USING INTERACTIVE TECHNOLOGIES FOR REHABILITATION FOLLOWING REVISION KNEE ARTHROPLASTY

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A chronic periprosthetic infection after knee replacement typically requires two-stage treatment. However, the inter-stage rehabilitation protocol for patients with an articulating spacer has not been adequately developed. This study aimed to determine whether adding interactive biofeedback walking training on the Walker View treadmill enhances the effectiveness of a standard recovery program following the first stage of two-stage revision treatment. The prospective randomized controlled trial included 87 patients who had undergone removal of their endoprostheses and placement of articulating spacers. The treatment group ($n = 43$) had the standard 21-day rehabilitation program combined with Walker View sessions, while the control group ($n = 44$) only followed the program. We assessed knee joint movement volume, quadriceps EMG amplitude, stride length, walking speed, postural stability, and SF-36, WOMAC, and KSS scores. By the end of the rehabilitation course, the results registered in the treatment group were better than in the control group: flexion — 78 ± 6° versus 71 ± 7° ($p = 0.01$); EMG amplitude — 179 ± 16 versus 165 ± 16 μV ($p = 0.01$); step length — 54.2 ± 5.0 versus 49.5 ± 5.0 cm ($p = 0.01$); walking speed — 0.70 ± 0.05 versus 0.65 ± 0.05 m/s ($p = 0.02$); overall stability — 80 ± 8% versus 72 ± 7% ($p = 0.01$); physical component SF-36 — 51 ± 8 versus 47 ± 7 points ($p = 0.01$). The differences in WOMAC and KSS scores were insignificant ($p = 0.06$ and $p = 0.07$). The inclusion of Walker View sessions in the inter-stage rehabilitation program yields more pronounced improvements in mobility, neuromuscular function, walking, and balance restoration.

Keywords: revision arthroplasty, knee joint, periprosthetic infection, rehabilitation, biofeedback, Walker View, two-stage revision arthroplasty, articulating spacer

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Compliance with ethical standards: the study was approved by the Ethics Committee of the Bashkir State Medical University of the Ministry of Health of the Russian Federation (Minutes #2 of February 03, 2025). All procedures were performed in accordance with the requirements of the 2013 World Medical Association Declaration of Helsinki. All patients signed a voluntary informed consent form for participation in the study.

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ИСПОЛЬЗОВАНИЕ ИНТЕРАКТИВНЫХ ТЕХНОЛОГИЙ В ВОССТАНОВИТЕЛЬНОМ ЛЕЧЕНИИ ПОСЛЕ РЕВИЗИОННОЙ АРТРОПЛАСТИКИ КОЛЕННОГО СУСТАВА

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Хроническая перипротезная инфекция после эндопротезирования коленного сустава требует двухэтапного лечения, однако межэтапная реабилитация пациентов с артикулирующим спейсером разработана недостаточно. Целью работы было определить, повышает ли включение интерактивной тренировки ходьбы с биологической обратной связью на комплексе Walker View эффективность стандартной восстановительной программы после первого этапа двухэтапной ревизии. В проспективное рандомизированное контролируемое исследование включили 87 пациентов после удаления эндопротеза и установки артикулирующего спейсера. Основная группа ($n = 43$) проходила стандартную реабилитацию в сочетании с тренировкой на Walker View, контрольная ($n = 44$) — только стандартную программу; курс составил 21 день. Оценивали объем движений в коленном суставе, амплитуду ЭМГ четырехглавой мышцы, длину шага, скорость ходьбы, постуральную устойчивость, показатели SF-36, WOMAC и KSS. К окончанию курса в основной группе достигнуты лучшие результаты: сгибание 78 ± 6° против 71 ± 7° ($p = 0{,}01$), амплитуда ЭМГ 179 ± 16 против 165 ± 16 мкВ ($p = 0{,}01$), длина шага 54,2 ± 5,0 против 49,5 ± 5,0 см ($p = 0{,}01$), скорость ходьбы 0,70 ± 0,05 против 0,65 ± 0,05 м/с ($p = 0{,}02$), общая стабильность 80 ± 8% против 72 ± 7% ($p = 0{,}01$), физический компонент SF-36 — 51 ± 8 против 47 ± 7 баллов ($p = 0{,}01$). Различия по WOMAC и KSS были статистически незначимы ($p = 0{,}06$ и $p = 0{,}07$). Включение Walker View в межэтапную реабилитацию обеспечивает более выраженное восстановление подвижности, нейромышечной функции, ходьбы и равновесия.

