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Analysis of the quality of rehabilitation of patients with patellar tendinopathy using a robotic orthosis

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Objective. To analyze the results of treatment using a robotic orthosis during the rehabilitation of patients following arthroscopy who developed pain in the anterior compartment of the knee joint (KJ), using clinical and instrumental assessments of their condition. Methods. We reviewed the medical records of 120 patients with anterior knee pain syndrome (46 women aged (28.6 ± 7) years and 74 men aged (38.2 ± 8) years). Patients underwent rehabilitation in a robotic orthosis with various body weight support settings ranging from 65% to 10%. A multivariate analysis of clinical indicators was performed, including pain levels on the Visual Analog Scale (VAS) and the Anterior Knee Pain Scale (AKPS). Joint functional characteristics were assessed using the Knee Society Score (KSS). Results. The functional status of 60 patients was analyzed. Six weeks after surgery, the mean VAS score was 3.8 ± 0.3 in group 1 and 1.8 ± 0.4 in group 2; the difference 2.00, t ≈ 30.99, p < 0.001; for KSS (part 1) in group 1 — 68 ± 6.5; in group 2 — 83 ± 2.3; difference −15.00, t ≈ −16.85, p < 0.001; for KSS (part 2), the means were 72 ± 4.8 versus 80 ± 3.2; difference –8.00, t ≈ −10.74, p <0.001, indicating better function in group 2. The AKPS score was 64 ± 5.8 in group 1 and 76 ± 3.8 in group 2; difference −12.00, t ≈ −13.40, p < 0.001. After 3 months, the VAS score in group 1 was 2.2 ± 0.6, and in group 2 — 1.2 ± 0.4; difference 1.00, t ≈ 10.74, p < 0.001; for KSS (part 1) 78 ± 4.7 vs. 90 ± 2.2; difference −12.00, t ≈ −17.92, p < 0.001; for KSS (part 2) — 80 ± 3.8 vs. 90 ± 1.8; difference −10.00, t ≈ −18.42, p < 0.001; AKPS after 3 months was 76 ± 1.6 in group 1 and 89 ± 2.0 in group 2; difference −13.00, t ≈ −39.34, p < 0.001. Conclusions. All confidence intervals for the differences do not include 0, so the differences are statistically significant; the effect sizes are large, indicating a clinically important advantage of using a robotic orthosis for pain reduction and improvement of upper limb function.

Мета. Проаналізувати результати лікування зі застосуванням роботичного ортезу під час реабілітації пацієнтів після артроскопії, у яких розвинувся біль у передньому відділі колінного суглоба (КС) за допомогою клінічного й інструментального оцінювання його стану. Методи. Вивчено історії хвороб 120 осіб із синдромом переднього болю в КС (46 жінок віком (28,6 ± 7) років і 74 чоловіків (38,2 ± 8) років). Пацієнтам проводилась реабілітація в роботизованому ортезі з різними налаштуваннями підтримки маси тіла від 65 до 10 %. Виконано багатофакторний аналіз клінічних показників, включаючи рівень болю за візуальною аналоговою шкалою (ВАШ) та Anterior Knee Pain Scale (AKPS). Вивчено функціональні характеристики суглоба за Knee Society Score (KSS). Результати. Проаналізовано функції пацієнтів із 60 осіб. Через 6 тижнів після операції середній ВАШ складав у групі 1 — 3,8 ± 0,3; у 2 — 1,8 ± 0,4; різниця 2,00, t ≈ 30,99, p < 0,001; за KSS (част. 1) у групі 1 — 68 ± 6,5; у 2 — 83 ± 2,3; різниця −15,00, t ≈ −16,85, p < 0,001; за KSS (част. 2) середні становили 72 ± 4,8 проти 80 ± 3,2; різниця –8,00, t ≈ −10,74, p < 0,001, що свідчить про кращу функцію у групі 2. Показник AKPS був 64 ± 5,8 у групі 1 і 76 ± 3,8 у 2; різниця −12,00, t ≈ −13,40, p < 0,001. Через 3 міс. ВАШ у групі 1 становив 2,2 ± 0,6, у 2 — 1,2 ± 0,4; різниця 1,00, t ≈ 10,74, p < 0,001; за KSS (част. 1) 78 ± 4,7 проти 90 ± 2,2; різниця −12,00, t ≈ −17,92, p < 0,001; за KSS (част. 2) — 80 ± 3,8 проти 90 ± 1,8; різниця −10,00, t ≈ −18,42, p < 0,001; AKPS через 3 міс. становив 76 ± 1,6 у групі 1 і 89 ± 2,0 у 2; різниця −13,00, t ≈ −39,34, p < 0,001. Висновки. Усі довірчі інтервали для різниць не включають 0, отже відмінності є статистично значущими; величини ефекту великі, що свідчить про клінічно важливу перевагу застосування роботичного ортезу для зниження болю та покращення функції КС. Ключові слова. Артроскопія колінного суглоба; реабілітація; роботизовані ортези; синдром «переднього болю» колінного суглоба; тендинопатія влаяної зв'язки наколінка; нейропластичність.

