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Rehabilitation After Shoulder Arthroplasty

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ABSTRACT

BACKGROUND: Reverse shoulder arthroplasty is an effective surgical treatment for severe degenerative and post-traumatic conditions of the shoulder joint. However, despite its proven clinical efficacy, the optimal scope of medical rehabilitation required to maximize functional outcomes and quality of life remains unclear.

AIM: This study aimed to assess the efficacy of a specialized medical rehabilitation program after reverse shoulder arthroplasty based on modern techniques, including isokinetic dynamometry and biofeedback training.

METHODS: A comparative cohort study was conducted in 33 patients with omarthrosis who underwent reverse shoulder arthroplasty. The patients were divided into two groups. The treatment group ($n = 17$) underwent a structured rehabilitation program developed by the authors, whereas the control group ($n = 16$) did not receive organized rehabilitation. The primary endpoint was recovery of shoulder joint function, including range of motion, muscle strength, coordination, and patient-reported quality of life. Assessment methods included goniometry, isokinetic dynamometry, evaluation of complex coordinated movement abilities, volumetric analysis of upper limb motion using a spherical motion sector, and patient questionnaires (DASH, PSS, SF-36).

RESULTS: Patients who underwent the medical rehabilitation program had significantly better functional outcomes than the control group. Abduction range was 150° [150° – 160°] in the treatment group vs. 107.5° [93.75° – 140°] in the control group ($p < 0.001$). Flexion range was 160° [150° – 165°] in the treatment group vs. 120° [107.5° – 133.8°] in the control group ($p < 0.001$). External rotation range was also greater in the treatment group: 45° [40° – 55°] vs. 25° [20° – 36.3°], $p < 0.001$. Abduction strength reached 23.6 Nm [19.3 – 32.4] in the treatment group vs. 16.7 Nm [9.93 – 20.6] in the control group ($p = 0.005$). The spherical motion sector volume in the treatment group was $230,778$ cm³ [$207,921$ – $268,565$], exceeding that of the control group: $126,952$ cm³ [$107,894.25$ – $151,971.3$], $p = 0.001$. Correlation analysis revealed a strong positive relationship between shoulder joint range of motion and coordination parameters ($r = 0.78$, $p < 0.001$), as well as muscle strength ($r = 0.71$, $p < 0.001$). Moreover, higher patient-reported satisfaction scores (SF-36) were associated with increased muscle strength and greater external rotation range ($r = 0.63$, $p = 0.002$).

CONCLUSION: Implementing a comprehensive, personalized rehabilitation program after shoulder arthroplasty significantly improves functional outcomes. Optimized medical rehabilitation programs will improve the quality of medical care and long-term clinical outcomes in patients following reverse shoulder arthroplasty.

Keywords: reverse shoulder arthroplasty; medical rehabilitation; biofeedback; isokinetic dynamometry; range of motion; muscle strength; motor coordination.

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Реабилитация при артропластике плечевого сустава

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АННОТАЦИЯ

Обоснование. Реверсивное эндопротезирование плечевого сустава является эффективным методом хирургического лечения тяжёлых дегенеративных и посттравматических патологий плечевого сустава. Однако, несмотря на доказанную клиническую эффективность, остаётся открытым вопрос о выборе оптимального объёма медицинской реабилитации, способного максимизировать функциональные результаты и качество жизни пациентов.

Цель. Оценить эффективность специализированной программы медицинской реабилитации после реверсивного эндопротезирования плечевого сустава, основанной на применении современных методик, включая изокинетическую динамометрию, и тренировок с биологической обратной связью.

Материалы и методы. Проведено когортное сравнительное исследование, включавшее 33 пациента с диагнозом «омартроз», перенёвших реверсивное эндопротезирование плечевого сустава. Пациенты были разделены на две группы: основная группа ($n=17$) проходила структурированную программу медицинской реабилитации по разработанной методике, а контрольная ($n=16$) характеризовалась отсутствием организованной реабилитации. Первичной конечной точкой исследования являлось восстановление функциональных показателей плечевого сустава, включая амплитуду движений, силу мышц, координационные способности и субъективные показатели качества жизни. Методы оценки включали гониометрию, изокинетическую динамометрию, анализ способности выполнять сложнокоординированные движения, шарового сектора движений верхней конечности и анкетирование (DASH, PSS, SF-36).

Результаты. Пациенты, прошедшие курс медицинской реабилитации, продемонстрировали статистически значимо лучшие функциональные показатели по сравнению с контрольной группой. Амплитуда отведения составила 150° [150° – 160°] в основной группе против $107,5^\circ$ [$93,75^\circ$ – 140°] в контрольной ($p < 0,001$). Амплитуда сгибания составила 160° [150° – 165°] в основной группе против 120° [$107,5^\circ$ – $133,8^\circ$] в контрольной ($p < 0,001$). Амплитуда наружной ротации также была выше в основной группе (45° [40° – 55°] против 25° [20° – $36,3^\circ$] в контрольной ($p < 0,001$). Сила отведения в основной группе достигала 23,6 Нм [$19,3$ – $32,4$], тогда как в контрольной — 16,7 Нм [$9,93$ – $20,6$] ($p=0,005$). Шаровой сектор движений в основной группе составил $230\,778\text{ см}^3$ [$207\,921$ – $268\,565$], что превышало показатели контрольной группы — $126\,952\text{ см}^3$ [$107\,894,25$ – $151\,971,3$], $p=0,001$. Анализ корреляционных связей показал, что объём движений в плечевом суставе имел сильную положительную корреляцию с координационными показателями ($r=0,78$, $p < 0,001$) и силой мышц ($r=0,71$, $p < 0,001$). Кроме того, высокие показатели субъективной удовлетворённости пациентов (опросник SF-36) были ассоциированы с улучшением силы мышц и амплитуды наружной ротации ($r=0,63$, $p=0,002$).