Ключевые слова: ревизионная артропластика, коленный сустав, перипротезная инфекция, реабилитация, биологическая обратная связь, Walker View, двухэтапное ревизионное эндопротезирование, артикулирующий спейсер

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The rising prevalence of destructive and dystrophic musculoskeletal diseases has increased the frequency of large joint replacement surgery. According to federal statistics, the incidence of osteoarthritis in Russia rose from 546.9 cases per 100,000 population in 2015 to 650.0 in 2024, an 18% increase [1]. Knee replacement is the most effective surgery for destructive and dystrophic joint lesions. In modern orthopedics, it is the gold standard, considerably improving patients' quality of life and life expectancy. However, the implants placed are limited functionally, and over time, the components of the endoprosthesis wear out. It is projected that by 2030, more than 260,000 revision knee surgeries will be performed annually in the United States [2]. Over the years, tension force vectors in the bone and connective tissue around the endoprosthesis shift, leading to a biomechanical conflict with the supporting structures. As a result, aseptic instability, metallosis, and osteolysis can develop, as well as periprosthetic infection (PPI) if microbial factors are involved.

PPI is one of the most severe complications of knee replacement. Large-scale cohort studies report the incidence of PPI as 1–2% after primary arthroplasty, and up to 4% after revision surgeries [3]. PPI is the leading cause of revision intervention, more common than aseptic instability and wear of polyethylene [4]. Chronic periprosthetic knee joint infection causes soft tissue and bone destruction, impairing limb function. It often requires two-stage revision arthroplasty with a temporary antibiotic spacer.

Two-stage revision arthroplasty remains the most recognized treatment for chronic PPI. The first stage is aimed at rehabilitating the infection site, stabilizing soft tissue and bone structures, and partially preserving limb function when using an articulating spacer. The key factor in the effectiveness of the two-stage approach is the quality of recovery during the period between the stages, which usually ranges from 6 to 12 weeks [5]. The rehabilitation itself commonly includes early mobilization of the joint and physical therapy [6]. The use of articulating spacers allows patients to start recovery activities in the early postoperative period [7]. However, it is not yet fully clear which rehabilitation methods are optimal under these conditions. Some authors recommend a gentle regimen to prevent spacer dislocation, while others emphasize the need for early activation to prevent muscular atrophy [8].

In recent years, biofeedback technologies have been increasingly integrated into musculoskeletal rehabilitation. The Walker View platform (TecnoBody, Italy) is a treadmill with an integrated 3D motion analysis system and a touchscreen that allows real-time evaluation of temporal and spatial gait parameters, step symmetry, and joint kinematics [9, 10]. The technology has been proven effective in post-knee replacement rehabilitation [11], but there is no information about its efficacy in the context of a two-stage revision arthroplasty that involves a temporary spacer [12].

Thus, the relevance of this study stems from the availability of data on the effectiveness of interactive biofeedback technology in rehabilitation after primary knee joint arthroplasty, coupled with the lack of evidence on its use between stages of revision surgery with an articulating spacer.

This study aimed to evaluate the effectiveness of a comprehensive rehabilitation program that includes interactive biofeedback sessions on a Walker View treadmill in comparison with the standard rehabilitation protocol followed after the first stage of two-stage revision knee arthroplasty undertaken to treat PPI.

METHODS

This study was a prospective, randomized controlled trial designed to evaluate the effectiveness of comprehensive rehabilitation following the first stage of two-stage revision knee arthroplasty in patients with chronic periprosthetic joint infection. In the context of the study, we compared a standard rehabilitation program and an extended program that incorporates the use of interactive biofeedback technology.

Inclusion criteria: age 55–75 years, diagnosed chronic knee periprosthetic infection (ICD-10 code T84.5), absence of significant somatic diseases that could hinder rehabilitation, and informed consent to participate in the study.

