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Applicability of Impedance Cardiography During Heart Failure Flare-Ups

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Background: Heart failure (HF) accounts for about 5% of all causes of urgent hospital admissions, and the overall mortality of HF patients within 1 year after hospitalization is 17–45%. Transthoracic impedance cardiography (ICG) is a safe, non-invasive diagnostic technique that helps to detect various parameters that define different cardiac functions. The aim of this study was to investigate the value of ICG parameters in patients hospitalized due to HF flare-ups.

Material/Methods: The study included 60 patients (24 women and 36 men) who were admitted to intensive care units because of an acute episode of HF without signs of myocardial infarction. The diagnosis of HF as the main reason for hospitalization was verified according to the universally accepted techniques. ICG data were compared to those obtained via other HF diagnostic techniques.

Results: A moderately strong relationship was found between the ejection fraction (EF) and the systolic time ratio (STR) $r=-0.4$ ($p=0.002$). Findings for STR and thoracic fluid content index (TFCI) differed after dividing the subjects into groups according to the EF ($p<0.05$). A moderately strong relationship was found between brain natriuretic peptide and TFCI $r=0.425$ ($p=0.001$), left cardiac work index (LCWI) $r=-0.414$ ($p=0.001$). Findings for TFCI, LCWI, and cardiac output differed after dividing the subjects into groups according to HF NYHA classes ($p<0.05$).

Conclusions: Transthoracic impedance cardiography parameters could be applied for the diagnostics and monitoring of HF, but further studies are required to evaluate the associations between ICG findings and HF.

MeSH Keywords: **Cardiography, Impedance • Heart Failure • Stroke Volume**

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Background

Heart failure (HF) is a complex clinical syndrome that is common in medical practice. About 1–2% of the population in developed countries is diagnosed with HF, and this percentage exceeds 10% among people aged 70–80 years [1]. HF accounts for about 5% of all hospital admissions, and the overall mortality of HF patients within 1 year after hospitalization is 17–45%.

In 2014, the total proportion of registered HF patients in Lithuania was 37.77/1000 population (in total, 110 751 cases), HF (ICD-10-AM code I50) as the reason for hospitalization was registered in 6.38/1000 population (in total, in 18 720 cases), in-hospital mortality reached 133.81/1000 population, and the mean duration of hospital stay was 22.36 days [2]. Thus, HF is a relevant issue not only from the medical, but also from the financial perspective; 3–4% of the population is affected, it is a common cause of visits to physicians, about 17% of patients are hospitalized annually, and the hospital stay is prolonged. To improve HF diagnosis and treatment and to reduce financial costs, it is important to search for HF examination techniques that are cheap, effective, preferably non-invasive, and are usually performed on an outpatient basis so that family physicians can quickly adjust the treatment and refer the patients for more detailed examination or inpatient treatment.

The evaluation of hemodynamic indices and their changes during HF flare-ups have attracted significant attention worldwide. Previously, hemodynamic examinations were performed almost exclusively by invasive examination techniques that had limited applicability, but recently, alongside the application of the accepted (and frequently less readily accessible on an outpatient basis) methods such as echocardiography (I C), ECG (I C), brain natriuretic peptide (BNP) test (IIa C), or chest X-ray (IIa C), a search for other non-invasive techniques has started. Preferably, these techniques should be cheap and easily carried out in outpatient and inpatient settings.

Transthoracic impedance cardiography (ICG) is a safe, non-invasive, and cheap (disposable tools used in the procedure cost about 7–8 euros or 8–9 US dollars) diagnostic method that is easy to perform and does not require any special staff training. This method is based on the detection of thoracic electrical bioimpedance during systole or diastole, and has been researched since 1940. The parameters determined during ICG analysis are used for HF diagnostics, risk evaluation, treatment efficiency control, and differentiation of acute dyspnea *vs.* cardiological and non-cardiological causes. Over the last decade, a number of studies have been conducted on the possibilities of the use of ICG in HF diagnosis and monitoring.

