International Journal of Biology and Life Sciences
ISSN: 2957-9511 | Vol. 15, No. 3, 2026

Advances in the Application of Impedance Electrocardiography for Hemodynamic Assessment in Patients with Heart Failure

Guofeng Liu [1, 2], Yi Lu [2, *]

[1] Graduate School, Youjiang University of Ethnic Medicine, Baise, Guangxi, 533000, China
[2] Department of Critical Care Medicine, Affiliated Hospital of Youjiang University of Nationalities, Baise, Guangxi, 533000, China
*** Corresponding author:** Yi Lu

Abstract: Impedance cardiography (ICG) utilizes changes in thoracic impedance as an indicator to noninvasively and instantaneously obtain various hemodynamic data, which holds significant clinical importance for monitoring or treating patients with heart failure (HF). We conducted a systematic search of the literature in PubMed and CNKI, focusing on recent reports regarding the use of ICG for hemodynamic analysis in heart failure. We summarized and reviewed the diagnostic value, therapeutic implications, rehabilitative significance, and prognostic value of various ICG parameters for different types of HF. The findings indicate that ICG is highly useful for the auxiliary diagnosis of HF, the development of individualized treatment plans, and prognostic stratification; however, standardization of equipment and evidence supporting long-term favorable outcomes still need to be further established.

Keywords: Impedance Cardiography; Heart Failure; Hemodynamic Monitoring; Heart Failure with Preserved Ejection Fraction; Pleural Fluid Volume.

1. Introduction

Heart failure is a serious consequence of various cardiac diseases, and its prevalence has been on a long-term upward trend. Worldwide, the prevalence of heart failure among adults ranges from 1% to 3%; in China, the prevalence among individuals aged 25 and older, calculated according to standard criteria, has reached 1.10% and rises significantly with age [1-3] .Patients with heart failure (HF) are frequently hospitalized due to hemodynamic instability, placing a tremendous strain on healthcare resources [4, 5]. Therefore, from a clinical perspective, accurate analysis of cardiac function, volume, and hemodynamics is of great significance for the early detection, appropriate management, and prognosis assessment of HF patients. Currently, invasive procedures (right heart catheterization, RHC) are generally regarded as the gold standard for obtaining hemodynamic data such as cardiac output [6] ; however, their invasive nature, complexity, high cost, and high rate of complications impose significant limitations on their practical application [6, 7] . Consequently, the development of noninvasive alternative technologies capable of providing reliable hemodynamic information has become a major research focus in the cardiovascular field. Impedance cardiography emerged precisely against this backdrop [8] . This technique applies low-amplitude, high-frequency alternating current to the thoracic cavity and measures changes in thoracic bioimpedance during the cardiac cycle, thereby enabling non-invasive and uninterrupted measurement of hemodynamic parameters such as cardiac output (CO) and cardiac index (CI).Multiple studies have compared ICG with the thermal dilution method under right heart catheterization (RHC), confirming its accuracy and reproducibility in measuring CO and CI in patients with heart failure (HF); however, its clinical value remains controversial: regarding diagnosis itself, ICG's ability to distinguish HFpEF (heart failure with preserved ejection fraction) varies depending on the cutoff value selected. With regard to treatment guidance, while ICG-guided medication or device adjustments may improve short-term outcomes, there is a lack of support from long-term trials based on hard endpoints. In terms of prognostic prediction, although various ICG parameters have been reported to be associated with mortality or rehospitalization, their incremental value relative to traditional indicators has not yet been fully demonstrated.

The issues raised serve as the starting point for this discussion, which analyzes the hemodynamic effects of ICG on HF from four perspectives (validity of parameters, diagnostic utility, therapeutic benefit, and prognostic value). This paper synthesizes existing data, identifies areas of consensus and disagreement, and provides guidance for clinical practice and research.