Exclusion criteria: acute infectious diseases at the time of enrollment; severe comorbidities in the decompensation stage, such as class III–IV cardiovascular insufficiency (NYHA classification); diabetes mellitus with glycated hemoglobin (HbA1c) > 8.5%; severe chronic obstructive pulmonary disease with forced expiratory volume in 1 second (FEV1) <50% of predicted; end-stage chronic kidney disease (glomerular filtration rate < 15 mL/min/1.73 m^2 or dialysis dependence); patient's refusal to participate; cognitive impairments preventing completion of the rehabilitation program (MMSE score < 24 points).

Sample characteristics

The study included 87 patients hospitalized for chronic periprosthetic knee infection who underwent the first stage of two-stage revision arthroplasty with an articulating spacer (made in BSMU's Additive Technologies Laboratory; Eurasian Application No. 202492817).

The sample size was calculated using the G*Power 3.1.9.7 program. Based on the expected difference in the range of 10° knee joint motion (control group average: 70° ± 15°; treatment group average: 80° ± 15°), with 80% study power and a significance level of $\alpha = 0.05$, each group should have included at least 36 patients. Since it was assumed that 15% of the participants would drop out, the plan was to invite 44 patients to each group, for a total sample size of 88. Eventually, 87 patients were included (one patient refused to participate before the beginning of the rehabilitation). The mean age of the sample was 65.4 ± 5.2 years. Gender distribution: 51 female (58.6%) and 36 male (41.4%). The sample was randomized by the block randomization method (block size 4) using a random number generator: treatment group, $n = 43$; control group, $n = 44$.

The patients were divided into groups after the first stage of surgery. Blinding of patients and rehabilitation specialists was not possible due to the nature of the intervention. The functional outcomes and statistical data were analyzed by specialists who were uninvolved in the rehabilitation program and unaware of the patients' group affiliations. The groups were comparable in age and gender ($p > 0.05$).

Rehabilitation program

The rehabilitation program began on the first day after the first stage of revision arthroplasty. It lasted for 21 days, and the patients remained in the hospital throughout its duration. The program included two consecutive stages: the early postoperative period stage (days 1–4) and the core rehabilitation stage (days 5–21).

Early postoperative period stage (days 1–4)

In the early postoperative period, patients performed gentle isometric exercises to prevent thromboembolic complications, maintain muscle tone, and preserve basic motor activity.

Table 1. The standard medical rehabilitation program

Component	Brief description of the intervention	Parameters	Intended goal
Cryotherapy	Local cooling of the knee joint area	15-20 minutes, 2-3 times a day; t° –5...+5 °C	Reduction of pain and swelling, control of inflammation
Continuous passive motion (CPM)	Mechanical passive joint mobilization using the Artromot device with a gradual increase in amplitude	20–30 minutes, 2–3 times a day; increase of 5–10° a day	Contracture prevention, ROM maintenance
Pneumocompression lymphatic drainage	Sequential pneumocompression of the lower limb	30 minutes, 1–2 times a day; pressure 40–60 mmHg	Reduction of edema, improvement of lymphovenous drainage
Physical therapy	Active exercises for the muscles of the thigh, lower leg, buttocks using resistance bands and body weight	30–40 minutes a day; 2–3 sets of 10–15 repetitions	Restoration of strength and weight-bearing ability
Electrical muscle stimulation	Neuromuscular electrical stimulation of *m. quadriceps femoris* and *m. gastrocnemius*	Frequency 30–50 Hz, pulse duration 250–300 microseconds, 15–20 minutes	Prevention of atrophy, activation
Soft tissue massage	Classical and lymphatic drainage massage of the thigh and lower leg muscles	15–20 minutes a day, a course of 10–14 procedures	Improved microcirculation, decreased muscle tone
Graded walking	Learning walking techniques with the distance gradually increasing	10–15 minutes, 2 times a day; weight-bearing intensity as allowed by the spacer protocol	Normalization of walking patterns, early mobilization

The set included the following.