Most of the studies have demonstrated a good correlation between ICG, echocardiography (EC), and invasive diagnostic techniques. A significant correlation (r=0.85) was found between the ejection fraction (EF) determined during EC and ICG findings (cardiac output [CO] and systolic time ratio [STR]) observed when monitoring HF patients [3]. A number of studies found a good correlation between ICG data and CO calculated by applying thermodilution (TD); the mean correlation was r=0.65–0.8 [4,5]. It has been noticed that when evaluating reduced ICG parameters (the velocity and acceleration indices), systolic dysfunction can be diagnosed with 73% sensitivity and 70% specificity [6]. A study involving 54 patients showed a correlation between EF and STR on ICG (r=–0.54, p<0.01); if EF<50%, then STR>0.5 (93% sensitivity and 85% specificity) [7]. Another study, which included 36 patients, showed a correlation between EF and ICG parameters such as the pre-ejection period (PEP) (p=0.0069), left-ventricular ejection time (LVET) (p=0.0462), and STR (p=0.0031) [8]. A study involving 29 patients showed a good correlation between the thoracic fluid content (TFC) on ICG and an increased pulmonary capillary wedge pressure (r=0.69, p<0.001), with 86% sensitivity and 94% specificity of TFC [9]. However, several studies failed to yield a good correlation. A study on 13 patients with severe HF did not show a good correlation between ICG and TD cardiac indices (CI), r=0.29 [10]. In a study involving 33 patients, the comparison of CO calculated using Transthoracic Aesculon ICG with that calculated by applying TD showed a weak correlation (r=0.35, p<0.013), and CO calculated by applying ICG was 17% greater [11].

A number of studies have been conducted on the associations between brain natriuretic peptide (BNP) and ICG in patients with HF. Most studies yielded positive results. A study on 331 patients showed that BNP and STR on ICG were good prognostic factors when evaluating HF flare-up [12,13]. A study involving 120 HF patients showed that TFC>35 1/kOmega determined by ICG together with BNP>350 pg/mL had 95% sensitivity and 96% specificity when diagnosing diastolic HF [14]. A study with 524 patients showed that ICG STR and BNP could be indicators of early HF flare-up, and the relative risk of HF flare-up increased by 12.5 times (p<0.001) at BNP>100 pg/mL and STR>0.45 [15]. A study involving 63 patients showed an elevation in left ventricular end-diastolic pressure and BNP levels (p=0.001) when the stroke index (SI) of the heart was <40 mL/m^2 and TFC was >30 1/kOhm (high-risk patients) [16]. However, several studies failed to yield a good correlation between these factors. A study involving 50 hemodynamically stable HF patients did not show a good correlation between ICG TFC and BNP, r=0.24, p=0.22 [17]. A study involving 163 patients showed that ICG TFC, irrespectively of systolic dysfunction or the New York Heart Association (NYHA) functional class of HF, may reflect BNP levels, but only BNP is suitable for prognosis as an independent factor [18]. Another study involving 54 patients with dyspnea also failed to show a good correlation between BNP and ICG parameters [19].

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Table 1. Characteristics of the population.

Parameters	mean (95% CI)
Sex (M/F)	36/24
Age (years)	67.9±3.4
Systolic blood pressure (mmHg)	123.1±4.6
Diastolic blood pressure (mmHg)	77.8±3.6
Respiratory rate (breaths/minute)	27.2±1.6
Intravenous dose of diuretics (mg/day)	103.6±5.8
Parameters	**%**
Antihypertensive treatment	65.0
Diuretics treatment	93.3
Oxygen treatment	100.0
Coronary arterial disease (relevant diagnosis)	85.0
Arterial hypertension (relevant diagnosis)	71.7
Cardiomyopathy (relevant diagnosis)	90.0
Atrial fibrillation (relevant diagnosis)	45.0
Chest X-ray: pulmonary congestion/ edema	93.3
ECG: hypertrophy findings	90.0

