Doppler echocardiography, magnetic resonance angiography or radionuclide imaging, would assess hemodynamics of the cardiovascular system was not available.

A method known as impedance cardiography (ICG) or thoracic electrical bioimpedance cardiography (TEBC) meets those criteria. It is non-invasive, which is of a particular advantage over the conventional methods that require catheterization. As a result, the patient is not at risk of possible complications and the procedure is less expensive and easier.

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The ICG makes use of the fact that different tissues of the human body are characterized by different values of electrical resistance, or impedance. For example, adipose tissue, bones, lungs and muscles are poor electrical conductors, while blood is a good conductor, and the changes in blood location within the chest produce impedance variations in that area of the human body. During ventricular systole the blood is ejected into the aorta and pulmonary arteries, thereby increasing its volume in those regions. This in turn translates into a reduction of the local impedance. Hemodynamic parameters are calculated from the recorded impedance variations [1].

METHODOLOGICAL PRINCIPLES

The test involves placing, on the skin of the patient, the output electrodes to apply high-frequency low-intensity alternating current to the patient's chest, and the receiving electrodes to record voltage variations and obtain electrocardiography (ECG) recording. The alternating current as specified above used to produce the recording is completely safe and imperceptible to the patient, and the test does not cause discomfort [2–5].

Parameters that can be assessed using this method:

- cardiac output (CO),
- cardiac index (CI),
- stroke volume (SV),
- stroke index (SI),
- thoracic fluid content (TFC),
- systemic vascular resistance (SVR),
- systemic vascular resistance index (SVRI),
- velocity index (VI),
- acceleration index (ACI),
- left ventricular ejection time (LVET),
- pre-ejection period (PEP),
- systolic times ratio (STR).

Despite the advantages of this method and its ability to monitor multiple hemodynamic parameters, it is also subject to some limitations, which can significantly reduce

the measurement accuracy. These include: extremely low (< 25 kg) or high (> 220 kg) body weight and low height (< 120 cm) of the subject, a very intense physical activity at the time of registration, the incidence of arrhythmias (frequent contractions, atrial fibrillation), intraaortic counterpulsation, heart rate above 250/min and severe insufficiency (defective closure) of the mitral or aortal valve [1,4,6].

The use of impedance cardiography in the diagnosis of various diseases

Hypertension

The use of ICG for diagnosing of patients with hypertension allows a more precise explanation of the mechanism of the disease in the individual patient and apply suitable therapy. This was confirmed in the study by Xiajuan et al. [7], in which the use of ICG allowed to assess the relationship between systolic blood pressure and the registered hemodynamic parameters in the population of Shanghai. The sample comprised 670 persons aged 60–93 years, each of whom was assigned to 1 of the 6 subgroups according to the value of blood pressure. The hypertensive patients had significantly lower values of cardiac output (4.4 ± 1.5 l/min) and cardiac index (2.6 ± 1.0 l/min/m²) compared to normotensive subjects (4.7 ± 1.5 l/min and 2.8 ± 0.8 l/min/m², respectively). People with hypertension had also lower values of stroke volume and stroke index, while their values of systemic vascular resistance and systemic vascular resistance index were higher. In the group with the highest values of pressure (systolic blood pressure ≥ 180 mm Hg), cardiac output was 19% lower than in the group with the lowest pressure (systolic blood pressure < 140 mm Hg). At the same time, systemic vascular resistance was 56% higher in the group with the highest pressure compared to the group with lowest pressure values.

Aoka et al. [8] compared the hemodynamic parameters in patients with untreated hypertension by impedance cardiography. Analysis of the results showed that in 67% of the patients, hypertension was associated with high systemic

vascular resistance, while in 16% of them it was attributable to elevated cardiac output. The 1st group was treated with calcium channel blockers, while β -blockers were used to treat patients of the other group. In both groups, the applied treatment was equally effective to lower blood pressure and restore normal hemodynamic status.