2. Principles of ICG Technology and Validation of Hemodynamic Parameters

The scientific principle underlying impedance cardiography is the use of differences in electrical conductivity among various tissues in the thoracic cavity to make hemodynamic assessments. As described by Karpiel [9] , when ICG applies low-amplitude alternating current to the chest wall, the transient decrease (or increase) in intrathoracic blood volume during systole (or diastole) observed with each cardiac beat (i.e., each cycle) causes a corresponding change in bioimpedance (ΔZ), resulting in a ΔZ trace. Analysis of these impedance signals, using equations such as those proposed by Sramek-Bernstein, allows for the calculation of various hemodynamic parameters: stroke volume (SV), cardiac output, cardiac index, thoracic fluid content, SI (stroke index), total fluid content (TFC), pre-ejection period (PEP), systolic time ratio (STR), systemic vascular resistance (SVR), and indicators reflecting myocardial contractility (acceleration index ACI, Heather index HI), among others. The accuracy of ICG measurement is the fundamental prerequisite for its clinical application. Consequently, numerous studies have compared it with the thermal dilution method (including right heart catheterization). Ausbuettel [10] conducted simultaneous RHC and systemic ICG measurements on 203 hospitalized HF patients. The results showed that, with regard to RHC, the CO obtained by ICG was mostly moderately positively correlated with the CO reported by RHC ($r = 0.47$, $P < 0.001$), while the correlation for CI was slightly weaker ($r = 0.38$, $P < 0.001$).An analysis of Bland-Altman bias showed no significant bias in ICG-measured CO and CI compared to RHC (CO bias −0.14 L/min, $P = 0.1$; CI bias −0.09 L/min/m², $P = 0.06$); therefore, ICG-measured CO and CI can be considered relatively accurate. Studies by Kööbi [11]and in patients following coronary artery bypass grafting also demonstrated that ICG-measured CO showed high consistency with thermal dilution, and that the impedance method was significantly superior to the thermal dilution method in terms of stability of repeated measurements. The aforementioned cross-validation data establish a strong evidence-based foundation for the practical application of ICG.

However, the accuracy of ICG is limited by a variety of factors. From a purely technical perspective, there are several key points to consider. The placement of the electrodes, the patient's movements or body position, skin hydration, and body conformation can all interfere with the bioimpedance signal to varying degrees [9]. Secondly, the pathophysiological status of a particular patient can also pose challenges. Tang WH [12] explicitly points out that conditions such as severe arrhythmias and severe obesity can affect the precise calculation of ICG parameters; therefore, corresponding exclusion criteria are often required in clinical applications. Kieback [13] found in a study of 13 patients with severe chronic heart failure (NYHA III–IV) that the correlation between ICG and the SI measured by invasive hemodynamic thermal dilution (TD) was weak ($r = 0.29$), suggesting that the accuracy of ICG-derived parameters such as SI may be reduced in patients with severe or advanced HF.

3. Applications of ICG in the Diagnosis and Clinical Assessment of Heart Failure

The multi-level, diverse hemodynamic data provided by ICG inherently hold unique value for the diagnosis and clinical assessment of HF. For example, a study by Lopes[14] compared patients with hypertension complicated by HF to those without HF and found that in the HF group, cardiac index (CI), stroke index (SI),ejection fraction contraction index (EPCI), contractility status index (ISI), and left ventricular stroke work index (LSWI) were all significantly lower in the HF group compared to the group without HF. This suggests that ICG can quantitatively reflect hemodynamic abnormalities in hypertensive patients with heart failure from multiple dimensions, including pumping function, myocardial contractility, and cardiac work efficiency. A study by Chinese researchers Zhu Lin conducted a stratified analysis of HF patients based on the NYHA cardiac function classification. The results showed that as cardiac function deteriorated (Class I → II → III → IV), CO, CI, and SV—which reflect cardiac pumping function—as well as ACI (acceleration index) and VI (velocity index), which reflect myocardial contractility, all decreased; conversely, SVR and SVRI (systemic vascular resistance index)—which reflect peripheral vascular resistance—as well as STR (stroke time ratio), which reflects left ventricular ejection efficiency, all increased as the class progressed. The trends indicated by these parameters clearly demonstrate that ICG can provide a multidimensional quantitative assessment of the severity of cardiac dysfunction in HF patients. It is worth noting that ICG can also provide useful hemodynamic information for patients with heart failure with preserved ejection fraction (HFpEF), a condition that is clinically challenging to diagnose. Zhang Ruiqi and Zhang Lijun[16] found that the systolic indices corresponding to SV, SI, LSW (left ventricular stroke work), and LSWI (left ventricular stroke work index) in the HFpEF group did not differ significantly from those in the control group; however, their TFC, PEP, and STR were all significantly elevated. Regarding further ROC curve analysis, TFC, PEP, and STR demonstrated good specificity for the diagnosis of HFpEF (AUC values of 0.730, 0.808, and 0.774, respectively). This finding provides objective diagnostic clues and an auxiliary diagnostic method for assessing diastolic function in patients with HFpEF and normal systolic function who are difficult to identify clinically.