Studies have shown that ICG parameters could help to differentiate the causes of dyspnea. In 38 patients, the cause of dyspnea was evaluated using conventional techniques (an interview, EC, and chest X-ray) and ICG (the cardiological cause of dyspnea was determined when CO≤2.4 L/min or STR≥0.55 and CO≤3.0 L/min). The study showed that ICG had 92% sensitivity and 88% specificity compared to 83% sensitivity and 77% specificity of the conventional techniques [20]. In the ED-IMPACT study, 89 patients over 65 years of age were examined to ascertain the cause of dyspnea. The results of the study showed that in cases when ICG was performed after conventional examinations, the diagnosis was altered in 13% of cases, and treatment adjustments were made in 39% of cases [21]. ICG parameters (PEP, CO, CI, STR, and the velocity index) help to differentiate between cardiological and non-cardiological causes of dyspnea. A study on 52 patients showed that the sensitivity of ICG was 75%, and specificity was 88%, compared to 60% sensitivity and 66% specificity of the conventional examination techniques ($p<0.01$) [22,23].

Since research data are quite controversial, especially in cases of severe HF, we investigated the value of ICG parameters in patients admitted to intensive care units due to HF flare-ups.

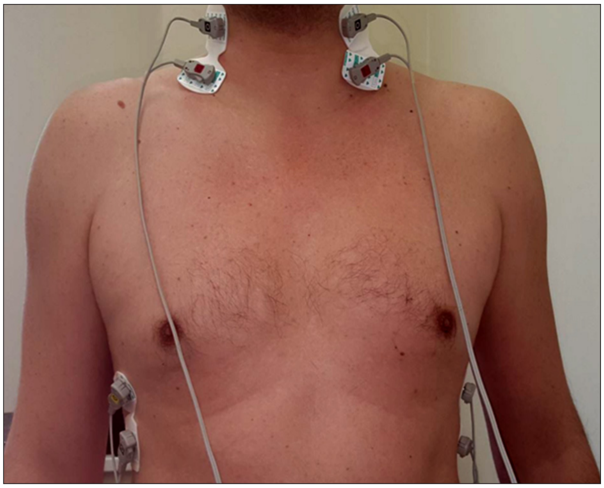

Figure 1. Electrode placement for impedance cardiography measurement.

Material and Methods

The studied sample

The study was carried out between 2012 and 2015 at the Department of Intensive Cardiology of the Hospital of the Lithuanian University of Health Sciences and the Intensive Care Unit of Kaunas Clinical Hospital (Lithuania). The study was performed with the approval of the Lithuanian Bioethics Committee, No. BE-2-51, and informed consent was obtained from each participant. The study included (random) 60 patients (24 women and 36 men) over 18 years of age who were admitted to intensive care units for HF flare-ups without signs of myocardial infarction (MI). The main characteristics of the population are presented in Table 1. The diagnosis of HF as the main reason for hospitalization was verified prior to the study according to the universally accepted techniques [1]. According to the accepted guidelines for ICG examination, to rule out the effect of the poor quality of the ICG signal and the errors in the calculated parameters, patients were excluded from the study if they had any of the following conditions: septic shock, severe regurgitation through the aortic valve, ventricular septal defect, severe aortic sclerosis, aortic valve prosthesis, severe arterial hypertension, tachycardia >200 bpm, height <120 cm or >230 cm, or weight <30 kg or >155 kg [24,25].

Methods of examination

HF flare-ups in the subjects were verified by applying the following techniques: an interview (age, dyspnea, HF NYHA class, and anamnesis); objective examination (height, weight, respiration rate, rhonchus, edemas, blood pressure, and heart rate), electrocardiography, chest X-ray, BNP, troponin I; and two-dimensional EC (performed with the participation of a professional cardiologist-cardiac sonographer, using a two-dimensional EC machine with spectral Doppler ultrasound capacity).

Table 2. The list of ICG parameters.