Заключение. Применение комплексной персонализированной программы реабилитации после артропластики плечевого сустава способствует значительному улучшению его функциональных показателей. Оптимизация программ медицинской реабилитации позволит повысить качество медицинской помощи и улучшить долгосрочные клинические исходы у пациентов после реверсивного эндопротезирования плечевого сустава.

Ключевые слова: реверсивное эндопротезирование плечевого сустава; медицинская реабилитация; биологическая обратная связь; изокинетическая динамометрия; амплитуда движений; сила мышц; координация движений.

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BACKGROUND

Reverse shoulder arthroplasty is an effective surgical treatment method for severe degenerative diseases of the shoulder joint, such as arthrosis and sequelae of complex fractures, particularly in elderly patients [1]. This method was originally developed for the treatment of rotator cuff tear arthropathy; however, its indications have now expanded to include massive rotator cuff tears, unsuccessful surgical interventions, revision arthroplasties, fractures of the proximal humerus, and tumors [2–4].

This surgical method of treating the shoulder joint demonstrates significant improvement in function and reduction of pain, especially in primary operations, compared with revision procedures [5]. However, the operation causes major biomechanical changes in the shoulder joint, including medialization of the center of rotation, redistribution of load from the rotator cuff to the deltoid muscle, and altered movement patterns [6–8]. These factors complicate the recovery process and necessitate the development of tailored rehabilitation programs. Postoperative complications such as dislocations, fractures, and infections may occur, especially in revision arthroplasty cases [9]. As the indications for reverse arthroplasty continue to broaden, long-term studies are becoming increasingly important to optimize patient management strategies [10].

Rehabilitation plays a key role in restoring motor function and quality of life after arthroplasty. Recent studies suggest that early active mobilization may be more effective than delayed mobilization, improving arm flexion within three months postoperatively [11]. Some protocols allow immediate shoulder mobilization without immobilization, demonstrating the safety and efficacy of this approach [12, 13]. However, rehabilitation practices vary greatly among medical institutions, and there is no unified standard of patient management [14].

Currently, in Russia, a significant number of patients who have undergone reverse shoulder arthroplasty face limited access to qualified rehabilitation care. This is due to several factors, including socioeconomic barriers, geographical remoteness from specialized rehabilitation centers, insufficient awareness among patients and healthcare professionals about postoperative recovery specifics, and a shortage of specialists with the necessary knowledge and skills. As a result, patients are often compelled to limit themselves to self-performed exercises without professional supervision, which can reduce the effectiveness of recovery and increase the risk of complications.

The lack of a unified rehabilitation approach also contributes to variability in implemented interventions, making it difficult to objectively assess their effectiveness and leading to heterogeneous clinical outcomes. In this regard, the development of a standardized rehabilitation program adapted to the specifics of reverse shoulder arthroplasty

is of particular relevance. Establishing a scientifically grounded system of restorative measures and testing it with subsequent evaluation of its effectiveness will improve the quality of medical care for this patient population, reduce the risk of functional limitations, and enhance quality of life.

Overall, rehabilitation after shoulder arthroplasty consists of three stages: tissue healing and trophic restoration, recovery of mobility, and strengthening of the muscular apparatus [15]. Howard et al. demonstrated that early mobilization of patients after shoulder arthroplasty promotes faster functional recovery, improves the range of motion, and reduces the risk of postoperative complications without increasing the likelihood of instability or prosthesis damage [16]. Despite evidence supporting the safety of returning to physical activity in elderly patients, caution is required in planning rehabilitation interventions for younger and high-functioning patients [17].

Despite the large number of studies on early and late rehabilitation, the evaluations of program effectiveness in the residual period (6 months or more after surgery) are rare [18]. Patients undergoing unsupervised rehabilitation often underestimate the necessity of regular training, which leads to persistent functional limitations. This underscores the need to develop specialized rehabilitation programs aimed at restoring the functional capacity of the shoulder joint in the long term.

Optimal rehabilitation protocols after shoulder arthroplasty remain a subject of scientific debate, highlighting the importance of further research focused on the development and evaluation of specialized recovery programs [19]. Accordingly, the relevance of the present study lies in the development and analysis of the effectiveness of a comprehensive rehabilitation program targeted at patients in the late postoperative period, with the goal of maximizing upper limb motor function recovery and improving quality of life.

The work aimed to assess the efficacy of a rehabilitation program developed for patients with osteoarthritis following reverse shoulder arthroplasty.

METHODS

Study Design

It was an experimental, prospective, single-center, controlled, open-label study was conducted to assess the efficacy and safety of a rehabilitation program for patients.