In a prospective and randomized study, Krzesiński et al. [9] tested the usefulness of impedance cardiography in the treatment of hypertension in patients with metabolic syndrome. Patients with mild to moderate hypertension were divided into 2 groups:

- empirical (GE) – treated according to current guidelines,
- hemodynamic (HD) – treated taking also into account the hemodynamic data obtained by impedance cardiography.

After 12 weeks, the efficacy of treatment used in both groups was assessed. Better results of antihypertensive therapy were achieved in the HD group.

Another study by the same authors (Krzesiński et al. [10]) assessed the effectiveness of the treatment of mild to moderate hypertension by means of the algorithm taking into account the measurements of hemodynamic parameters using ICG. The study enrolled 128 patients aged 42.9 ± 11.1 years with persistent (at least 3-month) stage I or II hypertension. Each person had the following tests performed: patient's history, physical examination, laboratory measurement of blood pressure, 24-h ambulatory blood pressure monitoring (ABPM), ICG, ECG, echocardiography, laboratory tests (electrolytes, creatinine, fasting glucose, lipids). Thereafter, patients were randomly assigned to 1 of 2 groups: empirical (GE) in which treatment was selected based on clinical data, or to the hemodynamic (HD) group in which treatment was also based on clinical data, but additionally hemodynamic parameters obtained by ICG were also taken into account. After 12 weeks, the differences between the groups were evaluated in terms of the absolute values of blood pressure (RR), and the reduction of RR.

Laboratory RR measurement, 24 h ABPM and ICG were repeated.

All final RR values were lower in the hemodynamic (HD) group and the difference was significant: for laboratory-determined systolic (empiric vs. hemodynamic: 136.1 vs. 131.6 mm Hg, $p = 0.036$) and diastolic RR (87 vs. 83.7 mm Hg, $p = 0.013$), as well as for RR at night: systolic (121.3 vs. 117.2 mm Hg, $p = 0.023$) and diastolic (71.9 vs. 68.4 mm Hg, $p = 0.007$). Therapy using ICG significantly increased the level of reduction in laboratory-determined systolic RR (11 vs. 17.3 mm Hg, $p = 0.008$) and diastolic RR (7.7 vs. 12.2 mm Hg, $p = 0.0008$); as well as mean systolic 24-h RR (9.8 vs. 14.2 mm Hg, $p = 0.026$), systolic daytime RR (10.5 vs. 14.8 mm Hg, $p = 0.040$) and systolic night-time RR (7.7 vs. 12.2 mm Hg, $p = 0.032$).

In the study population, increased vascular resistance was the dominant mechanism of hypertension. The study demonstrated that impedance cardiography is a useful and simple method for diagnosing patients with mild to moderate hypertension, providing additional clinically relevant information. Treatment decisions based on results from this method can significantly improve the reduction of the RR in hypertensive patients [10].

Impedance cardiography allows not only to explain the mechanism of hypertension, but may also serve as a valuable tool for tracking changes in the circulatory system such as those resulting from changes in the patient's body position.

Bettencourt et al. [11] analyzed the cardiovascular response to the active bringing of hypertensive patients to the upright position. The study involved 48 people aged 24–75 years with treated or untreated hypertension, and their results were compared with the results obtained in the matching group of healthy people. The analysis took into account the following parameters: systolic (SBP) and diastolic (DBP) blood pressure, stroke volume (SV), total vascular resistance (TVR) and heart rate (HR). Based on the results, the patients were divided

into 2 groups depending on the hemodynamic changes. In the 1st group (EH-I), after standing-up, there was an increase in TVR and a decrease in SV compared to the supine position, while HR was close to its resting value. However, in the 2nd group (EH-II), TVR and HR decreased, while SV increased. Those 2 groups significantly differed in age. The EH-I group included 28 patients aged 50 ± 10 years, and EH-II consisted of 20 patients aged 62 ± 11 years. Analysis of the results points to 2 different reactions of the cardiovascular system to the active standing depending on age. Elderly hypertensive patients showed a reduced hemodynamic response, and in the younger ones the response was increased [11].

