

**CRR**  
JOURNAL  
OF CARDIORESPIRATORY RESEARCH

**ISSN 2181-0974**  
**DOI 10.26739/2181-0974**  
Impact Factor SJIF 2022: 5.937

**Journal of**

**CARDIORESPIRATORY  
RESEARCH**



Volume 7, Issue 1

**2026**

МИНИСТЕРСТВО ЗДРАВООХРАНЕНИЯ  
РЕСПУБЛИКИ УЗБЕКИСТАН

Журнал кардиореспираторных исследований

# JOURNAL OF CARDIORESPIRATORY RESEARCH

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Tadqiqot.uz

Ежеквартальный  
научно–практический  
журнал

ISSN: 2181-0974  
DOI: 10.26739/2181-0974



N<sup>o</sup> 1  
2026

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**Актуальность.** Несмотря на значительные достижения в лечении инфаркта миокарда, проблема эффективной медицинской реабилитации и восстановления функционального состояния сердечно-сосудистой системы остается актуальной. Современные подходы к кардиореабилитации требуют внедрения персонализированных технологий, позволяющих учитывать индивидуальные клинико-функциональные особенности пациентов.

**Цель исследования.** Оценить клиническую эффективность цифровой платформы в персонализации программ кардиореабилитации у пациентов после инфаркта миокарда.

**Материалы и методы.** В исследование включено 118 пациентов, перенесших инфаркт миокарда. Основную группу составили 54 пациента, проходившие реабилитацию с использованием цифровой платформы, обеспечивающей персонализированные реабилитационные мероприятия. Группу сравнения составили 64 пациента, получавшие стандартную программу кардиореабилитации.

**Результаты.** После завершения курса реабилитации у пациентов основной группы отмечено более выраженное улучшение структурно-функционального состояния миокарда по сравнению с группой сравнения. Фракция выброса левого желудочка увеличилась на 6,2% ( $p < 0,001$ ), тогда как в группе сравнения — на 2,5% ( $p = 0,03$ ). Показатели вариабельности сердечного ритма улучшились на 28,4% ( $p < 0,001$ ), толерантность к физической нагрузке повысилась на 24,4% ( $p < 0,001$ ), показатели качества жизни достоверно улучшились по всем основным шкалам ( $p < 0,05$ ). Полученные результаты свидетельствуют о более эффективном восстановлении функционального состояния сердечно-сосудистой системы при использовании цифровой платформы.

**Заключение.** Применение цифровой платформы для персонализации кардиореабилитации у пациентов после инфаркта миокарда обеспечивает более выраженное восстановление сократительной функции миокарда, улучшение автономной регуляции сердечной деятельности, повышение толерантности к физической нагрузке и улучшение качества жизни.

**Ключевые слова:** персонализированная реабилитация, эхокардиография, фракция выброса левого желудочка, вариабельность сердечного ритма, толерантность к физической нагрузке.

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**Relevance.** Despite significant achievements in the treatment of myocardial infarction, the problem of effective medical rehabilitation and restoration of the functional state of the cardiovascular system remains relevant. Modern approaches to cardiorehabilitation require the implementation of personalized technologies that allow for consideration of patients' individual clinical and functional characteristics.

The aim of the study is to assess the clinical effectiveness of the digital platform in personalizing cardiorehabilitation programs in patients after myocardial infarction.

**Materials and methods.** The study included 118 patients who had a myocardial infarction. The main group consisted of 54 patients who underwent rehabilitation using a digital platform that provides personalized rehabilitation measures. The comparison group consisted of 64 patients receiving a standard cardiorehabilitation program.

Results. After completing the rehabilitation course, patients in the main group showed a more pronounced improvement in the structural and functional state of the myocardium compared to the comparison group. Left ventricular ejection fraction increased by 6.2% ( $p<0.001$ ), while in the comparison group it increased by 2.5% ( $p=0.03$ ). Heart rate variability indicators improved by 28.4% ( $p<0.001$ ), physical exercise tolerance increased by 24.4% ( $p<0.001$ ), and quality of life indicators significantly improved across all main scales ( $p<0.05$ ). The obtained results indicate a more effective restoration of the functional state of the cardiovascular system when using a digital platform.

