

To Study Hemodynamic Parameters According to Bioimpedance Monitoring Data in Patients with Apparent, Latent and Absent CHF

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Abstract Chronic heart failure (CHF) remains one of the leading causes of hospitalization and mortality in the world. In recent years, special attention has been paid to latent, asymptomatic forms of CHF conditions in which the left ventricular ejection fraction persists, but hemodynamic abnormalities are already present. These forms are often not detected by traditional methods, including EchoCG. Bioimpedance analysis (BIA) is a non-invasive, safe and affordable method for assessing systemic hemodynamics, which makes it possible to diagnose circulatory disorders at an early stage. The implementation of this approach is especially important for primary health care institutions in Uzbekistan.

Keywords Chronic heart failure, A method for assessing systemic hemodynamics, Mean blood pressure

1. Introduction

Chronic heart failure (CHF) continues to be one of the leading causes of hospitalization, disability and mortality in the world. According to the World Health Organization, over 64 million people are currently living with CHF, with a steady upward trend in this indicator. Latent forms of CHF, characterized by an asymptomatic course and difficulties in detection using traditional diagnostic tools, including echocardiography (EchoCG), have become increasingly important in recent years. The most common difficulties in diagnosis occur in patients with CHF with preserved ejection fraction (HFpEF-Heart Failure with preserved Ejection Fraction), when LVEF remains $\geq 50\%$, but at the same time manifestations of diastolic dysfunction, increased filling pressure and signs of venous congestion are revealed. This issue is of particular importance for Uzbekistan, given the widespread occurrence of cardiometabolic disorders such as hypertension, obesity and type 2 diabetes mellitus. The world's leading guidelines (ESC, AHA, ACC) emphasize the importance of introducing objective noninvasive techniques that allow for the detection of initial hemodynamic abnormalities and early stratification of the risk of CHF. Bioimpedance analysis (BIA), a safe and quantifiably accurate method for assessing key parameters of systemic hemodynamics, is considered one of the promising approaches. Modern devices such as NICaS make it possible to quickly determine the most important hemodynamic parameters: cardiac index (CI), total peripheral resistance

index (TPRI), mean blood pressure (MAP), integral hemodynamic efficiency index (GGI) and a number of others. The BIA technique does not require complex preliminary preparation and can be used both in hospitals and in polyclinics, including institutions that are not equipped with ultrasound equipment. BIA is especially useful in cases where the patient is suspected to have a latent form of CHF, in which EchoCG does not show characteristic abnormalities, and markers such as NT-proBNP may be insensitive or ambiguous. The formation and implementation of a diagnostic approach using BIA correspond to the key tasks of the Ministry of Health of the Republic of Uzbekistan, including the prevention of CVD, the development of screening programs and the digital transformation of the primary health care system. These guidelines are intended to regulate the use of bioimpedance analysis for the early detection of latent CHF in patients at risk, mainly at the primary health care level [1,3,5,7,9,11,13,15,17,19].

The purpose of the study. To evaluate the diagnostic significance of bioimpedance analysis in identifying hidden forms of chronic heart failure.

2. Materials and Methods

The prospective study included 69 patients with arterial hypertension of II-III degree. The average age was 61.2 ± 8.7 years. All patients underwent: Clinical and anamnestic examination; Laboratory tests; Bioimpedance analysis (NICaS), Echocardiography. All patients were divided into 3 groups: Group A with signs of CHF 28 patients (43.7%); Group B without signs of CHF 26 patients (40.6%); As a control group ($n = 15$) included individuals comparable in

age and gender with the main cohort, who did not have clinical and instrumental signs of cardiovascular pathology. The data of the control group were used for an approximate comparison of the obtained values with physiological norms.