Key words. Knee arthroscopy; rehabilitation; robotic orthoses; Lokomat Pro; anterior knee pain syndrome; neuroplasticity

Introduction

Patellar tendinopathy is a common condition after arthroscopic procedures on the knee joint (KJ). It is associated with pain, functional limitations, and a reduction in the quality of life of patients [3]. Rehabilitation after knee arthroscopy is generally aimed at restoring mobility, muscle strength, and normal biomechanics. Its programs include controlled development of the range of motion, gradual load increase on the quadriceps, proprioceptive exercises, and work on gait and functional tasks [1, 2]. The goal is to reduce pain and swelling, restore muscle strength symmetry and coordination, as well as prevent contractures and chronic movement disorders. However, traditional rehabilitation approaches, which are based on relative rest and load management, are often lengthy and do not always ensure optimal recovery [4]. In patients diagnosed with patellar tendinopathy during the postoperative period, rehabilitation becomes more complicated and often yields unsatisfactory results. Pain during loading, a reduced range of motion, and quadriceps weakness complicate the execution of standard rehabilitation exercises, slowing progress and potentially leading to compensatory movement disorders [5–9]. These patients more often require modifications to protocols, namely slower load increments, targeted eccentric exercises, additional physiotherapeutic methods (ultrasound, laser, electrical muscle stimulation), and longer periods of activity restriction. As a result, recovery of function and return to preoperative activity levels may take considerably more time, and the risk of recurrence or chronic pain remains higher.

Currently, there is a demand for innovative methods that can accelerate and improve rehabilitation outcomes, especially for younger individuals seeking a swift return to physical activity [10]. Therefore, the use of advanced technologies, such as robotic rehabilitation, is becoming increasingly relevant in the context of optimizing recovery after arthroscopic interventions [10]. At the same time, in many cases, rehabilitation protocols are insufficiently detailed, complicating their application and objective assessment of results.

In this study, we compare the effectiveness of rehabilitation for individuals with patellar tendinopathy after knee arthroscopy using a robotic orthosis with traditional methods, focusing on objective recovery indicators and functional outcomes.

Purpose: To analyze the results of rehabilitation treatment using a robotic orthosis for patients who developed anterior knee pain after arthroscopy, through clinical and instrumental assessment of their condition, and to lay the foundation for the development of more effective and individualized rehabilitation protocols for patients with patellar tendinopathy.

Materials and Methods

We conducted a prospective study that included the following stages: patient examination before surgery, 14 days, 6 weeks, and 3 months after the operation. The study was conducted at the clinical base of the Department of Joint Diseases in Adults of the State Institution “Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine” (Kyiv) and approved by the local ethics committee (protocol No. 1 dated 07.01.2026) in accordance with the ICH GCP amendment, the Helsinki Declaration of Human Rights and Biomedicine, and current Ukrainian legislation. All participating patients were informed about the study plan and conditions and provided written and verbal consent.

Inclusion Criteria: Age between 18 and 50 years, BMI < 30, confirmed meniscus injury (Stoller 3A-3B) on MRI, no other intra-articular structural injuries, history of arthroscopic intervention on KJ (resection of the affected part of the meniscus), development of pain in the anterior KJ area in the patellar tendon region, patellar tendinopathy confirmed by clinical and instrumental data within 14 days post-surgery.