ICG parameters	Normal value
Thoracic Fluid Content (TFC)	Men: 30–50 1/kOhm Women: 21–37 1/kOhm
Thoracic Fluid Content Index (TFCI)	Men: 15–25 1/kOhm/m^2 Women: 12–21 1/kOhm/m^2
Stroke Volume (SV)	60–130 ml
Stroke Index (SI)	30–65 ml/m^2
Cardiac Index (CI)	2.5–4.7 l/min/m^2
Cardiac Output (CO)	4.5–8.5 l/min
Velocity Index (VI)	33–65×1000^{-1} sec^{-1}
Acceleration Index (ACI)	Men: 70–150/100 sec^2 Women: 90–170/100 sec^2
Systemic Vascular Resistance (SVR)	750–1500 dynes sec cm^{-5}
Systemic Vascular Resistance Index (SVRI)	1700–2600 dyne sec cm^{-5} m^2
Total Arterial Compliance (TAC)	1.3–2.8 ml/mmHg
Total Arterial Compliance Index (TACI)	0.7–1.4 ml/mmHg/m^2
Systolic Time Ratio (STR)	0.3–0.5
Left Ventricular Ejection Time (LVET)	Normal value depends on the heart rate
Pre-ejection Period (PEP)	Normal value depends on the heart rate
Left Cardiac Work (LCW)	5.4–10 kg m
Left Cardiac Work Index (LCWI)	3–5.5 kg m/m^2

In this study, we used a Niccomo™ transthoracic ICG monitor with 8 electrodes (Bernstein's 8-electrode modification) (Figure 1) produced by the German company "Medis Medizinische Messtechnik GmbH, Germany" [25,26]. ICG was performed after a 10-min rest, the patient being in the lying position, with the vertex of the head elevated by 30°; the procedure was performed after EC. The sensors measure the baseline impedance of the thorax. Impedance changes with each beat of the heart due to changes in the volume and velocity in the aorta. This produces a change in the electrical resistance (impedance) of the thorax to electrical alternating current. The changes in impedance can be used to measure or calculate hemodynamic parameters. The main parameters of ICG are presented in Table 2.

In the study, we selected the ICG parameters that in our opinion best reflect the changes that occur in the presence of HF: TFC, TFCI, SV, SI, CI, CO, STR, LVET, PEP, LCW, and LCWI.

Statistical data analysis

Statistical data analysis was performed using the software Statistical Package for the Social Sciences (SPSS) 16.0. In descriptive statistics, mean values were evaluated, the comparison of multiple distributions was performed by applying the Kruskal-Wallis test, and relationships between the attributes were evaluated by using Spearman correlation coefficient. Multivariate regression analysis was performed to evaluate the role of confounding factors on results. The post hoc tests (LSD and Tukey) were performed to make pairwise comparisons between groups. The level of significance was set at $p<0.05$.

Results

The studied group consisted of 24 women (40%) and 36 men (60%) with a mean age of 67.9 years (95% CI 64.5-71.3); the youngest subject was 35 and the oldest was 89.

The obtained ICG parameters are presented in Table 3.

The mean EF detected on EC was 36% (95% CI 32.2-39.8), the minimal value being 10%, and the maximal 60%. A moderately strong relationship was found between EF and ICG STR, correlation coefficient $r=-0.4$ ($p=0.002$) (Figure 2), and a

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Table 3. ICG data.

ICG parameter	Mean (95% Cl)		Minimum	Maximum
TFC (1/kOhm)	44.5	(40.7–48.3)	27.8	86.3
TFCI (1/kOhm/m²)	23.4	(21.1–25.7)	11.4	45.2
SV (ml)	66.2	(59.2–73.2)	24	138
SI (ml/m²)	33.5	(30.5–36.5)	14.0	59.6
CI (l/min/m²)	2.7	(2.5–2.9)	1.0	3.9
CO (l/min)	5.3	(4.9–5.7)	1.6	8.6
STR	0.4	(0.37–0.43)	0.14	0.74
LVET (ms)	270.6	(256.6–284.6)	150	408
PEP (ms)	103	(95–111)	47	186
LCW (kg*m)	6.3	(5.7–6.9)	1.8	12.0
LCWI (kg*m/m²)	3.2	(2.9–3.5)	1.0	6.4

