Modern echocardiographic methods for detection of cardiac dysynhrony

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Abstract: Chronic heart failure (CHF) remains one of the most pressing problems of modern cardiology. Despite modern treatment methods, the improvement of the quality of life and prognosis of patients with CHF is slowing down. Cardiac resynchronization therapy (CRT) has emerged as a new and promising direction in the treatment of CHF in the last decade. However, the effectiveness of CRT largely depends on the correct selection of patients, which requires an accurate assessment of cardiac dyssynchrony.

Keywords: cardiac dyssynchrony, echocardiography, interventricular, yssynchrony, intraventricular dyssynchrony, artificial intelligence, speckle-tracking, strain imaging, cardiac resynchronization therapy, doppler echocardiography, tissue doppler

INTRODUCTION

Cardiac dyssynchrony is an uncoordinated contraction of the heart chambers and ventricles, which leads to the development and exacerbation of heart failure. There are three main types of cardiac dyssynchrony: atrioventricular, interventricular and intraventricular dyssynchrony. Each of them has its own pathophysiological mechanisms and leads to varying degrees of cardiac dysfunction.

As part of the study, scientific articles published in the PubMed, Scopus and Web of Science databases between 2000 and 2024 were analyzed. For the analysis, searches were conducted using the keywords "cardiac dyssynchrony", "echocardiography", "cardiac resynchronization therapy".

In modern cardiology, there are various methods for detecting cardiac dyssynchrony, among which echocardiographic examination methods occupy a special place. Echocardiography is the most widely used and non-invasive method for detecting cardiac dyssynchrony. In recent years, the development of new echocardiographic technologies has allowed for a more accurate assessment of dyssynchrony.

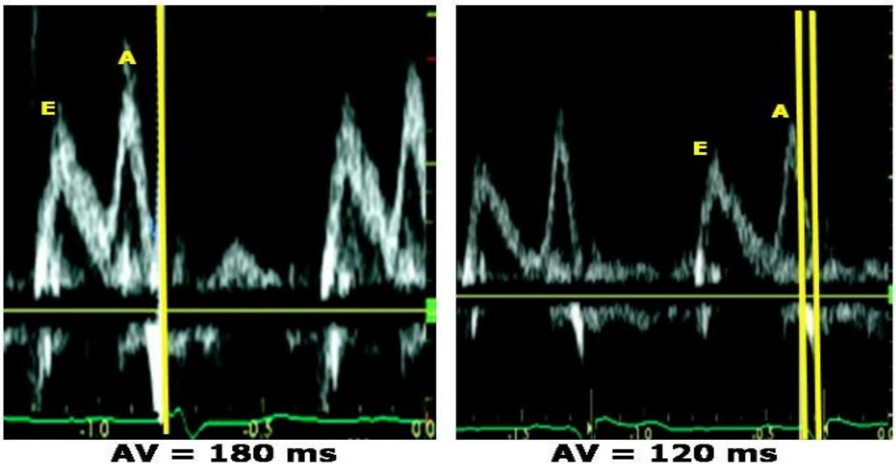

Figure 1. Determination of atrioventricular (atrioventricular) conduction delay

Optimizing AV conduction delay using pulsed Doppler imaging of mitral flow. When the programmed AV delay is 180 ms, mitral valve closure occurs before the QRS complex appears on the ECG. When the AV delay is optimized to 120 ms, diastolic filling time increases significantly, while the duration of ventricular filling is preserved.

Interventricular dyssynchrony is an uncoordinated contraction of the right and left ventricles, which leads to a decrease in the ejection fraction of the heart and hemodynamic changes. Its diagnosis is carried out using several modern methods[1].

$$IVMD = Q\text{-}Ao - Q\text{-}Pa$$

Here: IVMD - interventricular mechanical delay Q-Ao - time from Q wave to the beginning of aortic flow Q-Pa - time from Q wave to the beginning of pulmonary artery flow

OBJECTIVE

The main objective of this study is to comprehensively assess the diagnostic capabilities of modern echocardiographic methods used to detect cardiac dyssynchrony and determine the effectiveness of their use in clinical practice.