1. Isometric exercises for the thigh muscles — static tension of the quadriceps femoris and adductor muscles with a gradual increase in the duration of tension from 5 to 10–15 seconds, followed by 10-second relaxation; 10 repetitions, 3 times a day.
2. Active movements of the ankle joints — flexion and extension of the foot, circular movements; 15–20 repetitions of each exercise, 4–5 times a day to stimulate venous outflow.
3. Straight leg lift while supine: knee extension followed by lifting the straightened leg 15–20 cm from the bed surface, with a 5-second hold; 8–10 repetitions, twice daily, emphasizing the anterior thigh muscles.
4. Knee joint passive flexion and extension — performed within the permissible range of motion (usually 0–30 ° on the first day), taking into account the features of the installed spacer and muscle balance; 5–10 repetitions, 2 times a day.
5. Respiratory exercises — diaphragmatic breathing, chest expander exercises to prevent congestion in the lungs.

Core rehabilitation stage (days 5–21)

On days 5–7 post-surgery, once the patients' condition had stabilized and provided there were no signs of inflammatory complications and the postoperative wound was satisfactory, they advanced to the core rehabilitation stage. Table 1 presents the standard rehabilitation program followed in both groups.

Interactive rehabilitation program (treatment group)

In the treatment group, the standard rehabilitation program was extended to include sessions on the Walker View 3.0 SCX system (TecnoBody S.r.l., Italy). This integrated platform features a treadmill with load sensors, an optical 3D motion analysis array with four cameras, a touch surface for assessing weight-bearing distribution, and real-time gait analysis software.

The Walker View sessions took place every day starting from days 5–7 post-surgery, provided that the postoperative wound had healed and there were no signs of an active inflammatory process. Each session lasted for 20–30 minutes. The patients held onto a support bar at all times. On days 5–10, they walked on the treadmill while resting their weight on the side rails of the Walker View platform, which ensured a stable position and prevented loss of balance. The load on the operated limb was controlled according to an individual protocol, based on the type of articulating spacer implanted and the postoperative wound condition. As patients regained the ability to bear their own weight and gained walking confidence, handrail support was gradually reduced. The axial load was monitored using Walker View's built-in pressure sensors. These enabled real-time control of load distribution across the limbs and prevented exceeding the safe load limit on the operated side.

Each session included three consecutive stages.

Stage one — basic gait analysis: patients performed a standard walking test to record baseline parameters at a comfortable pace. "The system automatically recorded the following parameters: step length and symmetry between the operated and contralateral limbs; duration of the weight-bearing and transfer phases; movement speed and cadence; spatial parameters of pelvis and trunk motion (lateral shifts and rotation); kinematic characteristics of the hip and knee joints (sagittal-plane movement amplitude); and load distribution between the limbs. The data obtained was used to determine the individual targets for the current training session.

Stage two — Gait Trainer module, interactive learning involving real-time visual biofeedback: the patients saw the target parameters of the step and the walking cycle phases on the screen in front of them. The training included the following components.

1. Step length symmetry correction — visualization of the difference in step length between the operated and healthy limbs to equalize the metrics.
2. Walking phases optimization — gradual increase of weight-bearing time on the operated limb, normalization of the push-off moment.
3. Control trunk's lateral motions and rotation of the pelvis — visualization of deviations of the center of mass from the midline with feedback on the accuracy of the trajectory.
4. Restoration of the axis of the lower limb — stabilization of the knee joint in the sagittal plane and correction of varus/valgus deviations.
5. Kinematic exercises — execution of movements with visualization of the angular parameters of the knee joint to restore the amplitude of flexion and extension.
6. Load distribution normalization — control of symmetry in the load response recorded by the platform's pressure sensors.

To ensure physiological accuracy and safety of movements, we used SCX Speed Control technology, which automatically adapts treadmill speed to the patient's pace. The technology eliminated the need to maintain the set speed and reduced the risk of loss of balance.

Stage 3 — session report. At the end of the training, the patient received a summary visual assessment of the achieved changes in key parameters: step length, phase symmetry, movement speed, lateral stability, and angular kinematics of the joints. These data were stored in the system and used for subsequent adjustment of training tasks.

We used the interactive Walker View program to establish a physiological gait pattern early on, reduce limb movement asymmetry, improve neuromuscular control, and restore the limb's supporting function while using the articulating spacer.