Patients who had concomitant injuries of KJ structures (chondromalacia, injuries of the anterior/posterior cruciate ligaments, collateral ligaments, free bodies in the joint cavity) or joint dysplasia, high patella (patella alta), and degenerative changes in its ligaments on MRI were excluded.

Using simple randomization and gradual inclusion, 120 individuals with patellar tendinopathy (46 women, aged (28.6 ± 7) years, and 74 men (38.2 ± 8) years) were selected. The patients were divided into two groups:

1. Group 1 — Classical rehabilitation;
2. Group 2 — Rehabilitation using a robotic orthosis.

In Group 2, rehabilitation treatment started from the 15th day post-surgery. It consisted of 15 sessions and subsequent observation for up to 3 months after knee arthroscopy. A final examination was conducted and the patient's condition was evaluated using scales with and without the robotic orthosis [10-12].

The intervention performed on patients included arthroscopic resection of the damaged part of the medial meniscus (Stoller 3A-3B damage based on MRI results).

General principles of classical rehabilitation for group 1 [16] considering tendinopathy:

– Avoidance of early peak and rapid eccentric loads;

– Start with isometrics, gradually introduce eccentric exercises according to tolerance.

Phase 0 (0–3 days):

– Measures: ice compresses for 10–15 minutes several times a day, leg elevation, compression / elastic bandage, light movements in the ankle joint, isometric quadriceps contractions (10–20 seconds hold, 8–10 times/hour);

– Load: partial weight-bearing / walking with crutches as instructed by the surgeon.

Phase 1 (3–14 days):

– ROM: passive and active-passive exercises within the pain limit; avoid deep flexion if painful;

– Muscle work: isometric quadriceps, isometric adductors, light isometric exercises for the calf; 3–5 sets of 8–12 reps (holding for 10–20 seconds);

– Balance/proprioception: standing on both legs, gradual transition to single leg stance if possible;

– Tendinopathy prevention: isometric exercises to reduce pain (5–6 times a day, 30–45 seconds).

Phase 2 (2–6 weeks):

– ROM: full, slow ROM to tolerated limits; joint mobilization;

– Strength: isolation exercises (direct integration of quadriceps): partial squats to 45°, leg extension in sitting position (without pain), gradual load exercises; 3 sets of 10–15 reps;

– Tendinopathy: initial controlled eccentric exercises (e.g., slow eccentric squats/single-leg lowering or on a sloped plane) starting with low intensity twice a day, progression gradually; during exacerbations — return to isometrics;

– Cardio: low-resistance cycling, walking — gradually increasing duration;

– Frequency: 3–4 physiotherapy sessions per week plus home program.

Group 2 rehabilitation involved a robotic orthosis, with patients moving in it with various body weight support settings, from 65 % to 10 %. The duration of each session was 1 to 1.5 hours, 3–4 times per week.

Main rehabilitation stages using robotic orthosis:

1. Assessment of the patient's physical parameters — determining the physical condition and capabilities before starting the training;

2. Patient adaptation. Before the first session, patients were introduced to the device, placed in gloves, pants, or straps for smooth movement;

3. Individual device adjustment according to the patient’s medical condition:

– Body weight support (BWS) level;

– Walking speed;

– Range of motion;

– Load according to the patient's specific needs.

4. Conducting the training:

– Automatic walking: Under the control of the robotic orthosis, the patient begins to walk with a natural or adapted gait;

– Symmetrical or asymmetrical program depending on the condition (training of both or one lower limb);

– Speed and load: The initial walking speed was set by the patient at a comfortable pace, usually 1.5 km/h, gradually increasing to 3.0 km/h. Load on the lower limbs was modeled by BWS, ranging dynamically from 100 % (full body weight support) to 10–20 %;

– Mobilization: Using the movement system of the device and the active participation of the patient, which contributes to the recovery of muscle tone, coordination, and motor skills.

5. Monitoring and adjustment:

– During the training session, activity, movement coordination, load, and walking speed of the patient are monitored.

6. Conclusion and results analysis:

– At the end of the session, progress is assessed, and parameters are recorded (session duration, distance, range of motion (L-ROM) in the lower limb, muscle strength (L-Force) in the lower limbs, level of stiffness or resistance to movement (L-Stiff)).