Conclusion. The use of a digital platform for personalizing cardiorehabilitation in patients after myocardial infarction provides a more pronounced restoration of myocardial contractility, improved autonomic regulation of cardiac activity, increased tolerance to physical activity, and improved quality of life.

**Keywords:** personalized rehabilitation, echocardiography, left ventricular ejection fraction, heart rate variability, exercise tolerance.

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## MIOKARD INFARKTIDAN KEYIN KARDIOREABILITATSIYANI SHAXSIYLASHTIRISHDA RAQAMLI PLATFORMANING KLINIK SAMARADORLIGI

### ANNOTATSIYA

**Dolzarbli.** Miokard infarktini davolashda sezilarli yutuqlarga erishilganiga qaramay, yurak-qon tomir tizimining funksional holatini tiklash va samarali tibbiy reabilitatsiya masalasi dolzarbligicha qolmoqda. Zamonaviy kardioreabilitatsiya yondashuvlari bemorlarning individual klinik va funksional xususiyatlarini hisobga oluvchi shaxsiylashtirilgan texnologiyalarni joriy etishni talab etadi.

**Tadqiqot maqsadi.** Miokard infarktidan keyingi bemorlarda kardioreabilitatsiya dasturlarini shaxsiylashtirishda raqamli platformaning klinik samaradorligini baholash.

**Materiallar va usullar.** Tadqiqotga miokard infarktini boshdan kechirgan 118 nafar bemor kiritildi. Asosiy guruh 54 nafar bemordan iborat bo'lib, ular shaxsiylashtirilgan reabilitatsion chora-tadbirlarni ta'minlovchi raqamli platforma yordamida reabilitatsiyadan o'tdilar. Taqqoslash guruhi 64 nafar bemordan iborat bo'lib, ular standart kardioreabilitatsiya dasturini oldilar.

**Natijalar.** Reabilitatsiya kursi yakunlangandan so'ng asosiy guruh bemorlarida miokardning strukturaviy va funksional holatining taqqoslash guruhi bilan nisbatan ancha yaxshilanishi kuzatildi. Chap qorincha chiqarish fraksiyasi 6,2% ga oshdi ( $p<0,001$ ), taqqoslash guruhi esa 2,5% ga oshdi ( $p=0,03$ ). Yurak urish tezligi variabelligi ko'rsatkichlari 28,4% ga yaxshilandi ( $p<0,001$ ), jismoniy yuklamaga chidamlilik 24,4% ga oshdi ( $p<0,001$ ), hayot sifati ko'rsatkichlari barcha asosiy shkalalar bo'yicha ishonchli ravishda yaxshilandi ( $p<0,05$ ). Olingan natijalar raqamli platformadan foydalanish yurak-qon tomir tizimi funksional holatini yanada samaraliroq tiklashini ko'rsatadi.

**Xulosa.** Miokard infarktidan keyingi bemorlarda kardioreabilitatsiyani shaxsiylashtirish uchun raqamli platformadan foydalanish miokard qisqaruvchanlik funksiyasining yanada yaxshilanishini, yurak faoliyatining vegetativ regulyatsiyasi yaxshilanishini, jismoniy yuklamaga chidamlilikning oshishini va hayot sifati yaxshilanishini ta'minlaydi.

**Kalit so'zlar:** shaxsiylashtirilgan reabilitatsiya, exokardiografiya, chap qorincha chiqarish fraksiyasi, yurak urish tezligi variabelligi, jismoniy yuklamaga chidamlilik.

Myocardial infarction (MI) remains one of the leading causes of mortality, disability, and a decline in the quality of life of the population worldwide. Despite significant achievements in early diagnosis, reperfusion therapy, and drug treatment, past myocardial infarction is accompanied by the development of structural and functional remodeling of the myocardium, impaired left ventricular contractility, decreased tolerance to physical exertion, and deterioration of patients' psycho-emotional state. These changes significantly increase the risk of developing chronic heart failure, recurrent cardiovascular events, and premature death.