3. Results and Analyzes

The criteria for the diagnosis of CHF in the study cohort included: Increased LVEF: more than 115 g/m² in men and 95 g/m² in women; Enlarged left atrium: more than 40 mm; Impaired diastolic function by type of delayed relaxation: E/A < 0.8 (or in rare cases E/A > 2.0). Patients who combined two or more of these criteria were assigned to the group with signs of CHF. The distribution of patients according to clinical and anamnestic data is given. Echocardiographic examination was performed for all study participants in order to objectively assess the structural and functional state of the myocardium and verify signs of chronic heart failure (CHF). The study was performed on an ultrasound machine using sensors with a frequency of 2.5–3.5 MHz in the patient's lying position on his left side. The echocardiography protocol included standard positions: parasternal, apical and subcostal sections in two-dimensional (2D), M-mode and Doppler modes, according to the recommendations of the American Echocardiographic Society (ASE) (Schiller N.B. et al., 1989). The following parameters were determined: end-diastolic size of the left ventricle (CDR, mm); end-systolic size of the left ventricle (DAC, mm); left ventricular ejection fraction (LVEF, %); thickness of the interventricular septum and the posterior wall of the left ventricle (mm); left ventricular myocardial mass index (LVMI, g/m²); indicators diastolic function (E/A, E/e', isovolumic relaxation time, etc.); systolic pressure in the pulmonary artery (SDLA, mmHg). Echocardiographic data were used to confirm or exclude latent (diastolic or initial systolic) CHF, as well as to compare it with bioimpedance parameters. A comparison of echocardiographic parameters with bioimpedance data made it possible to assess the diagnostic significance of bioimpedance measurement as a noninvasive method for early detection of signs of chronic heart failure. Bioimpedance measurement. Systemic hemodynamics was assessed by noninvasive bioimpedance analysis using NICaS (Non-Invasive Cardiac System, Israel). This method is based on recording changes in the electrical impedance (resistance) of body tissues when a weak alternating current of high frequency passes through them. Impedance fluctuations that occur synchronously with cardiac cycles reflect the dynamics of vascular blood supply and make it possible to quantify the main parameters of blood circulation. The NICaS system uses the technology of reactance bioimpedance analysis, providing high accuracy of measurements of both central and peripheral hemodynamic parameters. The technique is certified for clinical use, is safe, painless and does not require special patient training. Conditions and technique of the event. The study was conducted in the morning, in a state of physical and emotional rest, after 10-15 minutes of adaptation in the supine position

of the patient. NICaS system electrode sensors were superimposed on the wrist and the opposite ankle (single-channel tetrapolar circuit). The registration of the impedance signals was carried out within 5-7 minutes in automatic mode. To improve accuracy, the results of each measurement were averaged from three consecutive records. The data obtained was stored in an electronic database and used for subsequent analysis and statistical processing [2,4,6,8,10,12,14,16,18].

The main parameters to be determined: The NICaS system allows you to obtain both direct and calculated hemodynamic parameters reflecting the state of central and peripheral circulation: CO (Cardiac Output) minute volume of blood circulation, l/min; CI (Cardiac Index) cardiac index, l/min/m², characterizing the pumping function of the heart; SV (Stroke Volume) stroke volume, ml; TPRI (Total Peripheral Resistance Index) index of total peripheral vascular resistance, units c m²/ml; MAP (Mean Arterial Pressure) average arterial pressure, mmHg. GGI (Global Hemodynamic Index) is an integral hemodynamic index that combines indicators of pumping function and vascular tone. Characteristics of indicators: Cardiac Index (CI) - Reflects the volume of blood released by the heart in one minute, adjusted for body surface area. Values below 2.2 l/min/m² indicate a decrease in the pumping function of the heart and may indicate the presence of latent chronic heart failure. Total Peripheral Vascular Resistance Index (TPRI): Reflects the degree of resistance exerted by blood vessels to systemic blood flow. An increase in TPRI above 3,500 u c m²/ml indicates pronounced vasoconstriction and overloading, typical for patients with CHF or hypertension. Mean arterial pressure (MAP): Defined as an integral indicator of perfusion of organs and tissues. Values above 105 mmHg are considered elevated and require the exclusion of hypertensive conditions; values below 85 mmHg may indicate hypoperfusion. Integral hemodynamic index (GGI): It is a complex indicator that combines parameters of the pumping function of the heart and vascular tone. The GGI value < 45 units reflects a pronounced violation of central hemodynamics and serves as an early indicator of a decrease in adaptive reserves of the cardiovascular system. With an ejection fraction below 40% combined with a decrease in CI and GGI, there is a high probability of CHF with a reduced ejection fraction (HFrEF), confirmed by echocardiography data. The analysis of these hemodynamic parameters makes it possible to comprehensively assess the functional state of the cardiovascular system and identify early signs of latent chronic heart failure, even in the absence of pronounced clinical symptoms. Thus: CI reflects the efficiency of the pumping function of the heart and is a marker of a decrease in the minute volume of blood circulation, regardless of the size of the ejection fraction. TPRI characterizes the overall vascular resistance and reflects afterload, increasing with vasoconstriction and diastolic dysfunction. The MAP is used to assess the level of tissue perfusion and overall hemodynamic balance. The GGI is a composite integral index that combines indicators of cardiac output and vascular resistance; a decrease in its value indicates systemic hemodynamic disorders.