Study Setting

The clinical study was carried out at the Department of Medical Rehabilitation of the Federal State Budgetary Institution N.N. Priorov National Medical Research Center of Traumatology and Orthopedics, Ministry of Health of the Russian Federation. All study participants were hospitalized as part of the second stage of medical rehabilitation after shoulder arthroplasty and received treatment in an inpatient

setting. The rehabilitation program was implemented in accordance with an individual plan approved by the Multidisciplinary Rehabilitation Team (MDRT) and included daily therapeutic exercise sessions and physiotherapy procedures. The average duration of inpatient stay was 14 days.

Study Duration

The study was conducted from June 2024 to December 2024. Each patient was followed for one year after shoulder arthroplasty.

Eligibility Criteria

The inclusion criteria were as follows: age from 40 to 80 years, regardless of sex; reverse shoulder arthroplasty for degenerative–dystrophic shoulder joint diseases (no later than 24 hours after surgery); voluntary signing of an informed consent form to participate in the study. The exclusion criteria were as follows: refusal of the patient to continue participation in the study; occurrence or exacerbation of somatic diseases during the study that prevent its continuation or lead to disruption of the procedure schedule; noncompliance by the patient with the study protocol; adverse events during the study (including a significant increase in pain in the operated shoulder joint [more than 4 points on the VAS], a marked decrease in range of motion in the operated shoulder joint (more than 50% of baseline), aseptic loosening of endoprosthesis components, rotator cuff tear, periprosthetic fracture of the humeral shaft, or signs of injury to the radial or axillary nerves [for both the treatment and control groups]).

Intervention

Rehabilitation after reverse shoulder arthroplasty is a multistage process aimed at restoring joint function, preventing complications, and improving patients' quality of life. This protocol comprises three main periods: the early period (0–6 weeks), the late period (6–12 weeks), and the residual period (from 12 weeks onward), each with specific goals, therapeutic physical exercise (TPE), and efficacy criteria.

In the early period (0–6 weeks), the main goals are to protect the postoperative area, prevent complications, minimize pain, and prevent hypotrophy and hypokinesia by maintaining mobility in the distal segments of the limb. In this period shoulder immobilization with an orthosis (abduction brace with up to 60° abduction) is used, along with passive exercises for the shoulder joint via CPM therapy or with a TPE instructor (flexion up to 120°, abduction up to 90°, external rotation in the scapular plane up to 30°). Efficacy criteria for this phase include the absence of complications or signs of joint instability, pain level $\leq 4/10$ on the visual analog scale (VAS), and increased passive range of motion.

In the late period (6–12 weeks), the focus shifts to gradually increasing the range of motion, initiating active-assisted and active movements, and activating the deltoid and

periscapular muscles. During rehabilitation, the use of the orthosis is gradually discontinued, active-assisted exercises (flexion, abduction, and external rotation) are introduced, and isometric exercises for the deltoid muscle are performed. Effectiveness at this stage is assessed according to the following criteria: increased active and passive movements without marked pain, and a pain level $\leq 4/10$ on the VAS.

The residual period (from 12 weeks onward) is aimed at restoring the full range of motion in the shoulder joint, recovering strength and endurance to static and dynamic loads, increasing the functional load on the joint, and enabling the patient's return to daily activities. During this period, exercises are aimed at increasing muscle strength (resistance exercises) and include active exercises in functional positions. Subsequently, the rehabilitation program incorporates weight-bearing exercises (free weights, machines), progressive movement exercises to develop strength and endurance, and training to improve the ability to perform complex coordinated movements with the upper limb. The effectiveness of this stage is evaluated based on achieving full pain-free range of motion, symmetrical scapulohumeral complex function, performance of functional tests without marked discomfort, restoration of shoulder muscle strength to $\geq 80\%$ of the healthy limb, and the ability to perform daily and occupational activities without pain.

Outcomes Registration

Patient evaluation methods included clinical examination, instrumental assessments of shoulder joint function, including isokinetic dynamometry, analysis of coordination abilities using biofeedback (BFB), and questionnaire-based subjective assessment of functional limitations and quality of life.

Range of motion in the shoulder joint was measured by goniometry in standard planes: abduction, flexion, external rotation, and internal rotation. Muscle strength was assessed using isokinetic dynamometry with the Primus RS system (BTE, USA), including measurement of the following parameters: shoulder abduction and adduction, as well as total work in abduction and adduction tests. Additionally, the strength of the muscles responsible for external rotation was measured isometrically from the neutral position at 90° of shoulder abduction. Muscle endurance to static load was measured with the markerless video analysis system HABLECT (Russia) during a static test involving holding a 4 kg weight in 90° of shoulder abduction, 0° of shoulder rotation, and 90° of elbow flexion for 90 seconds.

Assessment of spherical motion sector and upper limb coordination abilities was performed using the Arneo Spring robotic rehabilitation device with BFB (Hocoma, Switzerland). The parameters analyzed were the spherical motion sector ("volume" parameter) and the score for performing a coordination task ("contour drawing" task, medium difficulty, 5-minute duration).