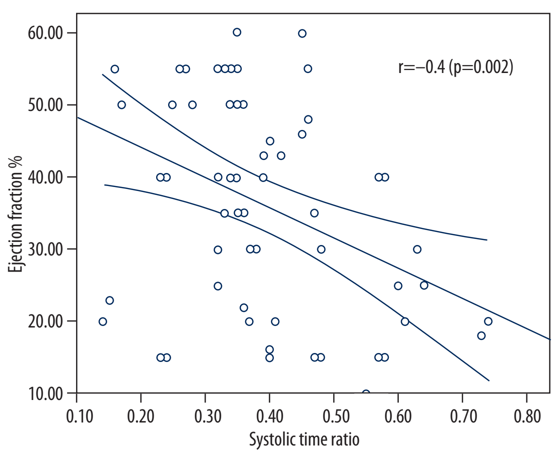

Figure 2. Correlation of the ejection fraction and systolic time ratio.

weak correlation was found between EF and ICG PEP, r=–0.28 (p=0.003). No statistically significant correlations between other ICG parameters and EF were found (p>0.05). The multivariate regression analysis showed that when using ICG parameters for the evaluation of EF, the summary multiple correlation coefficient in the model was R=0.658, p=0.002. Statistically significant (p<0.05) standardized coefficients (Beta) were obtained when evaluating STR, SI, CO, LCW, and LCWI.

Concerning systolic function impairment, the distribution of EF data was the following: we found significantly reduced systolic function (EF<30%) in 20 subjects (33.3% of cases); moderately reduced (EF 30–39%) in 9 subjects (15%), slightly reduced (EF 40–49%) in 15 subjects (25%), and in 16 subjects (26.7% of cases) the systolic function was unaffected (EF 50–60%). Depending on systolic function impairment, differences were found when evaluating TFC, TFCI, and STR; no differences in other ICG parameters were detected (p>0.05) (Table 4). The post hoc tests (LSD and Tukey) showed differences (p<0.05) in the evaluation of TFC and TFCI when comparing the group of patients with EF<30% to those with EF 30–39% and EF 40–49%, and no differences (p>0.05) when comparing the group of patients with EF 50–60% to those with EF<30%, EF 30–39%.

The mean BNP level in the subjects was 801.1 pg/mL (95% CI 637.5-964.7), the minimal value being 14.6 pg/mL, and the maximal 2800 pg/mL. A moderately strong relationship was detected between BNP and ICG TFC, TFCI (Figure 3), SV, SI, CI, CO, LCW, and LCWI (Table 5). The multivariate regression analysis showed that when using ICG parameters for the evaluation of BNP, the summary multiple correlation coefficient in the model was R=0.650, p=0.003. Statistically significant (p<0.05) standardized coefficients (Beta) were obtained when evaluating TFC, LCW, and LCWI.

The distribution of the patients according to the NYHA classes of HF was: 8 patients (13.3%) were in NYHA class II, 28 (46.7%) were in NYHA class III, and 24 patients (40%) were in NYHA class IV. After the analyzing the data according to NYHA classes, differences were found in the evaluation of BNP, TFC, TFCI (Figure 4), CO, LCW, and LCWI; there was no difference in other ICG parameters with respect to EF by NYHA classes of HF (p>0.05) (Table 6). The post hoc tests (LSD and Tukey) showed differences (p<0.05) in the evaluation of BNP, TFC, TFCI, CO, LCW, and LCWI when comparing the group of patients with NYHA class II to those with NYHA class III and IV, and no differences (p>0.05) when found when comparing the group of patients with NYHA III class to those with NYHA IV class.

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Table 4. Distribution of ICG data in groups with different ejection fraction according to the Kruskal-Wallis test.