Previous studies have demonstrated that the hemodynamic parameters measured by ICG can be categorized according to cardiac pumping capacity (CO, CI, SV),myocardial contractility (ACI, VI, EPCI, ISI), work efficiency (LSWI), peripheral vascular resistance (SVR, SVRI), as well as volume status (TFC) and systolic time intervals (PEP, STR), thereby providing a relatively comprehensive description of the pathophysiology of HF.ICG serves as an assessment tool of particular clinical significance for HF associated with hypertension, for cardiac dysfunction across all NYHA classes, and for heart failure with preserved ejection fraction (HFpEF).

4. The Role of ICG in Guiding Heart Failure Treatment and Rehabilitation

Accurate assessment of hemodynamic abnormalities is merely the starting point for clinical decision-making; designing and modifying treatment plans based on this assessment is key to improving the prognosis of patients with HF.ICG's capability for real-time, continuous monitoring precisely meets these needs: comparing hemodynamic data before and after the administration of medications, the use of devices, or the implementation of rehabilitation measures helps physicians rapidly determine the next course of treatment and implement truly individualized management. Zhuang Qichao [17] A dynamic observation study was conducted on 28 pregnant women who developed acute heart failure due to gestational hypertension. After establishing a control group based on criteria for the absence of heart failure, the CI, SI, and LCWI values observed in patients with heart failure were all significantly reduced, while HR, SBP, DBP, SVRI, and TFC generally showed an upward trend. The differences in these indicators were statistically significant ($P < 0.001$ for all parameters). Furthermore, as preeclampsia-related heart failure improved, the noninvasive blood flow parameters also improved accordingly. This indicates that

ICG is a relatively safe and reproducible quantitative method for high-risk conditions such as pregnancy complicated by heart failure. It also demonstrates that the combined analysis of multiple indices—including CI, SI, SVRI, TFC, and LCWI—enables the early detection of signs of heart failure, the rational administration of volume and vasopressor medications, and the timely assessment of treatment efficacy.