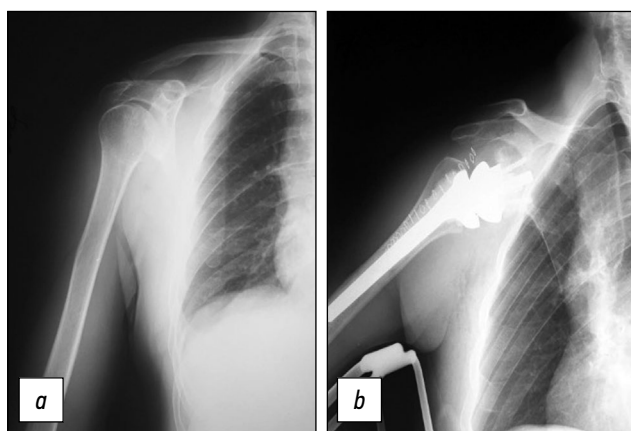


Fig. 1. Radiograph of the shoulder joint: *a*, omarthrosis; *b*, reverse shoulder prosthesis.

The questionnaire methods included the DASH (Disabilities of the Arm, Shoulder and Hand Questionnaire), PSS (Penn Shoulder Score), and SF-36 (Short Form-36 Health Survey) scales. The DASH scale was used to assess upper limb functional limitations, the PSS scale was used to evaluate pain and functional status of the shoulder joint, and the SF-36 was used to assess physical and psychological components of quality of life.

Ethics Approval

All study participants provided written informed consent after receiving full information about the study protocol. The study was approved by the Ethics Committee of the Association of Traumatologists and Orthopedists of Russia on April 26, 2024.

Statistical Analysis

Descriptive statistics were used, including calculation of the median and interquartile range (Me [Q1–Q3]). Intergroup comparisons were performed using the nonparametric Mann–Whitney U test, as graphical analysis and the Shapiro–Wilk test indicated that the data were not normally distributed ($p < 0.05$). Correlations between functional parameters were assessed using Spearman's correlation analysis (r). Statistical analysis was performed using Jamovi software version 0.1.3.

RESULTS

Participants

The study included 33 patients aged 40 to 83 years who underwent shoulder arthroplasty for osteoarthritis (Fig. 1), at postoperative interval of 48.03 ± 1.29 weeks. All patients were divided into two groups: the main group, which included 17 individuals (11 women and 6 men) who completed the developed medical rehabilitation program, and the control group, which included 16 individuals (11 women and 5 men) who did not undergo specialized rehabilitation or engaged in self-directed recovery of shoulder function. The mean age did not differ between the groups (61.6 ± 11.1 years in the rehabilitation group and 61.8 ± 8.64 years in the no-rehabilitation group).

Primary Results

When comparing range of motion parameters, statistically significant differences were identified for most measures. Shoulder abduction in the main group was 150° [150° – 160°], whereas in the control group this value was markedly lower at 107.5° [93.75° – 140°] ($p < 0.001$) (Fig. 2). Shoulder flexion was also significantly better in the rehabilitation group (160° [150° – 165°] vs. 120° [107.5° – 133.8°]; $p < 0.001$) (Fig. 3). Substantial differences were observed for external rotation as well: 45° [40° – 55°] in the main group compared with 25° [20° – 36.3°] in the control group ($p < 0.001$) (Fig. 4). Internal rotation did not differ significantly between the groups ($p = 0.294$).

Muscle strength assessment results also revealed notable intergroup differences. Abduction strength was 23.6 Nm [19.3 – 32.4] in the main group and 16.7 Nm [9.93 – 20.6] in the control group ($p = 0.005$) (Fig. 5). Adduction strength reached 40.1 Nm [34.8 – 55.1] in the main group versus 30.95 Nm [26.63 – 35.8] in the control group ($p = 0.012$) (Fig. 6). Total work (abduction/adduction) was 198.7 J [172 – 291] in the main group compared with 123.4 J [93.1 – 153.8] in the control group ($p = 0.004$). External rotation strength was higher in the main group (13.7 Nm [10.6 – 16.7]) than in the control group (6.35 Nm [5.6 – 12.6]) ($p = 0.002$) (Fig. 7).

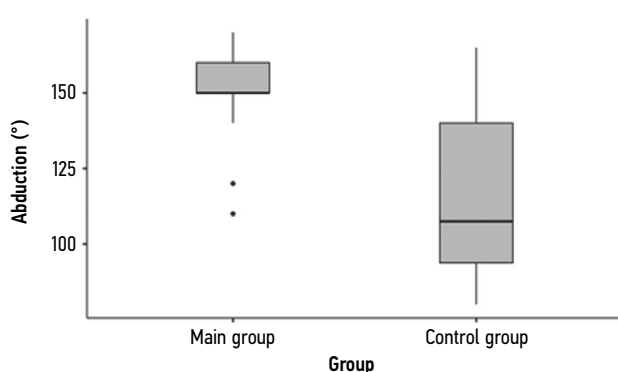


Fig. 2. Shoulder abduction range of motion.

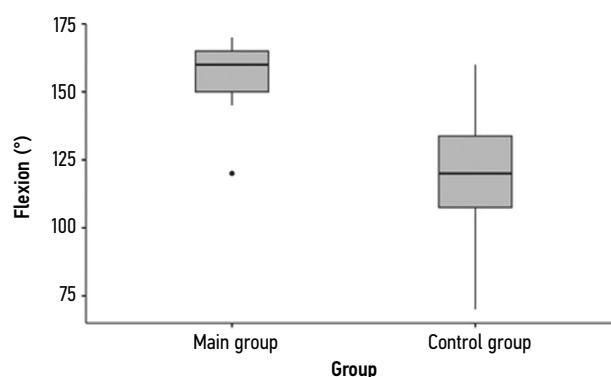


Fig. 3. Shoulder flexion range of motion.