EF	EF <30% (n=20) Mean Rank	EF 30–39% (n=9) Mean Rank	EF 40–49% (n=15) Mean Rank	EF 50–60% (n=16) Mean Rank	p value
TFC	34.1	14.5	45.2	21.2	**<0.001**
TFCI	29.9	16.2	43.9	26.6	**0.001**
SV	30.8	41.9	25.4	28.5	0.151
SI	28.4	42.0	25.5	31.4	0.141
CI	30.1	37.22	29.5	28.3	0.644
CO	34.2	37.6	27.2	25.1	0.219
STR	37.8	33.9	30.1	19.9	**0.02**
LVET	24.8	36.6	26.3	38.2	0.065
PEP	34.8	36.3	27.7	24.5	0.217
LCW	33.5	37.7	26.1	26.8	0.284
LCWI	29.5	36.5	30.0	28.8	0.732

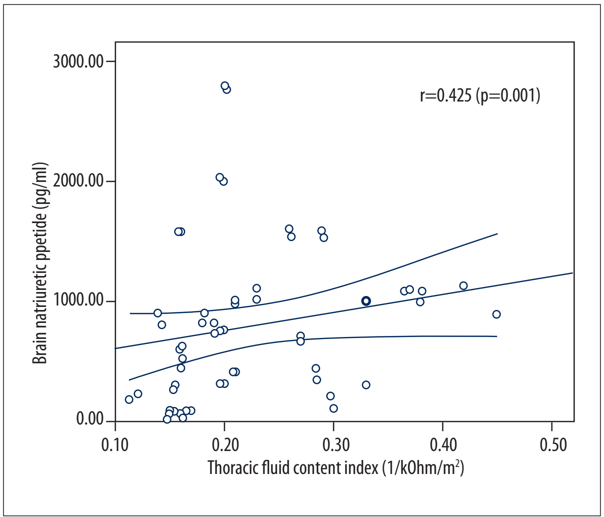

Figure 3. Correlation of BNP and the thoracic fluid content index.

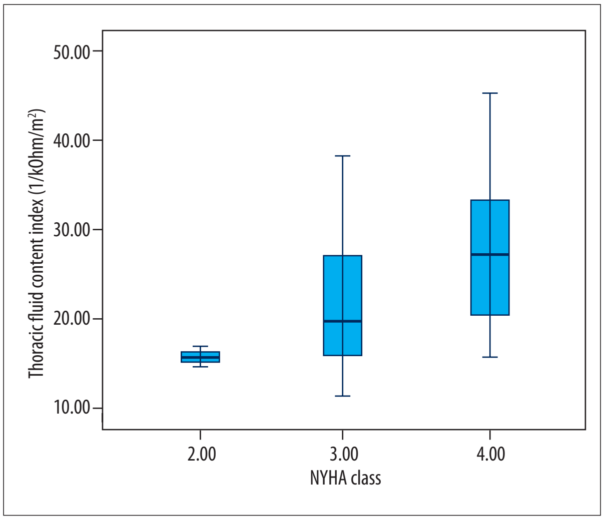

Figure 4. Distribution of the thoracic fluid content index in groups with different NYHA class of heart failure

Discussion

The aim of our study was to investigate the value of ICG parameters in patients admitted to intensive care units because of HF flare-ups. Most of the studies that evaluated the usefulness of ICG were performed on small groups of patients, and data obtained in larger studies, such as PREDICT [27] or ESCAPE [28], are controversial. The general tendency was that the results of studies on ICG applicability were worse in patients with severe HF (NYHA class III-IV, EF<30%), while in patients with milder forms of the disease the results were better [3,10,11,14,15]. Such results encouraged us to select patients treated in intensive care units, as such patients are considered to have clinically severe HF, but also have a broader distribution of diagnostic criteria of the condition (e.g., EF, BNP, or NYHA class). We also wanted to investigate the value of ICG during HF flare-ups, which is important for clinical practice. Since the presence of MI almost invariably requires invasive examination and treatment techniques, we think that ICG in cases of MI would not have any significant practical value for the evaluation of HF, and thus patients in whom HF flare-ups were caused by MI were excluded from the study.