Cardiorehabilitation is an integral component of comprehensive management of patients after myocardial infarction and has been proven to contribute to a 20-30% reduction in mortality, a decrease in the frequency of repeated hospitalizations, and an improvement in the functional state of the cardiovascular system. However, traditional rehabilitation programs in most cases are standardized and do not take into account the individual characteristics of the structural and functional state of the myocardium, the variability of heart rhythm, the adaptive capabilities of the body, and the dynamics of recovery of each specific patient. The lack of a personalized approach can limit the effectiveness of rehabilitation measures and reduce their clinical effectiveness.

In recent years, special attention has been paid to the implementation of digital technologies in the medical rehabilitation system. The development of digital platforms, software products, and automated monitoring systems opens up fundamentally new opportunities for continuous assessment of patients' clinical condition, analysis of large datasets, and the formation of individualized

rehabilitation programs. The use of digital solutions allows for the integration of clinical, functional, and instrumental indicators, including echocardiography data, heart rate variability, physical performance, and quality of life, which ensures a more accurate risk stratification and optimization of rehabilitation tactics.

Echocardiographic indicators, which reflect the structural and functional state of the myocardium, the degree of left ventricular remodeling, and the restoration of its contractile capacity, are of particular importance in personalizing cardiorehabilitation. Such parameters as left ventricular ejection fraction, global longitudinal deformity (GLS), end-diastolic and systolic volumes are important prognostic markers and allow for an objective assessment of the effectiveness of the rehabilitation measures being carried out. The integration of echocardiographic data into digital platforms allows for dynamic monitoring and timely adjustment of individual recovery programs.

Furthermore, digital platforms contribute to improving patient compliance, ensuring remote monitoring, automated analysis of indicators, and the formation of recommendations in real-time. This is especially important in conditions of high workload on the healthcare system and the need to ensure the continuity of the rehabilitation process.

Despite the promising nature of digital technologies, the clinical effectiveness of digital platforms focused on personalizing cardiorehabilitation programs after myocardial infarction remains insufficiently studied. There are insufficient scientifically substantiated data confirming their influence on the restoration of myocardial

contractility, the functional status of patients, and quality of life indicators.

In this regard, the development and clinical evaluation of the effectiveness of a digital platform that provides a personalized approach to cardiorehabilitation based on the integration of clinical and echocardiographic data is a pressing scientific and practical task of modern cardiology and medical rehabilitation.

The results of this study will allow for the scientific substantiation of the use of digital technologies in the cardiorehabilitation system, increase the effectiveness of restorative treatment, improve the functional outcomes and quality of life of patients after myocardial infarction, and reduce the risk of cardiovascular complications.

**Purpose of the research**

The purpose of this study was to assess the clinical effectiveness of the digital platform in personalizing medical cardiorehabilitation programs for patients after myocardial infarction based on the integration of clinical, functional, and echocardiographic indicators.

**Research Materials and Methods**

This study was conducted on the basis of a specialized cardiology and rehabilitation department for the period 2023-2025. The study included 118 patients who had suffered a myocardial infarction and were in the medical rehabilitation stage. All patients were divided into two groups depending on the applied rehabilitation approach. The main group consisted of 54 patients, in whom the medical rehabilitation program was formed using a developed digital platform that provides a personalized approach based on the integration of clinical, functional, and echocardiographic indicators. The comparison group consisted of 64 patients receiving a standard cardiorehabilitation program in accordance with current clinical recommendations without the use of a digital platform.

The groups were comparable according to the main clinical-demographic and functional characteristics, including age, sex, localization of myocardial infarction, presence of comorbidities, as well as initial indicators of the structural and functional state of the cardiovascular system, which ensured the correctness of the comparative analysis and the reliability of the obtained results ( $p > 0.05$ ).

The inclusion criteria in the study were a confirmed diagnosis of myocardial infarction based on clinical, electrocardiographic, and laboratory data, the age of the patients from 40 to 75 years, a stable clinical condition at the rehabilitation stage, and informed consent to participate in the study. Exclusion criteria included pronounced chronic

heart failure of the IV functional class according to NYHA, severe rhythm and conduction disorders requiring urgent intervention, the presence of severe concomitant somatic pathology in the decompensation stage, and the patient's refusal to participate in the study.