– Based on the results and the patient’s condition, further rehabilitation strategies are planned.

Initial sessions are performed in a passive or moderately assisted walking mode with moderate weight support (BWS 30–50 %), low speed (approximately 0.3–0.6 m/s), and limited L-ROM to avoid deep flexion during early stages; the duration of active walking at the beginning is approximately 10–20 minutes, with the overall session lasting 30–45 minutes.

Progression occurs gradually: reduction in weight support to 10–30 %, increase in walking duration and speed, decrease in BWS, and extension of L-ROM as tolerance improves and pain decreases; L-Force is monitored to prevent peak loads during active extension in case of muscle weakness.

Among the subjective pain assessment methods used in the study, the Visual Analog Scale (VAS) [20] was used, allowing patients to self-assess pain level from 0 (no pain) to 10 (maximum pain), as well as the Knee Society Score (KSS) and Kujala/Anterior Knee Pain Score (AKPS).

– KSS Scale includes the assessment of pain and function in the knee joint. The knee assessment allocates up to 100 points for indicators of range of motion (1 point for 5°, maximum 125°), stability (medial/lateral (15 points) and anterior/posterior (10 points)), and pain (50 points), subtracting points for lag in extension, presence of flexion contracture, and deformity (if the axis of the lower limb is < 5° or > 10° on radiological examination). The maximum score of 100 points indicates a well-aligned knee joint with a range of motion of 125°, almost complete absence of anterior-posterior or medial-lateral instability, and no pain. The functional score includes the walking distance (50 points) and stair climbing (50 points), taking into account the use of walking aids. A patient who can walk without restrictions and has no problems with stair climbing receives the maximum score in the Function Score subscale — 100.

– Anterior Knee Pain Scale (AKPS, Kujala Scale) is a 13-item self-reported questionnaire that evaluates subjective responses to specific activities and symptoms known to correlate with anterior knee pain syndrome. AKPS is scored from 0 to 100, with 100 being the highest possible score. Lower scores reflect greater pain and disability.

Pain in the anterior compartment of the KJ frequently leads to dysfunctions that cause difficulties during activities that load the KJ (running, squats, and stair climbing), and the AKPS assesses these types of activities. This index has high reliability for retesting and is a valuable tool for evaluating the patient's condition over time [13, 14]. It has been found that the four formats of the AKPS scale have acceptable standard measurement errors (from 0.82 to 3.00), high internal consistency (αcoef = 0.83–0.91), equivalency between the short and long forms (r = 0.98), and moderate to high criterion validity, as determined by the physician's diagnosis: 0.92 (13-item form), 0.90 (long form), and 0.90 (short form) (6-item form). The AKPS questionnaire is an effective tool for epidemiological screening with valid and reliable assessment of anterior knee pain [15].

Dynamic analysis was used to assess changes in pain levels, joint functionality, and muscle strength throughout the observation period (pre-surgery examination, 14 days, 6 weeks, and 3 months after surgery).

Muscle strength in both patient groups was studied using the robotic orthosis at the indicated time intervals.

Clinical analysis is the most appropriate tool and standard criterion for diagnosing tendinopathy of the patellar tendon.

The first clinical task is to determine if the tendon is the source of the patient's symptoms. The most common finding in manual examination is tenderness at a focal point [21, 22]. While this may be observed along the entire length of the patellar tendon, it most commonly occurs at the lower portion and the distal attachment to the tibial tuberosity. Pain intensifies during loading on the knee extensors.

Functional tests for patients with patellar tendinopathy include jumping and landing after jumping [23].

The main differential diagnosis of patellar tendinopathy is patellofemoral pain syndrome, which is defined as a form of nonspecific, nonstructural knee pain around or behind the patella. This pain syndrome is characterized by crepitus or "grinding" under the patella during knee flexion and tenderness along the facets [24].

Statistical analysis was conducted using standard approaches. The analysis used averaged values of patient indicators. Quantitative data (mean (M) and standard deviation (SD)) in the study groups were compared both within groups and over the observation period.