In our study we investigated ICG parameters that reflect the systolic function of the heart (SV, SI, CI, and CO), cardiac contractile

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Table 5. Correlation of BNP and ICG data.

ICG parameter	Spearman r	p value
TFC	**0.406**	**0.001**
TFCI	**0.425**	**0.001**
SV	**–0.379**	**0.003**
SI	**–0.34**	**0.008**
CI	**–0.322**	**0.012**
CO	**–0.368**	**0.004**
STR	0.21	0.107
LVET	–0.129	0.327
PEP	0.268	0.038
LCW	**–0.406**	**0.001**
LCWI	**–0.414**	**0.001**

Table 6. Distribution of ICG data in groups with different NYHA class of heart failure when applying the Kruskal-Wallis test.

HF NYHA class	NYHA class II (n=8) Mean Rank	NYHA class III (n=28) Mean Rank	NYHA class IV (n=24) Mean Rank	p value
TFC	14.9	27.8	38.9	**p=0.001**
TFCI	12.5	27.4	40.1	**p<0.001**
SV	41.5	32.1	25.0	p=0.056
SI	40.3	30.2	27.7	p=0.207
CI	43.3	27.0	30.3	p=0.067
CO	44.7	30.3	26.0	**p=0.032**
STR	23.1	29.6	34.0	p=0.293
LVET	33.0	35.3	24.1	p=0.064
PEP	18.8	32.5	32.0	p=0.126
LCW	48.3	27.9	27.7	**p=0.008**
LCWI	47.3	24.5	31.9	**p=0.004**
BNP	6.62	32.2	36.5	**p<0.001**
EF	37.4	28.5	30.5	p=0.442

function (STR, LVET, and PEP), cardiac work (LCW and LCWI), and the amount of fluids in the thoracic cavity (TFC and TFCI). We expected the ICG indices based on the physiological substantiation of ICG to correlate with other HF diagnostic criteria, such as EF, BNP, and the NYHA class of HF.

We found correlations between EF and STR and PEP (other studies yielded similar results [7,8]), yet we did not find any association between other ICG parameters and EF, which is in contrast with the results obtained by other researchers [3,6]. After the distribution of the subjects according to systolic function impairment, differences were found in the evaluation of TFC, TFCI, and STR, but other ICG parameters did not differ. As expected, STR changed according to medical logic – the lower the EF, the greater the STR – whereas findings for TFC and TFCI were contradictory (e.g., in the groups of patients with EF 40–49%, the indices were higher than in the group with EF <30%). We think this is because HF could have been both systolic and

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diastolic, and STR (the marker of contractility) best reflected systolic HF, whereas TFC and TFCI best reflected diastolic HF. We did not find any relationship between other ICG parameters – SV, SI, CI, CO, LVET, LCW, or LCWI – and EF, although this could have been expected according to medical logic. We did not find a clear explanation, but this might have been due to the relatively small number of subjects and the patients' severe condition, which might have resulted in greater measurement errors, such as in the presence of atrial fibrillation. There is ongoing discussion concerning the specificity of the ICG signal and possible confounding factors that can affect the thoracic fluid content, because throughout the cardiac cycle the amount of blood affects impedance by 60%, changes in the fluid volume in the aorta by 30%, and blood flow velocity by 10%. Therefore, one must consider that TFC may increase not only because of cardiac pathology, but also because of conditions such as pneumonia and traumatic hydrothorax [29].

