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Impedance Cardiography — Determined Parameters and Their Application in Assisting Patient Diagnosis: A Review

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Impedance cardiography is a non-invasive method for assessing the activity of the cardiovascular system. Despite some simplifications of the physical model used in the determination of several hemodynamic parameters, it is a constantly evolving non-invasive method with potential ambulatory and/or clinical applications in cardiac diagnostics and treatment support. Besides its applications in cardiology, this method might be used as an auxiliary tool in assisting the diagnosis of psychiatric disorders or hormonal imbalances. This highlights the potential importance of impedance cardiography as an area of research worth further development in terms of metrological and qualitative approaches, leading to the acceptance of this method in clinical/ambulatory practice. The review was created to present information on the results of studies conducted in recent years, which describe the current state of knowledge regarding cardiac and new areas of application for the impedance cardiography method.

topics: impedance cardiography, pre-ejection period, Heather index, cardiac output

1. Introduction

Impedance cardiography (ICG), which is a modification of the physical method used to analyse bioimpedance, is a non-invasive technique that allows for the quantitative assessment of heart function. It is based on changes in the electrical impedance of the chest associated with blood ejection from the subject's heart. Thanks to its non-invasive properties and relative simplicity of application, this method has significant potential for numerous applications in cardiovascular system analysis. Recently some other, non-cardiac applications of this method have occurred. Therefore, we have decided to collect information on the results of studies conducted in recent years, which describe the current state of knowledge regarding cardiac and new areas of application for the ICG method. Studies from the last five years were collected, presenting the applications of ICG in cardiology and illustrating the possibility of the implementation in assisting patient diagnosis in entirely different fields, such as psychiatric disorders or hormonal imbalances.

2. Hemodynamic parameters

The analysis of ICG signals is based on the identification of the characteristic points on one lead *electrocardiogram* (ECG) and the impedance trace (first derivative of impedance signal — $\mathrm{d}z/\mathrm{d}t$). It is commonly accepted in the literature to use the capital letters describing the position of characteristic points on the $\mathrm{d}z/\mathrm{d}t$ trace: A, B, C, X, Y, O, similarly to ECG, e.g., "the QRS complex". The example of these annotations is illustrated in Fig. 1 (see also [1]).

The described characteristic points are used to calculate a number of commonly used physiological parameters that can be characterised by ICG. For example, the length of B–X time corresponds to *left ventricle ejection time* (LVET) and from Q (in ECG) to B ($\mathrm{d}z/\mathrm{d}t$) reflects the *pre-ejection period* (PEP). Those *systolic time intervals* (STI) characterise the cardiac left ventricle contractility. Some of the parameters derived from ECG and ICG signals are presented in Table I.

3. Applications of ICG

3.1. Assessment of heart function

In [2], it has been shown that the ICG method is an important tool for assessing the condition of the heart in the case of performing *percutaneous coronary intervention* (PCI). The hemodynamic profile of 27 individuals who underwent this procedure was examined. The first measurements were taken during the PCI procedure, and the second were conducted after a month. During the first day after the

TABLE I

The list of hemodynamic parameters with definitions and units.

Parameter	Expansion of the abbreviation	Unit	Definition
ACI	acceleration index	$1/100/s^2$	peak aortic flow acceleration
CO	cardiac output	l/min	amount of blood pumped into the aorta in one minute
CI	cardiac index	$l/min/m^2$	CO per square meter of body surface area
HI	Heather index	Ω/s^2	the ratio of the maximum systolic outflow to the duration between the peak of the Q/R wave in the ECG and the peak of ICG waveform
LSWi	left stroke work index	$(g\ m)/m^2$	measure of work which the left ventricle must expend to pump blood per heartbeat
PEP	pre-ejection period	ms	time from the onset of electrical activation of the ventricle (Q-wave on ECG) to the beginning of the aortic valve opening phase
SV	stroke volume	ml	blood volume pumped in a single beat
SVi (or SI)	stroke index	ml/m^2	SV per square meter of body surface area
SVR	systemic vascular resistance	$dyn\ s/cm^5$	vascular resistance of the systemic vasculature as seen by the left ventricle
SVRi	systemic vascular resistance index	$dyn\ s/(cm^5\ m^2)$	indexed SVR
TFC	thoracic fluid content	$1/k\Omega$	parameter describing total fluid volume in thoracic
TFCi	thoracic fluid content index	$1/(k\Omega\ m^2)$	indexed TFC
VI	velocity index	1/1000/s	peak aortic flow velocity