Efficacy assessment methods

The efficacy of the rehabilitation program was assessed based on a comprehensive analysis of the functional state of the operated limb, kinematic characteristics of gait, neuromuscular activity, parameters of postural stability, and quality of life indicators (Table 2). The patients were examined twice: on the day after the first stage of revision arthroplasty (before active rehabilitation) and after completing the three-week inpatient rehabilitation program. All methods were standardized, with an identical examination protocol for both groups. Procedures were performed by a qualified specialist trained in the equipment used.

Knee joint range of motion assessment

The amplitude of knee joint flexion and extension was determined on an Arthromot ORMED FLEX-F01 Active complex (Ormed LLC, Russia). For the assessment, the patient lay supine with the hip joint fixed at 90° flexion to prevent compensatory movements. We measured the maximum angles of active flexion and extension that the patient could tolerate without a marked increase in pain. Each measurement was performed in triplicate, and the average was used for analysis. The measurement error was ±1°.

Electromyographic examination

The functional state of the lower extremity muscles was assessed using surface electromyography on a Neuro-MVP-4 device (NPP Medical Computer Technology, Russia). Biopotentials were recorded from the quadriceps femoris (rectus femoris) and gastrocnemius (medial head) muscles on the operated side. The electrodes were placed over the muscular abdomen, with the specific position selected based on anatomical landmarks; the skin was pre-treated with an alcohol solution. We analyzed the amplitude (in mV) of voluntary muscle contractions using standardized isometric tests: knee extension against resistance (quadriceps muscle) and standing on tiptoes (gastrocnemius muscle). The recording duration was 5 seconds, the gain — 1000 mV/div. The measurements were taken in triplicate, with an interval of 30 seconds.

Analysis of temporal and spatial gait parameters

The kinematic and temporal-spatial characteristics of gait were evaluated using the Walker View 3.0 SCX system (TecnoBody S.r.l., Italy). The patients walked at a comfortable self-selected pace on an instrumented treadmill 150 cm long. We recorded the following parameters: step length (cm), movement speed (m/s), load phase duration for the operated limb (ms), transfer phase duration for the operated limb (ms), and step symmetry coefficient between the operated and contralateral limbs.

The testing began after a two-minute adaptation to the treadmill. The parameters were registered for 30 seconds of continuous walking. The average values from stable walking cycles (at least 10 consecutive steps) were used for the analysis.

Stabilometric study

Postural stability and equilibrium reactions were assessed using the Huber 360 stabilometric complex (LPG Systems, France). The study included the following tests:

1) static test — recording of center of pressure (CP) deviations during 30-second quiet stance on two legs with eyes open;

2) statodynamic test — assessing stability limits during forward, backward, and sideways torso bending.

We recorded the following parameters: the area of the CP scattering ellipse (mm^2), the amplitude of trunk motions in the frontal and sagittal planes (mm), the integral index of overall stability (%), and the stability limit (% of the maximum possible bending). The stabilometric study served only diagnostic purposes, and Huber 360 was not used for rehabilitation.

Clinical questionnaires

The clinical efficacy of rehabilitation and its impact on the quality of life were assessed using validated Russian-language versions of the following questionnaires.

1. Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36): comprehensive assessment of quality of life's physical and mental components. We analyzed the total score of the physical component as the most sensitive to changes in motor function in the early postoperative period.
2. Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC): assessment of the severity of pain (5 questions), stiffness (2 questions) of the knee joint, and its physical function (17 questions). We used the Likert III version of the index (0-4 points); the maximum possible total score was 96 (the higher the score, the worse the condition).
3. Knee Society Score scale (KSS): assessment of the clinical status of the knee joint (Knee Score, maximum 100 points) and its functional state (Function Score, maximum 100 points).

All questionnaires were filled out by patients independently under the supervision of a researcher.

Standardization of measurements

To minimize variability in data processing, all studies and examinations were conducted by one certified specialist who was not involved in the rehabilitation. The equipment used was calibrated as prescribed by the manufacturer before each test/study. All quantitative indicators were measured in triplicate (or more); for statistical analysis, we used the arithmetic mean. All patients underwent a specific test or study in the same time of day (morning or afternoon).

The endpoints of the study

The primary endpoint was the knee joint active flexion index after 21 days of inpatient rehabilitation. The secondary endpoints were the index of active extension, the amplitude of EMG of m.quadriceps femoris, step length, walking speed, load phase duration, integral indicators of postural stability, as well as the data collected using the SF-36, WOMAC, and KSS questionnaires.