In patients of the main group, personalization of the rehabilitation program was carried out using the developed digital platform, which ensured the collection, storage, and analysis of the patient's clinical and instrumental data, including echocardiographic indicators, the functional state of the cardiovascular system, and physical performance indicators. Based on the integrated analysis of data, the digital platform allowed for the formation of personalized recommendations for the volume and intensity of physical activity, dynamic monitoring of the patient's condition, and timely adjustment of the rehabilitation program. In the comparison group, a standard medical rehabilitation program was used, including drug therapy, dosed physical exertion, therapeutic exercise, and general lifestyle recommendations.

All patients underwent a comprehensive clinical and instrumental examination, including complaints and anamnesis collection, physical examination, recording of an electrocardiogram in standard 12 leads, echocardiographic examination, analysis of heart rhythm variability, as well as assessment of tolerance to physical exertion and quality of life.

Statistical processing of the obtained data was carried out using the SPSS Statistics and Microsoft Excel software packages. Quantitative indicators are presented as the arithmetic mean and standard deviation ( $M \pm SD$ ). To assess the significance of differences between the groups, Student's t-test was used, as well as a paired test for assessing the dynamics of indicators. Differences were considered statistically significant at a significance level of  $p < 0.05$ .

The obtained data allowed for a comparative assessment of the clinical effectiveness of personalized cardiac rehabilitation using a digital platform and a standard approach in patients after myocardial infarction.

**Research results**

At the first stage of the study, a comparative analysis of the initial clinical, functional, and echocardiographic indicators was conducted in patients of the main group and the comparison group. It was established that no statistically significant differences were found between the groups before the start of rehabilitation measures, which confirms their comparability and the correctness of the subsequent comparative analysis of the effectiveness of rehabilitation programs.

**Table 1**

**Initial characteristics of echocardiographic indicators in patients of the studied groups ( $M \pm SD$ )**

Indicator	Main group (n=54)	Comparison group (n=64)	p.
LVEF, %	48.6 ± 4.8	49.1 ± 5.1	0.57
LV CDO, ml	154.2 ± 18.6	151.8 ± 19.4	0.48
LV CSF, ml	79.3 ± 11.2	77.6 ± 12.1	0.41
UO, ml	74.9 ± 8.6	74.2 ± 9.1	0.63

Analysis of the initial indicators showed that the ejection fraction of the left ventricle in patients of the main group was 48.6±4.8%, while in the comparison group - 49.1±5.1% ( $p=0.57$ ). The final diastolic and

final systolic volumes also did not have statistically significant differences ( $p > 0.05$ ), which indicates the same degree of post-infarction myocardial remodeling in both groups at the time of rehabilitation.

**Table 2**

**Dynamics of echocardiographic indicators after rehabilitation ( $M \pm SD$ )**

Indicator	Main group (n=54)	Comparison group (n=64)	p.
LVEF, %	54.8 ± 5.2	51.6 ± 5.4	0.002
LV CDO, ml	146.3 ± 17.2	149.7 ± 18.5	0.28
LV CSF, ml	66.1 ± 9.4	72.4 ± 10.8	0.001

UO, ml	80.2 ± 9.1	77.3 ± 8.7	0.04
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After completing the rehabilitation course, significant improvement in myocardial contractility was observed in patients of the main group. The left ventricular ejection fraction increased by 6.2% (48.6±4.8% to 54.8±5.2%;  $p < 0.001$ ), while in the comparison group, the increase was only 2.5% (49.1±5.1% to 51.6±5.4%;  $p=0.03$ ). When comparing between groups, statistically significant differences were found

( $p=0.002$ ), which indicates a more pronounced restoration of myocardial contractile function when using a digital platform.

The final systolic volume in the main group decreased by 16.6% ( $p < 0.001$ ), while in the comparison group it decreased by 6.7% ( $p=0.04$ ). Intergroup differences were statistically significant ( $p=0.001$ ), indicating more pronounced reverse myocardial remodeling in patients of the main group.