Based on early literature, Li Yinan[18] previously used the BioZ thoracic bioimpedance monitor to observe the treatment of 23 patients with HF in the ICU. The results showed that 2–4 hours after administering medication according to the monitor's recommendations, patients' heart rates slowed, SV and CO increased, and TFC and SVR decreased; all indicators showed statistically significant differences compared to pre-treatment levels ($P < 0.001$), cardiac function improved rapidly, indicating that ICG provides immediate guidance for acute HF. This "goal-directed" treatment approach has also been validated by other studies. For the long-term management of chronic HF, optimizing treatment regimens based on ICG is equally important. Urbanek [19] analyzed the value of using ICG to measure cardiac output for optimizing the atrioventricular delay (AVD) and ventricular-ventricular delay (VVD) in patients with heart failure characterized by left bundle branch block and a left ventricular ejection fraction (LVEF) ≤35% undergoing cardiac resynchronization therapy (CRT).There were no significant differences in echocardiographic findings between the two study groups; however, compared with the control group, the pacing parameters optimized using ICG resulted in higher cardiac output (CO) and more complete left ventricular reverse remodeling (decreased LVEDV and LVESV, increased LVEF). This demonstrates that ICG is a simple, noninvasive tool that can be used to improve CRT programming and achieve therapeutic goals. The AMULET project proposed by Krzesiński [20] represents one of the latest applications of ICG in the remote management of heart failure. The designed outpatient care protocol, administered by nurses, utilizes ICG to perform noninvasive hemodynamic analysis of patients with acute decompensated HF following discharge and employs telemedicine to determine whether to adjust medication regimens. In the initial analysis, where the physician's role was limited to data interpretation and clinical recommendations, significant improvements were observed in the New York Heart Association (NYHA) classification ($P = 0.013$) and in well-being as measured by the Visual Analog Scale (VAS) ($P = 0.002$).suggesting that this model effectively improves patients' functional status and subjective well-being and results in a high rate of medication adjustments, demonstrating ICG's potential for titrated management and reducing readmissions. However, there was no significant difference in the composite endpoint (all-cause mortality or readmission for heart failure) between the ICG group and the standard care group. This negative result suggests that while ICG-guided, nurse-led outpatient care may improve clinical status in the short term, its impact on long-term outcomes requires further evidence to confirm. Kirsch [21] In patients with heart failure with reduced ejection fraction (HFrEF), following 4 weeks of exercise training, those who responded to the training (i.e., an increase in VO_2peak) showed significant improvements in CO, HR, resting systolic blood pressure (SBP), and diastolic blood pressure (DBP) corresponding to peak exercise, whereas no similar changes were observed in the non-responders. In this context, peak CO serves as a useful indicator for distinguishing responders from non-responders (AUC = 0.77). Overall, the applications of ICG in heart failure treatment and rehabilitation can be categorized into four typical scenarios: (1) short-term bedside monitoring during the acute decompensated phase; (2) parameter optimization for CRT; (3) remote monitoring of the "vulnerable period" following discharge; and (4) individualized analysis of exercise rehabilitation efficacy and prescription. Regarding the commonalities and differences among these scenarios: The commonality is that ICG is used to track dynamic hemodynamic changes to determine whether a particular type of intervention (pharmacological, pacing, telemonitoring, or exercise) is appropriate. The differences primarily stem from the timing and objectives of the interventions: the acute phase focuses on improving parameters (CO, SVR) within a matter of hours; device optimization aims for long-term reverse remodeling (LVEDV, LVEF); remote management considers functional status and quality of life (NYHA, VAS); and exercise rehabilitation seeks to identify physiological responders (peak CO, VO_2peak).It should be noted that there is currently a lack of multicenter, large-sample, randomized controlled trials with hard endpoints (all-cause mortality, rehospitalization for heart failure) to demonstrate that the ICG-guided approach is superior to conventional management.

5. The Value of ICG in the Prognostic Assessment of Heart Failure

The real-time hemodynamic feedback described by ICG has dynamic significance for clinical decision-making, and the ultimate goal of treatment should be to improve patients' long-term prognosis. It should be noted in particular that ICG is not used solely to guide interventions: the various hemodynamic parameters involved have themselves been shown to be associated with the short- and long-term prognosis of patients with HF. Müller [22] included 11 studies in their systematic review and meta-analysis. The results showed that BNP and NT-proBNP levels were significantly positively correlated with TFC (pooled correlation coefficient 0.332, $P < 0.001$), while they were negatively correlated with SI and CI (–0.369 and –0.312, respectively) and positively correlated with STR (0.230). This suggests that ICG parameters provide a good indicator of the severity of HF and show reliable correlations with recognized prognostic markers. Sadauskas [23] conducted an analysis of 120 intensive care unit patients readmitted due to acute decompensation of HF to examine the prognostic significance of ICG parameters in greater detail. They concluded that a BNP level of 350 pg/mL or higher, a TFC of 341 kΩ or higher, and an STR of ≥0.55 at discharge were significant predictors of adverse outcomes, such as death, within 6 months, with odds ratios (ORs) of 4.4, 4.3, and 2.9, respectively. This indicates that ICG parameters can provide supplementary prognostic information independent of conventional indicators. Furthermore, the dynamic changes in ICG parameters are also significant for prognosis. Chang [24] used nocturnal measurements of the thoracic fluid content index (TFCi) in acute HF patients prior to discharge and confirmed that nocturnal ΔTFCi (the increase in TFCi) is an independent risk factor for predicting post-discharge hospitalization for heart failure or death (HR = 1.58). Individuals with ΔTFCi ≥ 0.5 had a very high probability of adverse outcomes (HR = 6.25). This observed association further underscores the importance of continuous changes in ICG parameters for assessing volume status and prognosis in HF patients. Ališauskas [25] included 301 patients with chronic HF in a single-center study and found that baseline TFC ≥ 36.91/kΩ (HR = 4.604) andLVEF ≤ 40% (HR = 4.942) were both independent predictors of cardiac death, and the combined use of these two indicators improved predictive accuracy. Jing[26] conducted an analysis of HF patients with concomitant permanent atrial fibrillation, showing that both admission and discharge SVR were independent risk factors and clinical predictors for rehospitalization due to HF exacerbation within 180 days. When the admission SVR was >320.89 kPas/L, the risk of rehospitalization increased 8.14-fold; for patients with a discharge SVR >169.94 kPas/L, the risk of rehospitalization was 6.57-fold higher (P=0.002).Krzesiński [27] investigated the hemodynamic effects of anemia in patients with acute decompensated HF and found that anemic patients with acute decompensated HF (particularly those with preserved LVEF) exhibited higher TFC and a state of relatively high cardiac output. They also noted that anemia itself was independently associated with a higher risk of death (for every 1 g/dL decrease in Hb, the risk of death increases by approximately 13%), suggesting that this high-output state does not confer clinical benefit and revealing the prognostic significance of hemodynamic patterns in the context of specific comorbidities. Overall, both individual ICG-derived parameters (i.e., TFC, SVR, STR) and their changes over time have been shown to be significantly associated with mortality or rehospitalization in patients with HF. The studies consistently regard ICG as a noninvasive, user-friendly method for prognostic assessment; the information it provides can supplement the limitations of general physical examinations and biomarkers, facilitating detailed risk analysis and enabling early intervention.