Statistical data processing

IBM SPSS Statistics 26.0 (IBM Corp., USA) was used for statistical processing of the data. Normality of distribution of

Table 2. Rehabilitation results assessment methods

Method	Measured parameters	Tool / equipment	Purpose
Range of motion (ROM) assessment	Angle of active flexion and extension of the knee joint	Arthromot ORMED FLEX-F01 Active (Russia)	Assessment of mobility restoration and contracture prevention
Electromyography (EMG)	The amplitude of arbitrary contractions of *m. quadriceps femoris* and *m. gastrocnemius*	Neuro-MVP-4 (Russia)	Analysis of neuromuscular activation and muscle tone
Gait analysis	Step length, movement speed, load phase duration, step symmetry coefficient	Walker View 3.0 SCX (Italy)	Assessment of recovery of motor patterns and gait parameters
Stabilometry	Pressure center, oscillation amplitude, stability limit, integral stability	Huber 360 (France)	Diagnosis of postural stability (not included in the rehabilitation program)
Clinical questionnaires	SF-36: quality of life; WOMAC: pain, stiffness, function; KSS: clinical and functional parameters of the joint.	Paper forms	Comprehensive assessment of clinical efficacy and functional status

the quantitative data was assessed using the Shapiro-Wilk test. We calculated the mean and standard deviation (M ± SD) for normally distributed data and the median and interquartile range (Me [Q_1; Q_3]) for non-normal data. The intergroup differences between the treatment and control groups were assessed using the independent Student's *t*-test for normally distributed quantitative data; the Mann–Whitney test for quantitative data without a normal distribution; and Pearson's χ^2 test or Fisher's exact test for categorical variables.

To assess dynamics within the groups (before and after rehabilitation), we used the paired *t*-test when differences were normally distributed and the Wilcoxon test otherwise.

The differences were considered significant at $p < 0.05$. The hypothesis testing at the primary endpoint was confirmatory. The analysis of secondary endpoints was exploratory; the obtained *p*-values were interpreted with adjustment for the multiplicity of compared indicators. To minimize systematic errors, all calculations were performed by one specialist who was not involved in the rehabilitation and clinical examination of patients.

RESULTS

The mean service life of the first endoprosthesis before the development of periprosthetic infection was 7.2 ± 2.8 years in the treatment group and 7.5 ± 3.1 years in the control group ($p = 0.64$). We confirmed the diagnosis of chronic periprosthetic infection in all participants according to the Musculoskeletal Infection Society (MSIS) criteria. The distribution of patients according to the Cierny-Mader classification did not differ between the groups ($p = 0.78$).

The initial values of all assessed indicators (range of motion, electromyographic parameters, gait parameters, stabilometry, quality of life) were statistically comparable between the treatment and control groups at baseline (all $p > 0.05$), enabling accurate evaluation of the rehabilitation programs' effectiveness.

Range of motion and neuromuscular activity

At the end of the three-week rehabilitation course, the knee joint motion amplitude has increased significantly in both groups (Table 3). In the treatment group, flexion increased by 30% from baseline, compared to 22% in the control group. Extension improved by 6% and 5%, respectively. The intergroup differences in the final values of flexion and extension were significant ($p = 0.010$ and $p = 0.040$ respectively).

Electromyographic study revealed that the amplitude of voluntary muscle contractions of *m. quadriceps femoris* has grown in both groups. The relative increase was 17.8% in the treatment group and 11.5% in the control group ($p = 0.010$ between the groups). A similar trend was observed for *m. gastrocnemius*, but the intergroup difference was smaller. The recorded increase in the amplitude of biopotentials indicates restoration of neuromuscular activation after surgery.

Gait parameters

The dynamics of temporal and spatial characteristics of gait were positive in both groups. The step length increased by 18% in the treatment group and by 12.5% in the control group ($p = 0.010$). Movement speed increased by 14.8% and 10.2%, respectively ($p = 0.020$).