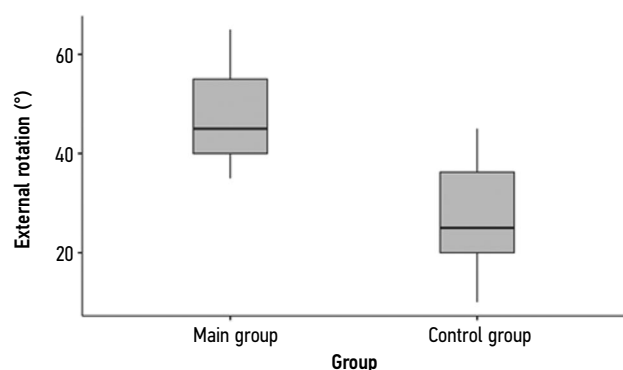


Fig. 4. Shoulder external rotation range of motion.

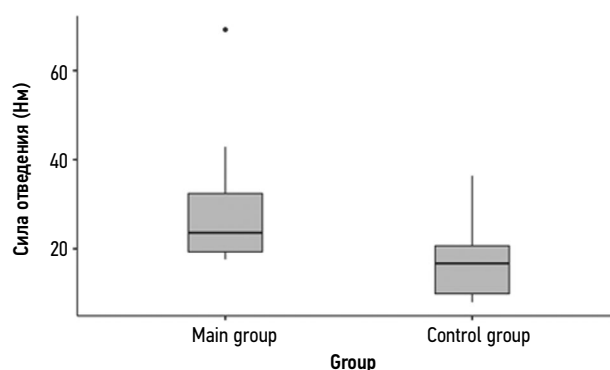


Fig. 5. Muscle strength in the isokinetic shoulder abduction test.

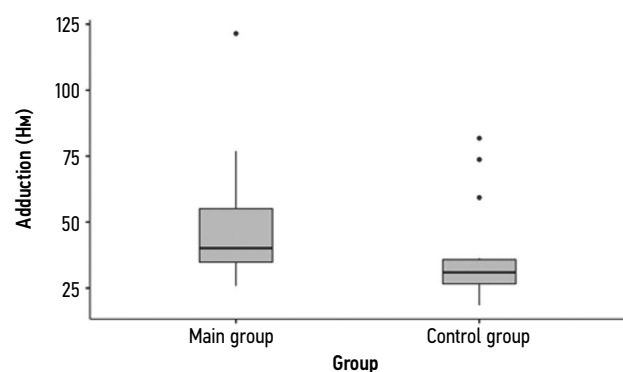


Fig. 6. Muscle strength in the isokinetic shoulder adduction test.

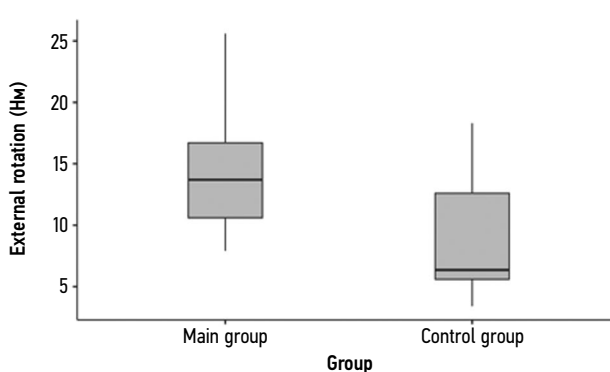


Fig. 7. Muscle strength in the isometric shoulder external rotation test.

Based on the obtained instrumental assessment data of the spherical motion sector and shoulder joint coordination using biofeedback, significant differences between the groups can be concluded. Spherical motion sector (volume) was 230,778 cm³ [207,921–268,565] in the main group and 126,952 cm³ in the control group [107,894.25–151,971.3] ($p = 0.001$) (Fig. 8). The “game score” parameter, reflecting the ability to perform complex coordinated actions with the arm, was higher in the main group (49 [45–65]) compared with the control group (35 [30.75–49.3]) ($p = 0.011$) (Fig. 9).

Patient-reported outcomes using DASH and PSS questionnaires confirmed the substantial impact of comprehensive medical rehabilitation on subjective

functional status. The mean DASH score was 10 [5.83–19] in the rehabilitation group and 35 [31.46–44.6] in the group without rehabilitation ($p < 0.001$) (Fig. 10). The results of the PSS assessment of shoulder functional status and pain also indicated significant differences: in the main group, patients demonstrated better shoulder joint function compared with the control group (54 [49–56] vs. 30.27 [22.63–39.3]; $p < 0.001$). In addition, after the rehabilitation course, patients reported less severe pain (30 [27–30]) than those without rehabilitation (23.5 [18–27.3]) ($p = 0.001$) (Fig. 11). The physical component score (PCS) of the SF-36 was significantly higher in the main group (50.1 [41.13–54.9]) than in the control group (37.74 [34.12–44]) ($p = 0.003$) (Fig. 12).