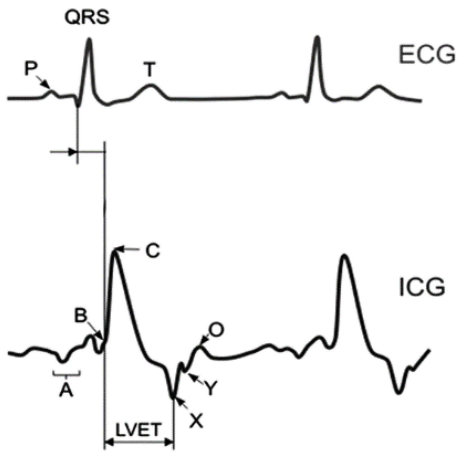

Fig. 1. ICG curve with characteristic points marked. Based on [1].

procedure, the values of SVRi and TFCi parameters were elevated, while the values of contractility parameters like CI or SVi decreased (see Table I for abbreviation explanations). All parameters returned to normal values after a month. Impedance cardiography can be used both for monitoring the condition of patients after PCI and for a better understanding of the changes in heart performance during the recovery period associated with this procedure.

In [3], the utility of hemodynamic parameters obtained through impedance cardiography was evaluated to assess the impact of *transcatheter aortic valve replacement* (TAVR) on cardiac function. ICG was performed on 74 patients 24 h before and one week after the TAVR procedure. The results demonstrated the dynamics of an improvement in diastolic function. This suggests that ICG may be a suitable tool for monitoring patients who have undergone aortic valve replacement.

The study detailed in article [4] evaluated the role of *impedance cardiography* (ICG) in assessing hemodynamic changes in patients following *off-pump coronary artery bypass grafting* (OPCABG). The analysis included 160 patients who underwent this procedure. Among the findings, a correlation was identified between the CO parameter obtained non-invasively via ICG and that obtained invasively using a Swan–Ganz catheter reference method. It was also demonstrated that specific parameters measured using ICG were correlated with parameters obtained standardly via echocardiography. These observations suggest that impedance cardiography could be used as an effective tool for real-time cardiac function assessment in clinical practice.

The aim of another study [5] was to evaluate the clinical importance of hemodynamic parameters obtained using ICG in patients with *heart failure* (HF) and concomitant *atrial fibrillation* (AF). The study involved 32 patients with HF, 9 of whom had also AF. It was demonstrated that in individuals with HF, AF adversely affects the *left stroke work index* (LSWi), which is associated with decreased arterial elasticity. In conclusion of the study, it was suggested that ICG may be effectively used to assess hemodynamics in patients with heart failure.

3.2. Mental disorders

In another study [6], the authors demonstrated a correlation between PEP, HI, and the occurrence of *post-traumatic stress disorder* (PTSD). Seventeen individuals suffering from PTSD and 120 individuals without this condition were examined. It was observed that PTSD is associated with a decrease in the values of PEP and HI parameters. The authors suggested that ICG can help to determine the relationship between heart failure and PTSD.

3.3. Hormonal imbalance

In paper [7], the authors examined the hemodynamic profile of individuals suffering from Cushing's disease (increased cortisol production). The study and control groups consisted of 54 individuals each. It has been shown that in individuals with Cushing's disease, the values of parameters such as SI, CI, VI, ACI, and HI were lower than in the control group, whereas the value of SVRI was higher. This indicates that this disease leads to dysfunction of the cardiovascular system, which might be spotted by using the ICG method. Moreover, in men with Cushing's disease, the hemodynamic profile was less favourable, which should be taken into account in planning further treatment, as it was found in [8]. The authors pointed out that ICG can serve as a tool for detecting early cardiovascular complications and may be helpful in decision-making about initiating appropriate therapeutic decisions.

A similar study was presented in paper [9], examining the impact of prolactinoma (increased prolactin production) in men on the hemodynamic profile. In this case, both the patients and control groups consisted of 20 men. Among men suffering from this illness, decreased values of parameters such as SI, CI, VI, ACI, and HI were observed, while the TFC value was increased, which may lead to worsening heart function. The authors suggested that in cases of prolactinoma in men, ICG may be used to detect hemodynamic abnormalities at an early stage, resulting in the implementation of appropriate medical treatment.