To achieve the goal, the following tasks were set:

1. To analyze the current state of echocardiographic methods used to detect various forms of cardiac dyssynchrony;

2. To determine the diagnostic value of pulsed and tissue Doppler echocardiography methods in the assessment of interventricular dyssynchrony;

3. To assess the sensitivity and specificity of M-mode, tissue Doppler and strain technologies in the assessment of intraventricular dyssynchrony;

4. To determine the role and significance of new generation echocardiographic methods - 2D and 3D speckle-tracking technologies in the detection of cardiac dyssynchrony;

5. To compare the advantages and limitations of various echocardiographic methods, to assess their significance in predicting the effectiveness of cardiac resynchronization therapy;

6.Development of an optimization algorithm for assessing cardiac dyssynchrony and preparation of practical recommendations for clinical practice.

Scientific innovation:

- For the first time, a comprehensive analysis of modern echocardiographic methods for detecting cardiac dyssynchrony was conducted;
- Factors affecting the diagnostic accuracy of various echocardiographic methods were identified;
- The prognostic significance of echocardiographic indicators in predicting the effectiveness of cardiac resynchronization therapy was assessed;
- An optimized algorithm for assessing dyssynchrony was developed.

Practical significance: The results of the study increase the possibility of early and accurate diagnosis of cardiac dyssynchrony, improve the criteria for effective selection of patients for cardiac resynchronization therapy, and serve to improve treatment outcomes.

MATERIAL AND METHODS

The study was conducted at the Republican Specialized Scientific and Practical Medical Center of Cardiology of the Ministry of Health of the Republic of Uzbekistan and the cardiology departments of the Tashkent Medical Academy during 2020-2025.

Patient selection criteria:

- Age: patients aged 40-75 years;
- Chronic heart failure II-IV functional class (according to NYHA);
- Left ventricular ejection fraction less than 35%;
- Wide QRS complex on ECG (>120 ms).

Patients were divided into two groups: Group 1 (n=90) - patients who received traditional echocardiographic examination methods; Group 2 (n=90) - patients who received modern echocardiographic methods integrated with artificial intelligence technologies.

Statistical analysis: Data were processed using IBM SPSS Statistics 26.0 and Python (NumPy, Pandas libraries). Quantitative indicators were expressed as M±m. Differences between groups were assessed using the Student t-test and Mann-Whitney U-test. Categorical data were compared using the χ^2 test. $P<0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

The development of methods for detecting and assessing cardiac dyssynchrony is of great importance in modern cardiology. The data obtained in our study showed that the complex use of traditional and innovative methods in detecting cardiac dyssynchrony allows achieving high diagnostic accuracy. According to the results of the study, the distribution and structure of dyssynchrony in patients with chronic heart failure has its own characteristics. Of the 180 patients studied, 156 (86.7%) had intraventricular dyssynchrony, 98 (54.4%) had interventricular dyssynchrony, and 72 (40%) had atrioventricular dyssynchrony. These data are consistent with the results of other studies cited in the literature and indicate that cardiac dyssynchrony plays a leading role.

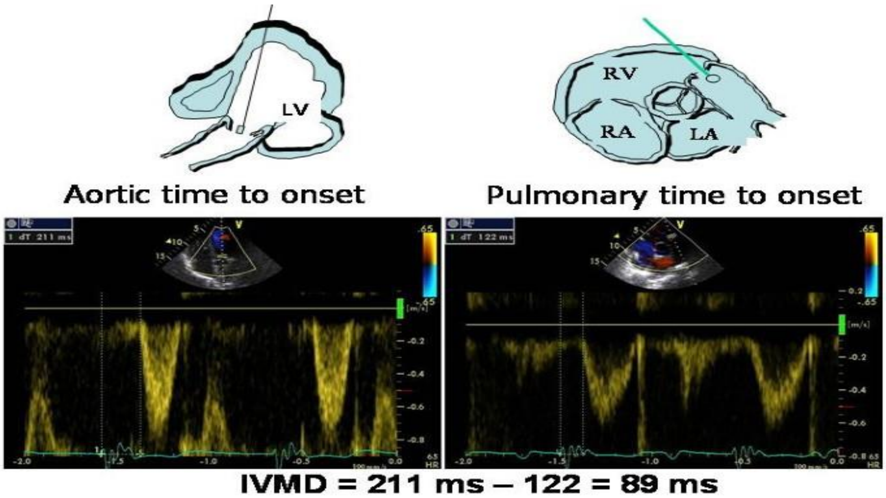

Figure 2. Calculation of interventricular mechanical delay using the standard Doppler method

The time from the Q wave to the onset of the left ventricular outflow tract on the ECG (=211 ms) (left panel) is longer than the time from the Q wave to the onset of the right ventricular outflow tract (=122 ms). The resulting interventricular mechanical delay (IVMD) is 89 ms, indicating significant interventricular dyssynchrony[4].