Relative reduction in symptom severity (% reduction in pain intensity and functional improvement) was calculated. A comparative analysis of the groups was performed using the Welch-test.

Results

Main demographic and diagnostic characteristics of participants: The average age was (28.6 ± 7) years for women (18 %) and (38.2 ± 8) years for men (82 %). The average body mass index (BMI) of the subjects was (28.6 ± 6.0) kg/m². The most common type of procedure performed on the patients was arthroscopic resection of the damaged part of the medial meniscus (74 %) and debridement of fibrous growths causing impingement with joint structures (26 %). Table 1 presents data on the dynamics of pain level changes on pain and functional scales over the observation period.

Comparative analysis of the effectiveness of rehabilitation measures in both groups was conducted after the rehabilitation course (15 sessions), corresponding to the 6-week and 3-month post-intervention periods.

In the study, which included 60 patients in each group, the rehabilitation used in Group 2 showed consistently better clinical outcomes compared to Group 1 at both the early (6 weeks) and mid-term

(3 months) stages of recovery. By the 6th week, patients in Group 2 experienced significantly less pain: their average VAS was about half that of Group 1 (1.8 vs 3.8; 95 % CI 1.87–2.13, $p < 0.001$). Functional scales also showed noticeable improvement: for KSS (parts 1 and 2) and AKPS, the difference between groups ranged from 8 to 15 points in favor of Group 2, which was both statistically significant and clinically relevant.

In 3 months, Group 2 continued to show better results and even increased functional indicators: the VAS remained lower (1.2 vs 2.2; 95% CI 0.82–1.19, $p < 0.001$), and the KSS and AKPS showed significant improvement in knee joint function in Group 2 (differences ranging from 10 to 13 points, all 95 % CI excluding 0, $p < 0.001$). These data indicate that treatment in Group 2 not only reduces pain symptoms more quickly but also provides better recovery of knee joint function, which is important for returning to everyday activities and professional duties.

The overall effect sizes and confidence intervals confirm the stability and reliability of the observed differences: the intervals for mean differences are narrow and exclude 0, meaning the estimates are precise, and the large Cohen's d values suggest a clinically meaningful effect. From a practical perspective, this means that the approach used in Group 2 contributes to a faster reduction in pain, improved walking ability, and better functional outcomes in the postoperative period.

Study Limitations. The study has several limitations that should be considered when interpreting the results. In particular, the analysis did not include patients with cartilage damage, capsular-ligamentous damage of the knee joint, osteoarthritis stages II–IV according to Kellgren-Lawrence, or knee joint dysplasia, which limits the ability to generalize the results to severe forms of the disease. The selected age range (18–50 years) analyzed also does not allow definitive conclusions about the effectiveness of the therapy in older patients. It is worth noting that the study describes a relatively short follow-up period, which did not exceed 3 months. This does not allow for an objective evaluation of the long-term effectiveness and stability of functional results in the distant period. Therefore, large-scale prospective studies with standardized treatment approaches, clear evaluation criteria, and long-term follow-up periods are necessary.

Discussion

The obtained results allowed for a comprehensive analysis of the impact of robotic rehabilitation on functional recovery, pain levels, and quali ty of life of patients after knee arthroscopy. Our study revealed statistically significant improvements in the recovery of range of motion and functional indicators of the knee joint in Group 2, compared to the traditional rehabilitation group.

Specifically, as early as 4 weeks after the start of the rehabilitation course, patients in Group 2 showed significant improvement in physical functioning, pain reduction, and by 3 months, the physical functioning level in this group reached (90 ± 1.8) points, surpassing the traditional rehabilitation group with (80 ± 3.8), indicating near-complete recovery to the preoperative state. Statistically significant differences and large effect sizes that exclude 0 in the 95 % confidence intervals indicate a clinically important advantage of using robotic orthosis

Table 1

Dynamics of changes in the studied indicators before and after classical rehabilitation