6. Shortcomings

First, technical standardization remains inadequate[28]. There are differences in electrode design, computational models, and parameter formulas among products from different manufacturers[29], making it difficult to directly compare research results and hindering the establishment of a unified clinical threshold. For example, in three studies conducted by the Ališauskas team within the same country, using different types of ICG devices, and targeting the same endpoint (cardiac death), different optimal TFC cutoff values were obtained: in 2018 (n=120), it was ≥34 1/kΩ[23] ; in 2022 (n=301), it was ≥36.9 1/kΩ[25]; and in 2024 (n=87), it was ≥41.1 1/kΩ [30]. Second, there is a lack of evidence for specific patient populations. Currently, there are very few ICG validation studies for patients who are obese or have severe arrhythmias, yet these are precisely the individuals who require noninvasive monitoring. Future research should focus on these subgroups. Third, most current studies only discuss associations, short-term function, or surrogate markers (such as NYHA classification and visual analog scales) [31]; there are as yet no randomized trials with multicenter designs and all-cause mortality as the primary outcome to demonstrate that ICG-guided treatment is superior to standard approaches. Fourth, the prognostic significance of dynamic parameters remains to be elucidated. Current research largely focuses on single-point ICG measurements, whereas the true power of ICG lies in time-series monitoring. Future efforts should aim to construct prognostic models based on ICG dynamics (such as nocturnal TFC elevation and post-exercise CO recovery).

7. Conclusion

Impedance cardiography is a noninvasive, simple, and continuous hemodynamic monitoring method with a wide range of applications in the comprehensive management of heart failure patients. A large body of literature demonstrates that the parameters provided by ICG (CO, CI, SV, TFC, SVR, STR, etc.) correlate closely with the "reference standards" obtained via right heart catheterization. The dynamic changes observed serve as important indicators of patient prognosis and hold significant value inauxiliary diagnosis, treatment selection, rehabilitation assessment, and even post-discharge follow-up. To achieve clinical translation in this field, four key challenges must still be addressed. Overall, the clinical application of ICG in heart failure management has progressed from the stage of "theoretical feasibility" to that of "validating clinical utility through comparative trials." This will help establish this noninvasive approach as an integral part of individualized heart failure diagnosis and treatment.

Acknowledgments

Foundation items: Guangxi Medical and Health Key (Cult ivation) Discipline Construction Project (No. Guiwei Kejiao fa [2019] 19); Baise Scientific Research and Technology De velopment Program Project (No. Baike 20184711); Youjiang Medical University for Nationalities Doctoral Program Dis cipline Construction Project (No. Youyi Fuyuan Yuanzi [201 8] 29).