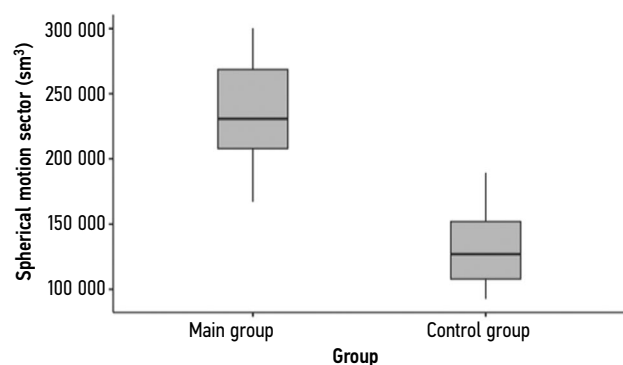


Fig. 8. Volume of shoulder joint motion in the spherical sector test using biofeedback.

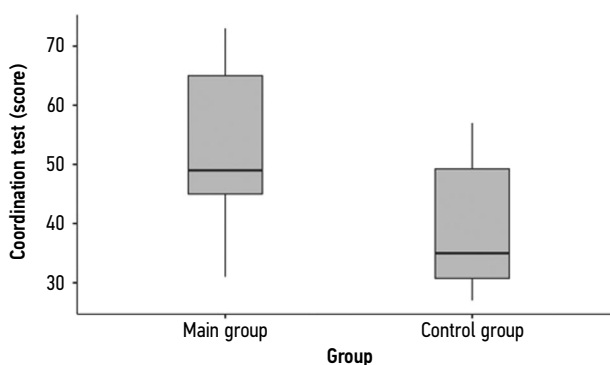


Fig. 9. Indicator of the ability to perform complex coordinated arm movements in a standard motor test with biofeedback.

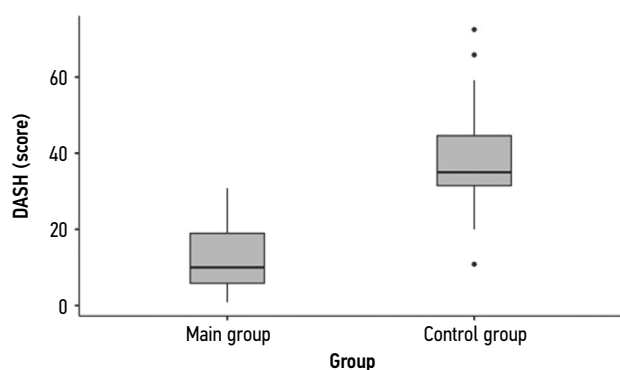


Fig. 10. Subjective functional assessment score (DASH).

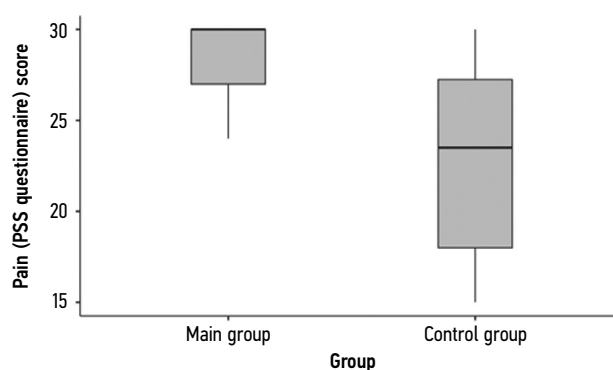


Fig. 11. Subjective pain score (PSS).

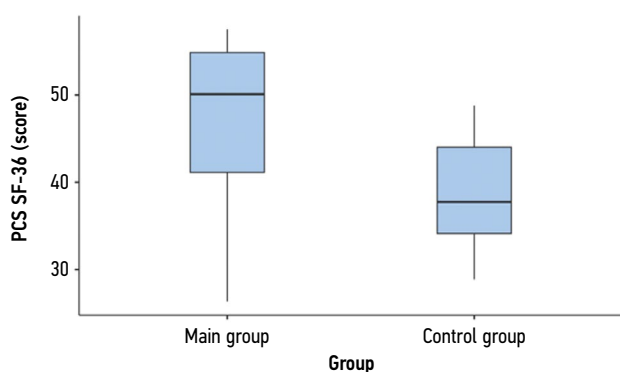


Fig. 12. Physical health (SF-36).

However, differences in the mental component score (MCS) of the SF-36 between groups did not reach statistical significance ($p > 0.05$).

Figs. 13 and 14 present instrumental graphical evidence of differences in shoulder girdle muscle endurance between patients who underwent a personalized course of medical rehabilitation and those without restorative treatment.

The assessment was performed using markerless video analysis with control of key points in the frontal plane: hand, elbow joint, and shoulder joint. The graphs illustrate spatial changes of the control points (joints) during a load test: in a patient who did not undergo organized rehabilitation, the elbow joint level dropped by 15 cm (vs. 7 cm in a patient after rehabilitation), and the hand shifted toward the center by 20 cm (vs. 10 cm after rehabilitation). These data indicate relatively low endurance of the shoulder joint muscles to static loads in patients who did not complete a course of medical rehabilitation.