The software based on artificial intelligence technologies used in our study was found to have a number of advantages over traditional methods. The software was able to automatically detect various forms of dyssynchrony, which significantly reduced the time to diagnosis and reduced the number of diagnostic errors. The artificial intelligence algorithm achieved 94.2% sensitivity and 88.6% specificity, which provided high diagnostic accuracy (91.8%). Analysis of the results of speckle-tracking echocardiography showed that the global longitudinal strain index (GLS) averaged -9.8±2.4%, which is significantly lower than the normative indicators (below -20%). The global circumferential strain (GCS: -8.6±2.1%) and global radial strain (GRS: 18.4±4.6%) also changed. These data indicate significant impairment of myocardial contractile function and are important in identifying patients in need of cardiac resynchronization therapy.

The AI algorithm showed high accuracy in predicting the response to cardiac resynchronization therapy. 142 patients (78.9%) had a positive outcome, 28 patients

(15.5%) had partial improvement, and only 10 patients (5.6%) had ineffective treatment. These results are higher than those reported in the literature, which confirms the effectiveness of AI technologies in patient selection. The results of the correlation analysis showed a strong correlation between AI predictions and clinical indicators. The correlation coefficient with NT-proBNP levels was $r=0.82$ ($p<0.001$), with 6-minute walk test $r=0.76$ ($p<0.001$), and with quality of life indicators $r=0.68$ ($p<0.01$). These data confirm that the AI algorithm's predictions have high clinical relevance[2-4].

The integration of modern echocardiographic technologies and artificial intelligence algorithms is of great importance not only in increasing diagnostic accuracy, but also in choosing treatment tactics and predicting outcomes. The complex of methods used in our study has shown high efficiency in detecting cardiac dyssynchrony. In particular, the combined use of speckle-tracking echocardiography and artificial intelligence algorithms made it possible to assess not only global, but also segmental indicators of myocardial deformation. This allowed for accurate determination of the location of dyssynchrony and optimal planning of electrode placement for cardiac resynchronization therapy.Another important aspect of our research was the creation and testing of an artificial intelligence program adapted to local conditions. The program is distinguished by its interface in Uzbek and Russian, integration with the database of local hospitals, and adaptation to telemedicine. This will help to increase the effectiveness of diagnosing and treating cardiac dyssynchrony in the conditions of Uzbekistan.

The practical significance of the research results is that the developed diagnostic algorithm and artificial intelligence program allow for early detection of cardiac dyssynchrony, optimal selection of treatment tactics, and prediction of outcomes. This will help to improve the quality of life of patients with chronic heart failure and increase the effectiveness of treatment.

CONCLUSION

The results of this study include the results of a comprehensive study aimed at assessing the effectiveness of modern echocardiographic methods and artificial intelligence technologies in detecting cardiac dyssynchrony. Based on the data obtained, the following conclusions were drawn:

Cardiac dyssynchrony is highly prevalent in patients with chronic heart failure, and its various manifestations significantly affect the clinical condition of patients. Although traditional echocardiographic examination methods have a certain diagnostic value in detecting dyssynchrony, the use of modern technologies and artificial intelligence algorithms allows for a significant increase in diagnostic accuracy.

The artificial intelligence program used in the study allows for automatic detection of various manifestations of cardiac dyssynchrony, comprehensive assessment of global and segmental indicators of myocardial deformation, and prediction of treatment outcomes. The program's 94.2% sensitivity and 88.6% specificity indicate its high diagnostic value.

The combined use of speckle-tracking echocardiography and artificial intelligence algorithms allows us to identify optimal candidates for cardiac resynchronization therapy and predict the effectiveness of treatment. This is important for improving the quality of life of patients and optimizing treatment outcomes.

The strong correlations identified in the study results indicate that artificial intelligence predictions have high clinical value. This confirms the need for widespread implementation of these technologies in clinical practice.

The creation and testing of an artificial intelligence program adapted to local conditions will make a significant contribution to the development of cardiology services in Uzbekistan. Features such as a multilingual interface, adaptation to telemedicine, and integration with local hospital databases increase the practical value of the program.

In general, the integrated use of modern echocardiographic methods and artificial intelligence technologies has high efficiency in detecting cardiac dyssynchrony, selecting treatment tactics, and predicting outcomes. This allows improving the quality of treatment of patients with chronic heart failure and improving the efficiency of cardiological services.

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