Our search of the literature yielded the highest number of studies on the relationship of transthoracic ICG with the cardiac biomarker BNP in the evaluation of HF. There were fewer studies on NT-proBNP, but the results were similar and are not presented in this article because our study only evaluated BNP. We failed to find any studies suitable for analysis and focusing on the relationship between transthoracic ICG with other cardiac biomarkers that are newly researched when evaluating HF, such as soluble ST2, GDF-15, and MR-proANP. This could be the object of future research because soluble ST2 could be a better cardiac biomarker than BNP or NT-proBNP [30]. A correlation was found between BNP and TFC, TFCI, LCW, LCWI, SV, SI, CI, and CO, which is similar to the results obtained in other studies [14,16], but we did not find any relationship between BNP and STR, which contradicts the results of other studies [12,13,15]. After dividing the patients into groups according to NYHA class, differences were detected when evaluating TFC, TFCI, CO, LCW, and LCWI, which is similar to results of other researchers [18]. Especially significant differences were observed when comparing the group of patients with NYHA class II to those with NYHA class III and IV HF. However, we did not find any relationship of other ICG parameters – SV, SI, CI, or STR – with the NYHA class, although, according to medical logic, this should have been expected. We think that this may have been due to the aforementioned reasons.

The study showed that during HF flare-ups, ICG indices were better correlated with BNP and HF NYHA class than with EF. This might have been because the number of subjects with either systolic of diastolic HF was relatively small.

Practical clinical implementation of ICG

There have been attempts to adapt ICG parameters to the HF issue in various aspects, yet so far no uniform recommendations for clinical practice have been globally approved. This is because the majority of studies have included small patient groups, whereas the data of larger studies such as PREDICT [27] and ESCAPE [28] are controversial. In general, transthoracic ICG is a safe, non-invasive, cheap, and simple to perform diagnostic technique that can be used to evaluate a number of important cardiological parameters, which may be useful when selecting diagnostic and treatment strategies for outpatients and inpatients. The results of the ICG technique might be improved by combining it with other relatively simple examination techniques such as patient interview, objective examination, ECG, and chest X-ray, if required. Recording an ICG may be expedient so that in the future, in case of a flare-up of a cardiac pathology, the dynamics of the markers could be evaluated and, if needed, the treatment could be adjusted or the patients could be referred for a more detailed examination. ICG may be performed not only by physicians, but also by trained nurses. Around the world, care management models are being tested (e.g., Project Leonardo [31] in Italy) with the aim of building smoothly operating teams consisting of family physicians, nurses, specialists, and actively participating patients, and these tests have yielded good results. We think that ICG might be applied in such models as well because this technique has a broad range of application:

- HF diagnostics, risk evaluation, and treatment efficiency control.
- Optimization of the atrioventricular (AV) interval when using cardiac stimulation for the improvement of hemodynamics.
- Diagnostics, risk evaluation, treatment efficiency control, and drug selection tactics in patients with arterial hypertension.
- Differentiation of acute dyspnea between cardiological and non-cardiological etiology.
- Intensive therapy: diagnostics, risk evaluation, treatment efficiency control, and perioperative patient monitoring.

In addition, other impedance analysis systems are also being actively researched, such as intrathoracic ICG (ICG electrodes are implanted together with cardiac pacemaker or defibrillator) [24] or Multifrequency Bioimpedance Analysis (BIA) (e.g., in a study with 77 patients on dialysis, fluid overload during BIA significantly correlated with pulmonary artery pressure) [32].

Limitations

Following the evaluation of the prevalence of HF in Lithuania, 60 subjects were selected for the pilot study. These subjects were not distributed according to the primary cause of HF flare-up, systolic and diastolic HF were examined together, and questionnaires were used to determine the NYHA class, which might have affected the test results described above. To obtain more precise results, a further study with more subjects is needed (according to the post hoc sample size calculation, 384 patients are required), dividing the patients into

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groups by the primary cause of HF and separately evaluating systolic and diastolic HF.

In our study, not all ICG parameters were correlated with the findings of other HF examination techniques, and since the data of other studies are controversial as well, further studies are required to evaluate the associations between ICG and HF, especially when the causes of HF flare-ups differ.

Conclusions

The following ICG parameters might be used for the diagnostics and monitoring of HF: Thoracic Fluid Content, Thoracic Fluid Content Index, Systolic Time Ratio, Cardiac Output, Left Cardiac Work, and Left Cardiac Work Index. However, further studies are required for the evaluation of the associations between ICG and HF.

Conflict of interest

The authors state no conflict of interest.

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