Correlation analysis revealed that shoulder joint range of motion and muscle strength were closely related. Abduction showed a strong positive correlation with abduction strength ($r = 0.804$, $p < 0.001$) and flexion strength ($r = 0.941$, $p < 0.001$), whereas external rotation demonstrated a significant relationship with the strength of the muscles responsible for this movement ($r = 0.813$, $p < 0.001$). Analysis of coordination parameters showed that the spherical motion sector (volume) positively correlated with abduction ($r = 0.725$, $p < 0.001$) and flexion ($r = 0.768$, $p < 0.001$).

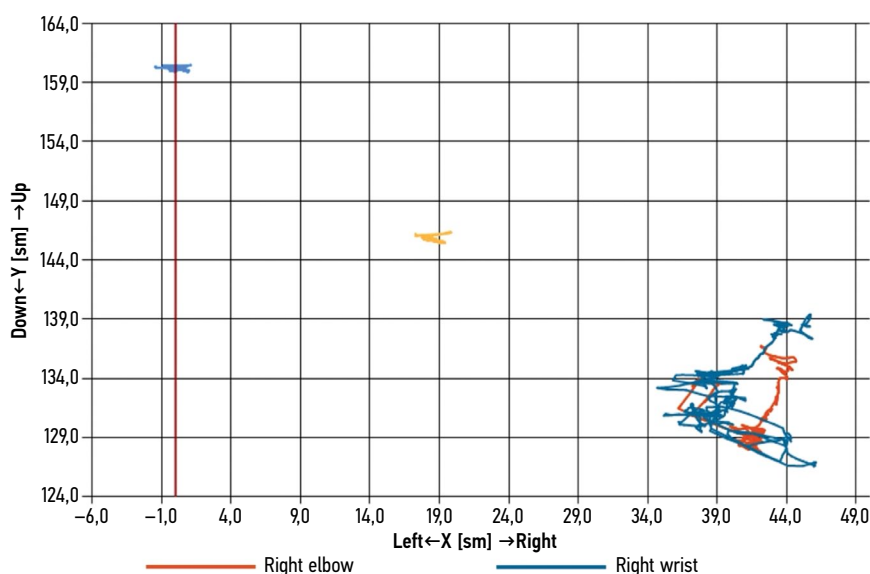


Fig. 13. Static load endurance test result: Patient K., 57 years old, treatment group.

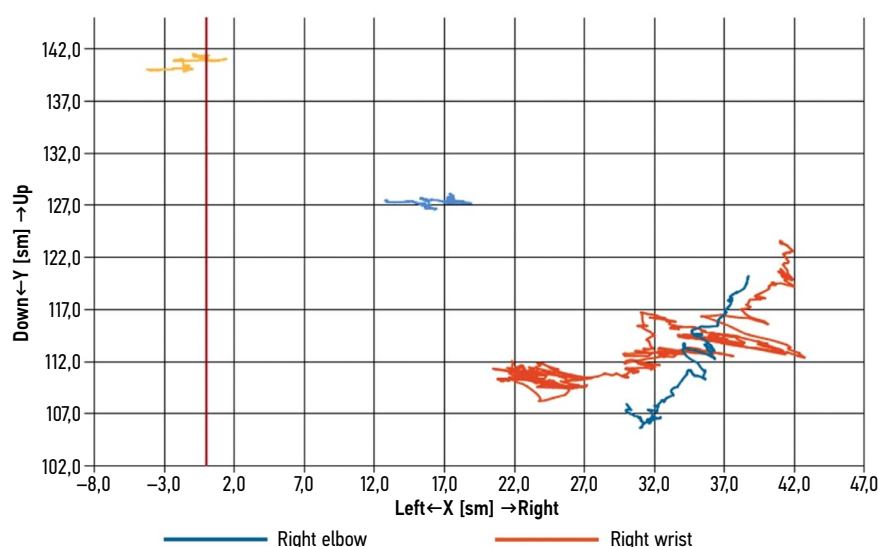


Fig. 14. Static load endurance test result: Patient N., 65 years old, control group.

Analysis of the relationship between pain and quality of life showed that pain level (PSS) was negatively correlated with range of motion parameters (abduction: $r = -0.368$, $p = 0.035$; flexion: $r = -0.446$, $p = 0.009$), indicating that lower subjective pain levels were associated with greater joint mobility. The DASH score had a strong negative correlation with functional parameters, particularly abduction range of motion ($r = -0.824$, $p < 0.001$) and coordination ability ($r = -0.708$, $p < 0.001$), which—given the scoring specificity of this scale (lower is better)—indicates a close relationship between these parameters. In addition, a positive correlation was found between the physical component of SF-36 and muscle strength ($r = 0.558$, $p = 0.001$), suggesting that muscle activity affects overall physical well-being, thereby improving patients' subjective quality of life.

DISCUSSION

This study confirmed that early mobilization of patients after reverse shoulder arthroplasty, combined with controlled load progression and inclusion of coordination training, leads to significant improvements in range of motion, muscle strength, and quality of life. Incorporating biofeedback into the rehabilitation program allowed for objective assessment of the spherical motion sector, which has not been accounted for in most previous studies.