References

[1] Chinese Geriatrics Society, Specialized Committee on Integrated Traditional Chinese and Western Medicine Cardiac Rehabilitation of the Chinese Medical Doctor Association, Specialized Committee on Cardiac Rehabilitation of the World Federation of Traditional Chinese Medicine, et al. (2026). Guidelines for the chronic disease management of heart failure in the elderly. Research on the Integration of Traditional Chinese and Western Medicine, 18(2), 110–155.

[2] Wang, H., Chai, K., Du, M., et al. (2021). Prevalence and incidence of heart failure among urban patients in China: A national population-based analysis. Circulation: Heart Failure, 14(10), e008406. https: //doi.org/10.1161/ CIR CHE ART FAILURE.121.008406.

[3] Wang, Q. L., Sun, H., Liu, W. J., et al. (2025). Advances in the application of remote monitoring in patients with heart failure. Chinese Journal of Circulation, 40(5), 516–520.

[4] Ji, R. Q. (2023). A study on the prognostic value of noninvasive hemodynamic congestion measurement indicators in acute heart failure. Peking Union Medical College.

[5] Wang, H., Li, Y. Y. (2026). Report on progress in the prevention and treatment of heart failure in China (White Paper). Chinese Journal of Circulation, 41(4), 318–342.

[6] Lee, S. H., Bae, D., Hong, D., et al. (2026). Right heart catheterization: Best practices and specific considerations. International Journal of Heart Failure, 8(2), 137–146. https:// doi. org/10.36628/ijhf.2026.0041.

[7] Hull, J. V., Padkins, M. R., El Hajj, S., et al. (2023). Risks of right heart catheterization and right ventricular biopsy: A 12-year, single-center experience. Mayo Clinic Proceedings, 98(3), 419–431. https://doi.org/10.1016/j.mayocp.2022.07.025.

[8] Xiong, Z. C., Chen, K. Y., Yan, J. (2019). Advances in the application of noninvasive hemodynamic assessment in heart failure. Advances in Cardiovascular Diseases, 40(6), 923–926.

[9] Karpiel, I., Richter-Laskowska, M., Feige, D., et al. (2022). An effective method for detecting characteristic points of the impedance cardiogram verified in a clinical pilot study. Sensors, 22(24). https://doi.org/10.3390/s22249872.

[10] Ausbuettel, F., Khwamurad, S., Abdo, M. H., et al. (2025). Non-invasive measurement of hemodynamic parameters via whole-body impedance cardiography among hospitalized heart failure patients: An effective alternative to invasive right heart catheterization? Journal of Cardiovascular Development and Disease, 12(4). https://doi.org/10.3390/jcdd12040128.

[11] Kööbi, T., Kaukinen, S., Turjanmaa, V. M., et al. (1997). Whole-body impedance cardiography in the measurement of cardiac output. Critical Care Medicine, 25(5), 779–785. https:// doi. org/10.1097/00003246-199705000-00012.

[12] Tang, W. H. W., Tong, W. (2009). Measuring impedance in congestive heart failure: current options and clinical applications. American Heart Journal, 157(3), 402–411. https:// doi. org/10.1016/j.ahj.2008.10.016.

[13] Kieback, A. G., Borges, A. C., Schink, T., et al. (2010). Impedance cardiography versus invasive measurements of stroke volume index in patients with chronic heart failure. International Journal of Cardiology, 143(2), 211–213. https:// doi. org/10.1016/j.ijcard.2008.11.201.

[14] Silva Lopes, B., Craveiro, N., Firmino-Machado, J., et al. (2019). Hemodynamic differences among hypertensive patients with and without heart failure using impedance cardiography. Therapeutic Advances in Cardiovascular Disease, 13. https://doi.org/10.1177/1753944719876517.

[15] Zhu, L., Zhang, Y. D., Hong, M. (2019). Application of noninvasive hemodynamic monitoring in the evaluation of cardiac function in patients with heart failure. Jiangsu Medicine, 45(2), 175–178.

[16] Zhang, R. Q., Zhang, L. J. (2022). A study on the value of noninvasive hemodynamic monitoring in the assessment of heart failure with preserved ejection fraction. Journal of Medical Research, 51(8), 131–135.

[17] Zhuang, Q. C., Cui, A. P. (2008). Application of a digital noninvasive hemodynamic monitoring system in the management of gestational hypertensive cardiopathy. Journal of Nanjing Medical University (Natural Science Edition), (10), 1325–1327.