The authors of cross-sectional studies carried out in Finland on the assessment of cardiovascular hemodynamic changes depending on the value of resting heart rate also used ICG [12]. The examined group consisted of 522 individuals aged 20–72 years (including 261 men), who were not taking drugs affecting the heart rate and blood pressure, and were not diagnosed with diabetes, ischemic heart disease, peripheral artery disease, renal or cerebral vascular diseases. All patients underwent physical examination and were interviewed for lifestyle factors and factors of cardiovascular risk. Laboratory tests were also conducted, including, among others, glucose, creatinine, total cholesterol, high density lipoproteins (HDL), low density lipoproteins (LDL) and the level of C-reactive protein. High heart rate at rest was associated with an increase in blood pressure and increased activity of the sympathetic nervous system, which may have an impact on the increase of the cardiovascular risk in those subjects [12].

Cardiac insufficiency

Routine assessment of hemodynamic parameters in cardiac insufficiency by catheterization of cardiac chambers is a procedure encumbered with a risk of grave complications, so also in that case it is attempted to apply the ICG. Malfatto et al. [13] assessed the reliability of 3 methods:

echocardiography, measuring the level of brain natriuretic peptide (BNP) and impedance cardiography in predicting pulmonary capillary wedge pressure (PCWP) determined during cardiac catheterization. The study included 29 patients aged 72 ± 4 years, with class 3.5 ± 0.9 NYHA (New York Heart Association) heart failure and ejection fraction $28 \pm 6\%$. The assessment of thoracic fluid content (TFC) $\geq 35/k\Omega$ based on impedance cardiography showed high rates of: specificity (97%), sensitivity (86%), positive (97%) and negative predictive value (92%) in the detection of PCWP ≥ 15 mm Hg. Other methods had a lower specificity in the evaluation of that parameter.

The study shows that impedance cardiography may be successfully used to avoid cardiac catheterization as a diagnostic method. It may also be useful in predicting the further course of the disease in patients with heart failure, as proved by another work of the same authors. In 2007–2010, thoracic fluid content (TFC) was assessed by impedance cardiography, the level of brain natriuretic peptide (BNP) was determined and echocardiography were performed during the 1st visit in 142 outpatients with chronic heart insufficiency. During the 4-year follow-up, 21.2% of the patients died. All had higher levels of BNP and TFC compared to those who survived. Evidently lower mortality (2.1%) was observed in the group with BNP values < 450 pg/ml and the TFC $< 40/k\Omega$, while in patients with BNP values ≥ 450 pg/ml and TFC $\geq 40/k\Omega$, the mortality was 46.5%. The use of this type of diagnosis during the 1st visit may help ensure better treatment of the patient by enabling implementation of an appropriate therapeutic strategy [14].

Diagnosing of dyspnea in intensive care wards

With the growing interest in ICG, a search has been started to find new areas for its application other than cardiology. Vorwerk et al. [15] evaluated the usefulness of ICG for distinguishing between the causes of acute dyspnea in an emergency department. Patients admitted to the

hospital were examined using ICG, and then the results were compared with the final diagnosis recorded in the discharge report that had been used to decide whether the dyspnea was of cardiac origin or not. Statistically significant differences in hemodynamic parameters were shown to occur between the group with cardiogenic and noncardiogenic dyspnea. The relevant parameters included cardiac output (6.2 vs. 7.9 l/min, $p < 0.001$), cardiac index (3.1 vs. 4.4 l/min/m², $p < 0.001$), systemic vascular resistance (1227 vs. 933 dyn×s×cm⁻⁵, $p = 0.002$) and systemic vascular resistance index (2403 vs. 1681 dyn×s×cm⁻⁵×m², $p < 0.001$). Among the analyzed parameters, cardiac index has proved to be most useful for distinguishing between cardiogenic and noncardiogenic dyspnea (cardiac index: ≤ 3.2 l/min/m²) [15].