Indicator	VAS	KSS		AKPS
		part 1	part 2	
Group 1: – before intervention;	6.9 ± 1.0	74 ± 5.2	62 ± 4.4	68 ± 4.3
after intervention: – 2 weeks; – 6 weeks; – 3 months	 5.2 ± 1.2 3.8 ± 0.3 2.2 ± 0.6	 38 ± 8.6 68 ± 6.5 78 ± 4.7	 32 ± 7.2 72 ± 4.8 80 ± 3.8	 28 ± 8.8 64 ± 5.8 76 ± 1.6
Group 2: – before intervention;	7.0 ± 1.2	78 ± 6.2	60 ± 5.3	68 ± 4.3
after intervention: – 2 weeks; – 6 weeks; – 3 months	 5.6 ± 1.0 1.8 ± 0.4 1.2 ± 0.4	 40 ± 7.4 83 ± 2.3 90 ± 2.2	 30 ± 6.8 80 ± 3.2 90 ± 1.8	 32 ± 8.4 76 ± 3.8 89 ± 2.0

Notes: VAS— Visual Analog Scale; KSS — Knee Society Score; AKPS — Anterior knee pain score.

Table 3

Comparison of changes in the studied indicators after rehabilitation in both groups

Indicators	Group 1	Group 2	CI	Welch	P
6 weeks after intervention:					
– VAS;	3.8 ± 0.3	1.8 ± 0.4	1.872; 2.128	t ≈ 31.0	p < 0.001
– KSS Part 1;	68.0 ± 6.5	83.0 ± 2.3	−16.770; −13.230	t ≈ −16.8	p < 0.001
– KSS Part 2;	72.0 ± 4.8	80.0 ± 3.2	−9.480; −6.520	t ≈ −10.7	p < 0.001
– AKPS	64.0 ± 5.8	76.0 ± 3.8	−13.780; −10.220	t ≈ −13.4	p < 0.001
3 months after intervention:					
– VAS;	2.2 ± 0.6	1.2 ± 0.4	0.815; 1.185	t ≈ 10.74	p < 0.001
– KSS Part 1;	78.0 ± 4.7	90.0 ± 2.2	−13.330; −10.670	t ≈ −17.92	p < 0.001
– KSS Part 2;	80.0 ± 3.8	90.0 ± 1.8	−11.080; −8.920	t ≈ −18.42	p < 0.001
– AKPS	76.0 ± 1.6	89.0 ± 2.0	−13.655; −12.345	t ≈ −39.30	p < 0.001

in pain reduction and improvement of joint function. This aligns with the results of previous studies, such as by S. Sancenzi et al., confirming the effectiveness of robotic systems in accelerating lower extremity function recovery after injuries and surgical interventions [25].

We demonstrated the high potential of using robotic orthosis in the rehabilitation process of patients with anterior knee pain syndrome after arthroscopy. The main outcomes are significant improvement in functional indicators, manifested by increased values in KSS and AKPS, which correspond to rapid recovery of movement functions and pain reduction.

The KSS values, which reflect the overall functional status of the knee joint, decreased in the first 2 weeks after the procedure, which suggests acute symptoms and limited motor activity during the acute period. However, by 6 weeks, the indicators had increased to levels almost comparable to the initial values (83 ± 2.3 and 80 ± 3.2, respectively) and stabilized above 90 by 3 months, corresponding to full functional recovery. Similarly, the AKPS scale values indicate significant improvement in both subjective and objective aspects of the knee joint condition.

These results align with numerous studies. T. M. Rossi et al., in their systematic review, noted that robotic rehabilitation contributes to faster functional recovery of the knee joint in patients with various pathologies [26]. A. C. Brito et al., in their meta-analysis, emphasized that the use of robotic systems positively affects joint range of motion, muscle strength, and the ability to move independently [27]. Additionally, S. Sancenzi et al. in their pilot study found that robotic devices help reduce pain and accelerate recovery after knee surgeries [28].

Furthermore, contemporary rehabilitation practice has concluded that robotic systems have advantages in stimulating neuromuscular pathways and creating conditions for more natural movements, which positively influence neuromuscular plasticity processes and contribute to more effective reintegration after injuries and surgeries. This confirms the potential of robotic devices not only for functional recovery but also for preventing complications due to muscle hypotrophy and weakness, which is especially important for patients with injuries or in the postoperative period, where early and adequate loading is a critical factor for preventing complications and ensuring faster recovery.