Application of neural network technologies In the framework of this study, neural network technology algorithms based on the ChatGPT-4 (OpenAI) platform were used to analyze the combined bioimpedance and echocardiography data. The model was used as an auxiliary tool for data processing and interpretation, including: structuring and systematization of indicators; identification of the relationship between hemodynamic and echocardiographic parameters; preliminary determination of the signs of latent chronic heart failure. The results obtained using neural network technologies were subject to expert verification by a cardiologist and compared with clinical observations, instrumental studies and statistical calculations performed in SPSS and Excel. The use of such technologies should be considered as a promising direction for the digital transformation of cardiological diagnostics and an important element in the development of personalized medicine. Research results: The results obtained in this study confirm the diagnostic and prognostic significance of noninvasive hemodynamic monitoring in the stratification of patients with suspected chronic heart failure (CHF). Based on the analysis of key hemodynamic parameters such as cardiac index (CI), total peripheral vascular resistance (TPRI), mean arterial pressure (MAP), heart pumping efficiency index (CPI) and energy efficiency index (GGI), a triad of clinically valid groups was identified: patients with apparent CHF (Group A), patients with latent CHF (group B), and relatively healthy or compensated patients (group C). Clinical profile of group A ($CI < 2.2 \text{ l/min/m}^2$, $TPRI > 3000 \text{ u} \cdot \text{s m}^2/\text{ml}$, $MAP > 110 \text{ mmHg}$) It corresponds to the hemodynamics of patients with decompensated CHF and reduced ejection fraction. Most of them had clinical manifestations of heart failure (shortness of breath, fatigue, edema), which confirms the presence of not only functional, but also symptomatic signs of decreased pumping function. The low CPI and GGI values found in this group reflect energy inefficiency and reduced myocardial reserves, which requires special attention when selecting therapy. This profile indicates a high probability of hospitalization and disease progression, which emphasizes the importance of early diagnosis and constant dynamic monitoring. Group B was characterized by intermediate CI values ($2.2\text{--}2.6 \text{ l/min/m}^2$), a marked increase in TPRI ($> 3000 \text{ u} \cdot \text{s m}^2/\text{ml}$), as well as a moderate increase in MAP (average $108.2 \pm 7.3 \text{ mmHg}$). Despite the preserved ejection fraction, EchoCG data revealed signs of diastolic dysfunction and/or hypertrophy of the left ventricle in a number of patients in this group, which indicates a latent phase of CHF, mainly with preserved LVEF (HFpEF). The almost complete absence of subjective complaints in this group may mask the initial manifestations of dysfunction, especially in patients with metabolic syndrome, obesity, and hypertension. It is in this category that the bioimpedance analysis method has demonstrated high sensitivity to early hemodynamic disorders. The control group (group C) included patients with normal CI values ($> 2.6 \text{ l/min/m}^2$), low TPRI ($< 3000 \text{ u} \cdot \text{s m}^2/\text{ml}$) and MAP $< 105 \text{ mmHg}$. These patients were characterized by a stable hemodynamic profile, absence of symptoms, normal EchoCG