The duration of load on the operated limb decreased in both groups ($p < 0.001$), which reflects the restoration of confidence in the functionality of that limb. The transfer phase shortened from 412 ± 38 ms to 371 ± 34 ms in the treatment group and from 415 ± 40 ms to 390 ± 37 ms in the control group ($p = 0.040$ between groups). This indicates improved movement control without load. The step symmetry coefficient (ratio of the operated limb's step length to that of the contralateral limb) improved from 0.82 to 0.94 in the treatment group and from 0.81 to 0.89 in the control group ($p = 0.015$ between groups).

Postural stability

The integral indicators of stabilometry significantly increased in both groups. Overall stability increased by 21% in the treatment group and 12.5% in the control group ($p = 0.010$). The stability limit increased by 24.6% and 13.3%, respectively ($p = 0.010$).

Meanwhile, local parameters (amplitude of pressure center fluctuations and pressure center deviation) did not differ significantly between groups ($p = 0.070$ and 0.080). This may indicate that the accuracy characteristics of postural control require a longer recovery period than the integral indicators.

Quality of life and functional status

The SF-36 score demonstrated an improvement in the physical component of the quality of life in both groups. The absolute increase was 10 points in the treatment group and 8 points in the control group ($p = 0.010$ between the groups).

The WOMAC score decreased by 30% in the treatment group and by 20% in the control group, indicating an improvement in condition. However, the intergroup differences in the final values did not reach statistical significance ($p = 0.060$). A similar trend was observed for the KSS score: both groups exhibited clinical status improvement, but the intergroup differences were insignificant ($p = 0.070$). This lack of significance may stem from the load limitation associated with

Table 3. Post-rehabilitation functional state assessment

Indicator	Treatment group (before)	Treatment group (before)	Control group (before)	Control group (before)	*p* between groups
Knee joint flexion, °	60 ± 7	78 ± 6	58 ± 8	71 ± 7	0.01
Knee joint extension, °	166 ± 4	176 ± 2	165 ± 5	173 ± 3	0.04
Quadriceps EMG, mV	152 ± 17	179 ± 16	148 ± 18	165 ± 16	0.01
Operated limb's step length, cm	46 ± 5	54.2 ± 5	44 ± 5	49.5 ± 5	0.01
Walking speed, m/s	0.61 ± 0.06	0.70 ± 0.05	0.59 ± 0.07	0.65 ± 0.05	0.02
Operated limb's load phase, ms	767 ± 49	690 ± 51	762 ± 52	714 ± 48	0.01
Operated limb's transfer phase, ms*	412 ± 38	371 ± 34	415 ± 40	390 ± 37	0.04
Step symmetry coefficient	0.82 ± 0.06	0.94 ± 0.04	0.81 ± 0.07	0.89 ± 0.05	0.015
Pressure center deviation, mm	23 ± 4	18 ± 3	22 ± 4	20 ± 3	0.08
Oscillation amplitude, mm	12 ± 2	10.8 ± 2	11 ± 2	10 ± 2	0.07
Overall stability, %	66 ± 9	80 ± 8	64 ± 9	72 ± 7	0.01
Limit of stability, %	61 ± 7	76 ± 7	60 ± 7	68 ± 7	0.01
SF-36, points	41 ± 7	51 ± 8	39 ± 8	47 ± 7	0.01
WOMAC, points	66 ± 8	46 ± 11	65 ± 9	52 ± 10	0.06
KSS, points	56 ± 9	81 ± 8	55 ± 9	76 ± 8	0.07

Note: the knee extension index is represented as the value of the external angle; full extension is 180°. The increase in the indicator reflects a decrease in the extension deficit. *p* — the level of statistical significance of intergroup differences; EMG — electromyography.

the spacer, and from insufficient sensitivity of instruments in the early postoperative period.

DISCUSSION

The data obtained reflect the features of the functional recovery dynamics observed in patients after the first stage of two-stage knee revision arthroplasty. Both groups exhibited extending motion amplitudes and increasing muscle activity indicators, which aligns with the recovery expectations. However, the differences between the groups reveal that the magnitude of these changes is not similar. An increase in the amplitude of flexion and extension may be associated with both a gradual reduction of postoperative pain and adaptation of periarticular tissues to new biomechanical conditions [13]. The observed post-rehabilitation intergroup differences suggest that the selection of patterns of motor activity in this context may affect the recovered range of motion [14].