Although conservative methods for treating patellar tendinopathy, such as progressive loading of tendons and eccentric exercises, demonstrate effectiveness [26, 31], our study points to the potential benefits of integrating robotic systems. It was found that robotic walking training allows the lower limbs to perform alternative and circular movements (effectively correcting their movement after ACL reconstruction and improving walking ability and muscle strength) [32]. Systems that provide resistance during walking can have significant biomechanical effects (which transfer to normal walking), making them a useful approach for improving locomotor functions [34].

In the context of robotic rehabilitation effectiveness, the research by C. Klampt et al. is of great importance, as it demonstrated that robotic walking training can significantly improve functional abilities in patients with various knee joint conditions, including osteoarthritis [29]. The authors emphasized that automated systems provide precise load adjustment and movement repetition, which promotes faster functional recovery, pain reduction, and increased patient motivation for active rehabilitation. Considering our results, which show significant improvements in functional status just a few weeks after starting rehabilitation, we can conclude that the use of robotic systems can be an effective tool for accelerating the recovery process and improving the quality of life for patients with various knee joint conditions. All of this emphasizes the need for widespread implementation of robotic methodologies into modern rehabilitation protocols, especially when traditional approaches are insufficient or require a long time to achieve desired results.

Moreover, in the systematic review by S. Hesse et al., although the focus was on the use of robotic walking during rehabilitation after stroke, the findings are highly relevant for individuals with knee joint injuries. Their findings underscore that robotic therapy not only aids in the restoration of walking skills but also improves muscle strength, stability, and coordination of lower limb movements [30]. These data demonstrate that such systems have universal potential for recovering damaged lower limb and knee structures across a wide range of neurological and orthopedic diseases. Our study shows that significant improvements in the functional state of the knee joint in patients with anterior knee pain syndrome after just a few weeks are facilitated by the use of robotic orthoses. This supports the idea that the neuromuscular plasticity mechanisms and improvements in motor skills described by S. Hesse et al. are relevant for orthopedic abnormalities as well.

It is also worth noting that Verheyden et al. have demonstrated that the use of robotic systems reduces fear of physical activity and improves emotional well-being, which plays an important role in boosting motivation and the long-term success of rehabilitation measures [33–35].

Thus, the use of robotic systems in rehabilitation appears to be promising, especially in combination with traditional approaches, allowing for improved speed and quality of patient recovery.

Conclusions

The use of a robotic orthosis in the rehabilitation process of patients with anterior knee pain syndrome after arthroscopy resulted in better outcomes. Compared to Group 1, Group 2 showed a significant relative improvement across all indicators: at the 6^{th} week, the pain intensity on the VAS decreased by almost 52.6% (3.8 → 1.8), KSS part 1 increased by approximately 22.1% (68 → 83), KSS part 2 by approximately 11.1% (72 → 80), and AKPS by approximately 18.8% (64 → 76). After 3 months, significant improvement was maintained: VAS decreased by approximately 45.5% (2.2 → 1.2), KSS part 1 increased by approximately 15.4% (78 → 90), KSS part 2 by approximately 12.5% (80 → 90), and AKPS by approximately 17.1% (76 → 89).

Compared to traditional rehabilitation, the use of such a system provides stable and high results, which are consistent with modern developments in neuromuscular plasticity and the technological capabilities of robotic therapy.

However, certain limitations should be noted, namely the small sample size and the lack of long-term follow-up. A crucial factor is also the individual characteristics of the patients, which may influence the speed and degree of recovery. Additionally, the application of robotics requires significant resources, which may limit its use.

Overall, the results confirm the promise of robotic systems in rehabilitation practice to improve the speed and quality of recovery, as well as to reduce the risk of complications and improve the quality of life for individuals with orthopedic and traumatic knee joint injuries.

Conflict of Interest. The authors declare no conflict of interest.

Future Research Prospects. Further studies should focus on optimizing protocols and evaluating the long-term effectiveness of such technologies, as well as analyzing the broader use of robotic techniques within comprehensive rehabilitation and recovery of lower limb functions after orthopedic and traumatic injuries.

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ANALYSIS OF THE QUALITY OF REHABILITATION OF PATIENTS WITH PATELLAR TENDINOPATHY USING A ROBOTIC ORTHOSIS

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