parameters and systemic perfusion parameters, which corresponds to a physiologically balanced type of blood circulation. The data for this group was used as a reference in assessing the severity of violations in the remaining categories. The clinical interpretation of the data obtained confirms that CI, TPRI and MAP indicators can serve as markers of the stage of cardiovascular insufficiency even in the absence of obvious symptoms. This is especially relevant in the context of the modern HFpEF early detection strategy, when classical criteria (EF, subjective complaints) may not be informative enough. In addition, the revealed relationships between CI and GFR, MAP, and age emphasize the importance of assessing hemodynamics not only as a reflection of cardiac function, but also as an integral indicator of the state of the cardiovascular and renal systems. The differences between the groups in the main hemodynamic parameters (CI, TPRI, MAP, GGI) were statistically significant ($p < 0.05$), which confirms the objectivity of the identified trends. Despite the fact that the purpose of the study is primarily methodological, these results demonstrate the reproducibility and clinical significance of the approach. Thus, the results of the study are of high clinical significance, as they demonstrate the possibility of early detection of hemodynamic abnormalities in patients with CHF risk factors. This makes it possible to use the bioimpedance analysis method as a stratification and monitoring tool, including in outpatient practice, which is especially important in conditions of high prevalence of comorbid conditions in older age groups. The results of the statistical analysis confirmed the significance of differences in the main hemodynamic parameters between the study groups ($p < 0.05$). Although the study was primarily methodical, the analysis of the data obtained showed significant differences between the groups ($p < 0.05$), confirming the diagnostic value of the proposed criteria for bioimpedance analysis. The study confirmed the high informative value and practical significance of noninvasive bioimpedance analysis (NICaS) in the early detection of latent forms of chronic heart failure (CHF) in patients with risk factors. The use of integral hemodynamic parameters — the cardiac index (CI), the index of total peripheral resistance (TPRI), mean blood pressure (MAP) and the integral hemodynamic index (GGI) — revealed the initial violations of the pumping function of the heart and vascular regulation at the preclinical stage, when standard methods (including EchoCG) do not always give clear diagnostic criteria. The use of bioimpedance monitoring in combination with echocardiography has demonstrated high sensitivity to latent hemodynamic changes, especially in patients with preserved ejection fraction (HFpEF). The NICaS methodology is safe, affordable and economically feasible for implementation at the primary health care level, which is especially important for the health conditions of the Republic of Uzbekistan.

The additional use of artificial intelligence algorithms (ChatGPT-4, OpenAI) in the process of data analysis made it possible to increase the accuracy of interpretation, structure a large volume of clinical and instrumental indicators,

and accelerate the identification of relationships between bioimpedance and echocardiography parameters. This approach illustrates the prospects for the digital transformation of cardiological diagnostics and the potential for integrating AI technologies into clinical practice. The results of the study confirm that the bioimpedance method (NICaS) can be effectively integrated into the system of primary and specialized medical care for early detection of latent forms of chronic heart failure (CHF) and assessment of systemic hemodynamics. Bioimpedance monitoring (NICaS) is recommended to be implemented through the training of specialists in the recording and interpretation of basic hemodynamic parameters with the appointment of a person responsible for quality control. The method should be included in the standard of examination of patients at risk and ensure that the results are integrated into an electronic medical history with comparison with EchoCG and laboratory data. It is advisable to use the obtained indicators for dynamic monitoring and evaluation of the effectiveness of therapy. Regular analytical data processing and the formation of clinical observations will make it possible to substantiate the effectiveness of the method and expand its application, including the use of telemedicine solutions and further inclusion in clinical recommendations.

4. Conclusions

The introduction of the BIA method into clinical practice will allow: to increase the detection of early stages of CHF; optimize patient routing and personalized treatment selection; reduce the frequency of hospitalizations due to early correction of hemodynamic disorders, thereby reducing the economic costs of hospitalization and instrumental research; development of digital technologies and artificial intelligence in healthcare; expand the scientific database on the prevalence and course of CHF in the population of Uzbekistan. The results obtained can be recommended for inclusion in methodological and clinical protocols for the early detection and monitoring of CHF in primary and specialized healthcare institutions of the Republic of Uzbekistan.

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