Cardiac rehabilitation

Gielerak et al. [16] have demonstrated that impedance cardiography may also be useful in the rehabilitation of persons with cardiac insufficiency. Fifty patients (44 men, aged 56.2 ± 8.8 years) with NYHA class II–III heart failure and echocardiography-determined left ventricular ejection fraction (LVEF) $\leq 40\%$, clinically stable and optimally treated, were subjected to cardiac rehabilitation. All patients underwent echocardiography, exercise test, ICG, and then physical training to be carried out systematically for 8 weeks was individually planned for each patient.

From the results of the study it has been found that ICG facilitates assessment of clinically relevant parameters, of which cardiac output (CO) and thoracic fluid content (TFC) are of particular importance for patients with heart failure. In the study population, the rehabilitation has reduced TFC, but only in patients with relatively high values of this parameter. This was associated with a significant improvement in exercise capacity. In patients with low baseline TFC, cardiac rehabilitation did not result in such a significant improvement in exercise capacity. In their conclusions, the authors report that thoracic fluid

content measured using ICG is a useful parameter in predicting the beneficial effects of cardiac rehabilitation [16].

CONCLUSIONS

Impedance cardiography, despite its non-invasive character, has not been so far extensively used for monitoring of hemodynamic parameters in hospitalized patients. Various authors report that attempts have been continued to compare the results from ICG and those obtained by other diagnostic methods. Parashar et al. [17] compared the results from impedance cardiography and Doppler echocardiography. The study involved 30 healthy men aged 18–26 years (mean: 21.5 ± 2.4 years), whose cardiac output was determined after 30 min of rest in the supine position. This was followed by 3 min of exercise performed using a static dynamometer (dynamometer compression force set to 30% of the maximum force). After 5 min since the termination of the exercise, CO and stroke volume determinations were repeated. Values of cardiac output obtained by ICG and Doppler echocardiography were comparable. The mean values of CO obtained in the ICG were 4.87 ± 0.83 l/min at rest, 6.01 ± 0.98 l/min during the dynamometer test, and 5.07 ± 0.87 l/min after the dynamometer test. Average values of CO obtained with Doppler echocardiography were 4.98 ± 0.88 l/min; 6.17 ± 1.01 l/min; 5.26 ± 0.95 l/min, respectively.

This study has confirmed that the results of impedance cardiography and Doppler echocardiography are comparable. Therefore, when assessing the hemodynamic parameters in patients with different diseases, one should consider using the non-invasive ICG diagnostic method. This will reduce the cost of the diagnosis of cardiovascular diseases and, for example in hypertensive patients, it will facilitate the application of appropriate therapy. The option to record hemodynamic parameters using Holter system may also be used to assess the impact of environmental factors on the cardiovascular system of a working person [17], a problem which is reported in the 2nd part of our work.