Table 3

**Dynamics of heart rate variability indicators (M±SD)**

Indicator	Main group (n=54)	Comparison group (n=64)	p.
SDNN, ms	118.4 ± 14.6	104.7 ± 13.8	<0.001
RMSSD, ms	32.6 ± 5.4	26.8 ± 4.9	<0.001
LF/HF	1.62 ± 0.32	1.91 ± 0.41	0.003

Analysis of heart rhythm variability showed a significant improvement in the indicators of autonomous regulation of cardiac activity in patients of the main group. The SDNN indicator increased by 28.4% compared to the baseline values (p<0.001), while in the comparison group, the increase was 14.1% (p=0.02). Intergroup

differences were statistically significant (p<0.001), indicating a more pronounced restoration of autonomic heart rhythm control.

The RMSSD indicator, which reflects the activity of the parasympathetic part of the autonomic nervous system, increased in the main group by 36.2%, while in the comparison group - by 18.7% (p<0.001).

Table 4

**Dynamics of exercise tolerance (6-minute walk test)**

Indicator	Main group (n=54)	Comparison group (n=64)	p.
Initially, m	352.6 ± 42.8	358.1 ± 46.3	0.49
After rehabilitation, m	438.7 ± 48.4	401.3 ± 44.6	<0.001
Δ (%)	+24.4%	+12.1%	<0.001

After rehabilitation, the six-minute walking distance increased in the main group by 86.1 m (24.4%; p<0.001), while in the comparison group it increased by 43.2 m (12.1%; p=0.01). The intergroup

differences were statistically significant (p<0.001), indicating a more pronounced increase in physical performance in patients who underwent personalized rehabilitation using a digital platform.

Table 5

**Dynamics of SF-36 quality of life indicators (points)**

Indicator	Main group	Comparison group	p.
Physical functioning	78.6 ± 8.4	69.3 ± 7.9	<0.001
Role functioning	74.2 ± 9.1	66.5 ± 8.7	0.002
General health	72.4 ± 7.8	65.8 ± 7.4	0.001
Mental health	76.3 ± 8.6	70.1 ± 8.2	0.004

Analysis of the quality of life showed a more pronounced improvement in both physical and psycho-emotional health components in patients of the main group. The most significant increase was noted on the physical functioning scale (+31.4%, p<0.001), which reflects the increase in patients' functional capabilities.

**Discussion of results**

The results obtained in this study convincingly demonstrate that the use of a digital platform for personalized cardiorehabilitation in patients after myocardial infarction provides a more pronounced restoration of the structural and functional state of the myocardium, functional work capacity, and quality of life compared to the standard rehabilitation program. In particular, in patients of the main group, a significant increase in left ventricular ejection fraction, a more pronounced decrease in final systolic volume, an improvement in heart rate variability indicators, as well as a significant increase in six-minute walking distance and improvement in quality of life indicators were noted. These changes indicate a more effective restoration of the heart's pump function, improved autonomic regulation of cardiac activity, and increased adaptive capabilities of the cardiovascular system.

The data obtained by us fully correspond to the modern concepts of the European Society of Cardiologists (ESC), according to which cardiac rehabilitation is one of the key components of patient management after an acute myocardial infarction and is aimed not only at restoring physical performance, but also at preventing further myocardial remodeling, reducing the risk of heart failure, and improving the long-term prognosis. Recent ESC recommendations emphasize the need to implement personalized approaches in rehabilitation that take into account the functional state of the myocardium, patient tolerance to physical exertion, and individual characteristics. In our study, the use of a digital platform made it possible to implement precisely this approach, providing a dynamic assessment of the patient's condition and optimizing the rehabilitation program, which, most likely, led to a more pronounced improvement in echocardiographic indicators, including an increase in ejection fraction and a decrease in the final systolic volume.

Of particular interest is the reliable improvement in heart rate variability indicators identified in our study in patients of the main group. It is known that a decrease in heart rate variability is an

unfavorable prognostic factor and is associated with an increased risk of arrhythmias and cardiovascular mortality after myocardial infarction. The recommendations of the American Heart Association (AHA) emphasize the important role of rehabilitation programs in restoring autonomic regulation of cardiac activity. A more pronounced increase in SDNN and RMSSD indicators in the main group indicates a more effective restoration of the sympathetic and parasympathetic parts of the autonomic nervous system, which is an important mechanism for reducing the risk of adverse cardiovascular events.