The interpretation of the results of this study should factor in the specifics of the period after the first stage of two-stage revision arthroplasty. Unlike patients after primary arthroplasty, those with an articulating temporary spacer naturally have limited functional restoration. This stems from the need for gentle exercise, preservation of postoperative soft tissue integrity, and gradual increases in range of motion. In this regard, it seems natural to expect an earlier response in the objective motor parameters (range of motion, EMG, and temporal-spatial gait indicators), while WOMAC and KSS clinical scales may be less sensitive during the early post-revision period.

Changes in electromyography parameters indicate a gradual restoration of neuromuscular activation. The increase in the amplitude of quadriceps biopotentials in both groups reflects reinnervation and normalization of muscle tone after surgery [15–17]. Statistical differences between groups after treatment suggest that exercise type and motor activity nature influence muscle group recruitment patterns, which in turn affect motor response development. Post-rehabilitation intergroup differences allow considering different rehabilitation models as a factor influencing the rate of change in kinematic characteristics [18–19].

Compared to gait and ROM parameters, the dynamics of stability indicators was less drastic. This may be explained by the compensatory action of intact components that help maintain posture after the first stage of revision arthroplasty [20].

The changes registered with the quality-of-life scales were also unidirectional; they revealed gradual improvement of the functional state. The differences in final SF-36 scores between groups reflect how motor activity influences patients' subjective perceptions of daily function. At the same time, the lack of statistically significant differences in WOMAC and KSS scores may stem from the limited workload imposed by the temporary spacer, as well as these scales' greater sensitivity in later rehabilitation stages [21].

The dynamics of temporal and spatial characteristics of gait were rather similar. Growing step length, movement speed, and a shortening load phase reflect the gradual restoration of basic parameters in the cyclic motor stereotype [22].

With an articulating spacer, such parameters are closely related to the specifics of load distribution and the degree of participation of the operated limb in the transfer of body weight.

Individual parameters (general stability, stability limit) were different between the groups, while local indicators (amplitude of fluctuations, deviation of the pressure center) remained comparable. This aligns with the faster changes in integral stability indicators during the early post-surgery period, while precision and local stabilization parameters take longer to recover [23].

A comprehensive interpretation of the results suggests that motor parameters — ROM, EMG, gait characteristics — are more susceptible to changes in the early recovery period. Postural stability and clinical scales exhibit different dynamics, reflecting the heterogeneity of recovery processes with an articulating spacer and the need for a differentiated approach to assessing rehabilitation effectiveness.

The results are comparable with data from previous studies, confirming the importance of a multi-level restorative approach in revision arthroplasty. Comparison with literature data shows that the observed range of motion (71–78° of flexion) corresponds to values expected in patients with an articulating temporal spacer during the early postoperative period [7]. They are slightly lower than after implantation of the final endoprosthesis (usually 90–110°), due to the design of the temporary implant and the need to limit loading during the interim period.

The present study has a number of limitations. Firstly, it was conducted in a single clinical center, which may limit the generalizability of the results. Secondly, the follow-up period was 21 days of inpatient rehabilitation; long-term outcomes, including after the second stage of revision arthroplasty, were not evaluated. Third, the relatively small sample size (87 patients) could be insufficient to identify intergroup differences on the WOMAC and KSS clinical scales, which are typically less sensitive in the early stages. Despite the blindness in assessing the primary outcomes, complete blindness of patients and researchers regarding the type of rehabilitation program was not possible due to the specifics of the intervention.

CONCLUSIONS

We conducted a prospective randomized controlled trial comparing a comprehensive rehabilitation program incorporating interactive biofeedback technology (Walker View) with a standard program in patients undergoing the interval phase between the two stages of revision knee arthroplasty for chronic periprosthetic joint infection. After the three-week interstage rehabilitation period, the treatment group showed significantly greater range of motion, neuromuscular activity, temporal-spatial gait characteristics, and overall postural stability indicators than the control group. Local stabilometry parameters and the WOMAC and KSS scores were not significantly different between groups. The data reveal distinct recovery dynamics depending on the rehabilitation model used, highlighting the need for a differentiated approach to assessing functional state with a temporary spacer. Further research could focus on assessing long-term outcomes after the second stage of surgery, evaluating how rehabilitation models affect complication rates, and developing criteria for readiness for final replacement.

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