[18] Li, Y. N., Zhou, L. X., Wen, W. B., et al. (2006). Clinical application of a chest bioimpedance-based noninvasive hemodynamic monitor in heart failure. Chinese Journal of Emergency Medicine, (9), 702–703.

[19] Urbanek, B., Kaczmarek, K., Klimczak, A., et al. (2017). Potential benefit of optimizing atrioventricular and interventricular delays in patients with cardiac resynchronization therapy. Indian Journal of Medical Research, 146(1), 71–77. https://doi.org/10.4103/ijmr.IJMR_1560_14.

[20] Krzesiński, P., Siebert, J., Jankowska, E. A., et al. (2021). Nurse-led ambulatory care supported by non-invasive hemodynamic assessment after acute heart failure decompensation. ESC Heart Failure, 8(2), 1018–1026. https: // doi. org/10.1002/ehf2.13207.

[21] Kirsch, M., Iliou, M., Vitiello, D. (2024). Hemodynamic response to exercise training in patients with heart failure and reduced ejection fraction. Cardiology Research, 15(1), 18–28. https://doi.org/10.14740/cr1591.

[22] Müller, C. (2025). Impedance cardiography in the diagnosis of congestive heart failure: A systematic review and meta-analysis. Cureus, 17(1), e77461. https://doi. org/10. 7759/ cureus. 77461.

[23] Sadauskas, S., Naudžiūnas, A., Unikauskas, A., et al. (2018). Diagnostic and outcome prediction value of transthoracic impedance cardiography in heart failure patients during heart failure flare-ups. Medical Science Monitor, 24, 6573–6578. https://doi.org/10.12659/MSM.910754.

[24] Chang, H., Huang, C., Cheng, H., et al. (2020). Nocturnal thoracic volume overload and post-discharge outcomes in patients hospitalized for acute heart failure. ESC Heart Failure, 7(5), 2807–2817. https://doi.org/10.1002/ehf2.12881.

[25] Committee Ališauskas, A., Naudžiūnas, A., Sadauskas, S., et al. (2022). A single-center study in Lithuania to evaluate the role of transthoracic impedance cardiography in the diagnosis and outcome evaluation of 301 patients with chronic heart failure exacerbation. Medical Science Monitor, 28, e938389. https://doi.org/10.12659/MSM.938389.

[26] Jing, Z., Zhang, J., Ding, J., et al. (2023). The prognostic value of systemic vascular resistance in heart failure patients with permanent atrial fibrillation: a retrospective study. Heart and Vessels, 38(12), 1431–1441. https://doi.org/10.1007/s00380-023-02314-0.

[27] Krzesiński, P., Galas, A., Gielerak, G., et al. (2020). Hemodynamic effects of anemia in patients with acute decompensated heart failure. Cardiology Research and Practice, 2020, 9371967. https://doi.org/10.1155/2020/9371967.

[28] Anand, G., Yu, Y., Lowe, A., et al. (2021). Bioimpedance analysis as a tool for hemodynamic monitoring: overview, methods, and challenges. Physiological Measurement, 42(3). https://doi.org/10.1088/1361-6579/abe80e.

[29] Hai, V. D., Hung, P. D., Dan, C. Q. (2020). Modified electrode placements for measurement of hemodynamic parameters using impedance cardiography. Journal of Medical Engineering & Technology, 44(7), 357–367. https://doi.org/ 10. 1080/ 03091902.2020.1799089.

[30] Ališauskas, A., Dzikevičiūtė, K., Rimšaitė, U., et al. (2024). Prognostic value of transthoracic impedance cardiography, amino-terminal pro-B-type natriuretic peptide levels, the six-minute walk test, and chest x-ray in elderly patients with chronic heart failure: A comparative study in Lithuania. Medical Science Monitor, 30, e945647. https://doi.org/ 10. 12659/ MSM.945647.

[31] Shochat, M. K., Shotan, A., Blondheim, D. S., et al. (2016). Non-invasive lung impedance-guided preemptive treatment in patients with chronic heart failure: A randomized controlled trial (IMPEDANCE-HF Trial). Journal of Cardiac Failure, 22(9), 713–722. https://doi.org/10.1016/j.cardfail.2016.03.015.