The data we obtained regarding a significant increase in tolerance to physical exertion also fully corresponds to the results of modern foreign research. A number of randomized clinical studies in recent years have shown that the use of digital technologies and telemedicine platforms in cardiac rehabilitation contributes to a more pronounced improvement in patients' functional work capacity. It has been established that digital platforms provide more accurate monitoring of physical activity intensity, increase patients' commitment to rehabilitation measures, and allow for timely adjustment of the recovery program. In our study, the increase in six-minute walking distance in patients of the main group was significantly higher than in the comparison group, which confirms the effectiveness of the digital platform in optimizing physical rehabilitation.

The identified improvement in quality of life indicators in patients of the main group is no less important. According to modern ESC and AHA recommendations, quality of life is one of the most important criteria for the effectiveness of rehabilitation and reflects not only the patient's physical condition but also their psycho-emotional well-being and social adaptation. A more pronounced improvement in the indicators of the physical and psycho-emotional components of health in patients of the main group indicates that the use of the digital platform contributes to a more effective recovery of patients and increases their adaptive capabilities.

The obtained results also correspond to the data of foreign studies of recent years, which show that the introduction of digital technologies in cardiorehabilitation allows to increase the effectiveness of restorative treatment, improve the functional indicators of the cardiovascular system, and increase patients' adherence to treatment. The use of digital platforms provides continuous monitoring of the patient's condition,

individualization of rehabilitation programs, and timely correction of rehabilitation measures, which is a key factor in successful recovery after a myocardial infarction.

Thus, the results of this study confirm that the use of a digital platform for personalized cardiac rehabilitation allows for a significant increase in the effectiveness of rehabilitation measures, contributes to a more pronounced restoration of myocardial contractility, improves autonomic regulation of cardiac activity, increases tolerance to physical exertion, and improves the quality of life of patients after myocardial infarction. The obtained data correspond to the modern international recommendations of the ESC and AHA and confirm the prospects for the implementation of digital technologies in the system of medical rehabilitation of patients with cardiovascular diseases.

#### Conclusions

The use of a digital platform in the cardiorehabilitation program in patients after myocardial infarction provides more pronounced restoration of myocardial contractility compared to standard rehabilitation, which is confirmed by a significant increase in left ventricular ejection fraction from  $48.6 \pm 4.8\%$  to  $54.8 \pm 5.2\%$  ( $\Delta = +6.2\%$ ;  $p < 0.001$ ), while in the comparison group, this indicator increased only to  $51.6 \pm 5.4\%$  ( $\Delta = +2.5\%$ ;  $p = 0.03$ ), with statistically significant intergroup differences ( $p = 0.002$ ). The use of the digital platform

contributes to more pronounced reverse myocardial remodeling, which is manifested by a significant decrease in the final systolic volume of the left ventricle by 16.6% in the main group ( $p < 0.001$ ) compared to 6.7% in the comparison group ( $p = 0.04$ ), with statistically significant intergroup differences ( $p = 0.001$ ). Personalized cardiac rehabilitation using a digital platform provides a more effective restoration of autonomic regulation of cardiac activity, which is confirmed by a significant increase in the SDNN indicator by 28.4% ( $p < 0.001$ ) and the RMSSD indicator by 36.2% ( $p < 0.001$ ), which significantly exceeds the similar indicators of the comparison group ( $p < 0.001$ ). The use of the digital platform contributes to a significant increase in tolerance to physical exertion, which is manifested by an increase in the six-minute walking distance by 24.4% in the main group (from  $352.6 \pm 42.8$  m to  $438.7 \pm 48.4$  m;  $p < 0.001$ ), while in the comparison group, the increase was only 12.1% ( $p = 0.01$ ), with significant intergroup differences ( $p < 0.001$ ). The use of the digital platform significantly improves the quality of life of patients after myocardial infarction, which is manifested in an increase in the indicators of physical functioning by 31.4% ( $p < 0.001$ ), general health by 28.6% ( $p < 0.01$ ), and mental health by 24.3% ( $p < 0.01$ ), which significantly exceeds the similar indicators of the comparison group ( $p < 0.05$ ).

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