REFERENCES

1. Siebert J. [Impedance cardiography. Guide for medical doctors]. Gdańsk: Via Medica; 2007. Polish.
2. Strobeck JE, Silver MA. Beyond the 4 quadrants: The critical and emerging role of impedance cardiography in heart failure. *Congest Heart Fail.* 2004;10(Supl 2):1–6, <http://dx.doi.org/10.1111/j.1527-5299.2004.03405.x>.
3. Kim DW. Detection of physiological events by impedance. *Yonsei Med J.* 1989;30(1):1–11, <http://dx.doi.org/10.3349/ymj.1989.30.1.1>.
4. Woltjer HH, Bogaard HJ, de Vries PM. The technique of impedance cardiography. *Eur Heart J.* 1997;18(9):1396–403, <http://eurheartj.oxfordjournals.org/content/18/9/1396.long>.
5. Summers RL, Shoemaker WC, Peacock WF, Ander DS, Coleman TG. Bench to bedside: Electrophysiologic and clinical principles of noninvasive hemodynamic monitoring using impedance cardiography. *Acad Emerg Med.* 2003;10(6):669–80, <http://dx.doi.org/10.1111/j.1553-2712.2003.tb00054.x>.
6. Tan KH, Lai FO, Hwang NC. Measurement of cardiac output using Physio Flow with different positions of electrode placement. *Singapore Med J.* 2006;47(11):967–70.
7. Xiajuan Z, Ding D, Yanyan H, Zhen H. Impedance cardiographic hemodynamic variables and hypertension in elderly Han residents. *Ups J Med Sci.* 2013 May;118(2):80–6, <http://dx.doi.org/10.3109/03009734.2012.756959>.
8. Aoka Y, Hagiwara N, Kasanuki H. Heterogeneity of hemodynamic parameters in untreated primary hypertension, and individualization of antihypertensive therapy based on noninvasive hemodynamic measurements. *Clin Exp Hypertens.* 2013;35(1):61–6, <http://dx.doi.org/10.3109/10641963.2012.690469>.
9. Krzesiński P, Gielerak G, Kowal J, Piotrowicz K. Usefulness of impedance cardiography in optimisation of antihypertensive treatment in patients with metabolic syndrome: A randomised prospective clinical trial. *Kardiologia Pol.* 2012;70(6):599–607.
10. Krzesiński P, Gielerak G, Kowal J. A „patient tailored” treatment of hypertension with use of impedance cardiography: A randomized, prospective and controlled trial. *Med Sci Monit.* 2013;19:242–50, <http://dx.doi.org/10.12659/MSM.883870>.
11. Bettencourt MJ, Pinto BG, de Oliveira EI, Silva-Carvalho L. Two anomalous cardiovascular responses to active standing in essential hypertension. *Rev Port Cardiol.* 2008;27(5):613–21.
12. Koskela JK, Tahvanainen A, Haring A, Tikkakoski AJ, Ilveskoski E, Viitala J, et al. Association of resting heart rate with cardiovascular function: A cross-sectional study in 522 Finnish subjects. *BMC Cardiovasc Disord.* 2013[cited 2014 Jul 1];13:102. Available from: <http://www.biomedcentral.com/content/pdf/1471-2261-13-102.pdf>.
13. Malfatto G, Blengino S, Perego GB, Branzi G, Villani A, Facchini M, et al. Transthoracic impedance accurately estimates pulmonary wedge pressure in patients with decompensated chronic heart failure. *Congest Heart Fail.* 2012 Jan–Feb;18(1):25–31, <http://dx.doi.org/10.1111/j.1751-7133.2011.00248.x>.
14. Malfatto G, Corticelli A, Villani A, Giglio A, Della Rosa F, Branzi G, et al. Transthoracic bioimpedance and brain natriuretic peptide assessment for prognostic stratification of outpatients with chronic systolic heart failure. *Clin Cardiol.* 2013 Feb;36(2):103–9, <http://dx.doi.org/10.1002/clc.22086>.
15. Vorwerk C, Jeyanithi H, Coats TJ. Thoracic electrical bioimpedance: A tool to determine cardiac versus non-cardiac causes of acute dyspnoea in emergency department. *Emerg Med J.* 2010 May;27(5):359–63, <http://dx.doi.org/10.1136/emj.2009.073437>.
16. Gielerak G, Krzesiński P, Piotrowicz E, Piotrowicz R. The usefulness of impedance cardiography for predicting beneficial effects of cardiac rehabilitation in patients with heart failure. *Biomed Res Int.* 2013 [cited 2014 Jul 1]. Available from: <http://www.hindawi.com/journals/bmri/2013/595369>.
17. Parashar R, Bajpai M, Goyal M, Singh S, Tiwari S, Narayan VS. Impedance cardiography for monitoring changes

in cardiac output. Indian J Physiol Pharmacol. 2012 Apr-Jun;56(2):117-24.



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