In another study [10], it was shown that ICG can also be used to monitor patients with acromegaly (excessive production of growth hormone). The control group consisted of 155 individuals, while the study group comprised 33 individuals diagnosed with acromegaly. The study showed that patients with acromegaly experienced an increase in TFC and a decrease in SI, VI, and HI. Assessing the values of these parameters may be helpful in determining optimal antihypertensive medications.

The topic of acromegaly was also addressed in article [11]. The aim of this study was to find a relationship between the balance in the *autonomic nervous system* (ANS) and the cardiovascular system in individuals suffering from this disease. For this purpose, *heart rate variability* (HRV) analysis based on ECG and the hemodynamic profile analysis determined by ICG were used. The study involved 33 newly diagnosed individuals without significant comorbidities. The correlation between ANS balance and the hemodynamic profile was proven. Consequently, impedance cardiography may be helpful in assessing cardiovascular risk in individuals with acromegaly, as ANS imbalance is associated with cardiovascular diseases [12, 13].

3.4. Physical effort

In another study [14], hemodynamic parameters were assessed using ICG to determine their relationship with exercise capacity parameters measured by cardiopulmonary exercise testing in patients with *coronary artery disease* (CAD). Evaluating exercise capacity is important in CAD as it can be a prognostic factor for mortality. The study was conducted with 54 CAD patients. A correlation was demonstrated, notably between cardiac output (CO) and the VO2 parameter (oxygen uptake), which has clinically validated application [15]. The authors concluded that ICG provides a reliable, indirect assessment of exercise capacity in individuals with CAD.

3.5. Sepsis

The aim of the study described in paper [16] was to assess the utility of hemodynamic parameters obtained through impedance cardiography in the treatment of sepsis. The study involved 9 patients. Measurements were taken twice, i.e., once at activation of the sepsis alert and again one hour after fluid resuscitation with 2 litres of intravenous crystalloid solution bolus.

The marked pronounced responses to the fluid challenge were observed in SVR and SVRi, which may indicate the usefulness of monitoring those parameters and, thereby, the utility of ICG in monitoring the effects of treatment in sepsis patients.

3.6. Hypertension

In another study [17], the values of hemodynamic parameters obtained using ICG were compared between patients with hypertension who had heart failure (HF) and those who did not. Among the 102 patients examined, 25 also had HF. Patients with HF had, among other dysfunctions, reduced values of CI and SI parameters. The observed differences, which were consistent with expectations, may indicate the effectiveness of ICG.

Yağmur et al. [18] conducted an analysis based on the comparison of the effectiveness of ICG with invasive methods used for measuring cardiac output, including the estimated Fick method and thermodilution, in predicting mortality in patients with pulmonary hypertension. The analysis included data from 215 individuals who underwent at least two measurement methods. They calculated Pearson correlation coefficients for each pair of the results. It was found that "for CO and CI measurements, ICG is moderately correlated with TD and fairly with eFick methods". Thermodilution was identified as the most effective method, but ICG proved to be more effective than the estimated Fick (eFick) method in predicting adverse events within a year. This may suggest the utility of ICG in survival prognosis for patients with pulmonary hypertension.

4. Veterinary

Impedance cardiography may also be applied in veterinary medicine, as was demonstrated in article [19]. ICG was used to monitor the condition of two dogs during the removal of *heartworms* (HW). The presence of these parasites disrupts blood flow, leading to a decrease in the cardiac output (CO) parameter. Monitoring this parameter revealed an increase of over 100% in its value after the procedure. The authors suggested the benefits of ICG application as a non-invasive method for monitoring CO during HW removal in dogs and recommended further research in this area.

5. Conclusions

Impedance cardiography has been evaluated as a non-invasive and inexpensive method for monitoring and assessing cardiac function. Studies have demonstrated its potential utility in several areas, including the evaluation of hemodynamic changes following surgical procedures such as off-pump coronary artery bypass grafting and transcatheter aortic valve replacement. ICG has also shown potential in monitoring and predicting outcomes in conditions such as sepsis and pulmonary hypertension, where it correlates with other established, gold-standard methods, such as thermodilution and the estimated Fick method. Additionally, ICG has been explored in the context of exercise capacity in patients with coronary artery disease, as well as in veterinary applications, where it effectively monitored cardiac parameters during heartworm removal in dogs. Overall, these findings suggest that ICG could be a valuable tool in both human and veterinary medicine, offering real-time, non-invasive insights into cardiac function and prognosis across a range of health conditions. However, it is important to note that in most of the cited studies, the number of individuals who underwent the examinations was relatively small; therefore, further research in this area is recommended.

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