The findings are consistent with those of Howard et al., who demonstrated the benefits of early mobilization for improving mobility and reducing postoperative pain syndrome [16]. However, their study did not account for the effect of coordination abilities on functional recovery. In contrast, our study demonstrated that patients who underwent rehabilitation with BFB exhibited significantly better movement control, which was confirmed by a larger spherical motion sector ($234,348.24 \pm 43,536.8 \text{ cm}^3$ vs. $133,506.56 \pm 30,866.74 \text{ cm}^3$ in the control group; $p = 0.001$).

Analysis of the recovery changes in range of motion revealed that patients who completed the developed rehabilitation course had a significant advantage over those without organized rehabilitation: shoulder abduction reached $151.18 \pm 16.16^\circ$ compared with $114.69 \pm 27.54^\circ$ in the control group ($p < 0.001$). These findings are in line with the works of Salamh and Speer, which confirmed that early mobilization does not increase the risk of prosthesis instability. However, unlike our study, their research did not include strict load control or coordination training, factors that could influence long-term functional outcomes [20].

Our data also demonstrate that active integration of strength and coordination exercises led to more pronounced improvements in muscle function. For example, abduction strength in the treatment group was $28.13 \pm 13.14 \text{ Nm}$, significantly higher than in patients without rehabilitation ($17.99 \pm 8.88 \text{ Nm}$; $p = 0.005$). The traditional approach described by Kirsch et al. emphasizes the need for prolonged immobilization (up to 6 weeks) to protect the prosthesis, but this may result in hypotrophy and contractures [21]. In our study, by contrast, early engagement in active exercises helped maintain muscle strength and improve functional parameters without increasing pain syndrome.

The personalized approach applied in our rehabilitation program is consistent with the principles described by Romano et al., where patients with different risk profiles were offered tailored recovery programs [22]. However, our study differed in that load individualization was based on objective instrumental diagnostics (isokinetic dynamometry, BFB), enabling flexible adaptation of the rehabilitation process and achieving superior functional outcomes.

Thus, the developed rehabilitation program combines the key advantages of existing approaches: early mobilization, personalized load distribution, and objective assessment of recovery. The inclusion of coordination control and spherical

motion sector measurement makes this program more precise and effective compared with traditional methods. These findings highlight the need for a comprehensive approach to recovery after reverse shoulder arthroplasty and can serve as a basis for further optimization of rehabilitation protocols.

Study Limitations

This study has several limitations that should be considered when interpreting its results. The relatively small sample size may limit the generalizability of the findings, highlighting the need for further research with greater representativeness. Additionally, the heterogeneity of the control group should be taken into account, as patients who performed self-directed rehabilitation could differ substantially in their level of activity and adherence to recovery measures, which may have influenced the significance of the comparisons. The study also did not include a detailed analysis of the impact of individual factors, such as baseline physical fitness, motivation, and neuromuscular adaptation characteristics, which could have had a substantial effect on rehabilitation outcomes. In the future, it will be important to consider these aspects when developing personalized rehabilitation protocols to improve the accuracy of evaluating the effectiveness of rehabilitation interventions and their long-term results.

CONCLUSION

Reverse shoulder arthroplasty is an effective surgical treatment method for degenerative and post-traumatic shoulder joint conditions, allowing substantial improvement of joint function and reduction of pain. Incorporating a personalized rehabilitation approach is essential to help patients adapt to the altered joint biomechanics, prevent possible complications, and accelerate recovery.

The optimal scope of medical rehabilitation plays a key role in restoring shoulder joint motor function, coordination, and muscle strength. This study confirms that a specialized rehabilitation program employing modern techniques, including biofeedback and isokinetic dynamometry, significantly improves range of motion, coordination, and patient-reported quality of life. Further research is required to refine rehabilitation protocols and determine the optimal timing and scope of restorative interventions.

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Consent for publication: Written informed consent was obtained from all patients for the publication of their medical data and images (November 24, 2024).

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. Все авторы одобрили финальную версию перед публикацией, а также согласились нести ответственность за все аспекты работы, гарантируя надлежащее рассмотрение и решение вопросов, связанных с точностью и добросовестностью любой её части.

Источники финансирования. Отсутствуют.

Раскрытие интересов. Авторы заявляют об отсутствии отношений, деятельности и интересов (личных, профессиональных или финансовых), связанных с третьими лицами (коммерческими, некоммерческими, частными), интересы которых могут быть затронуты содержанием статьи, а также иных отношений, деятельности и интересов за последние три года, о которых необходимо сообщить.

Оригинальность. При создании настоящей работы использовался способ роботизированной механотерапии, который был запатентован авторами и был отражён в прошлом исследовании, опубликованном в журнале «Медицинский алфавит» в 2024 году: Чугреев И.А., Фесюн А.Д., Стяжкина Е.М., Рожкова Е.А. Эффективность применения координационных тренировок в программе медицинской реабилитации пациентов после реверсивного эндопротезирования плечевого сустава // *Неврология и психиатрия* 2024;(2):43–46. doi: 10.33667/2078-5631-2024-2-43-46

Генеративный искусственный интеллект. При создании настоящей статьи технологии генеративного искусственного интеллекта не использовались.

Рассмотрение и рецензирование. Настоящая работа подана в журнал в инициативном порядке и рассмотрена по обычной процедуре. В рецензировании участвовали два внешних рецензента, член редакционной коллегии и научный редактор издания.

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