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Article

Tele-Rehabilitation Versus Exercise Booklet for Knee Osteoarthritis: A Randomized Trial on Patient-Reported and Clinically Meaningful Outcomes

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Abstract

Background: Knee osteoarthritis (OA) is a cause of pain and functional limitation. Exercise-based rehabilitation is recommended, yet access to supervised physiotherapy is often limited. This randomized controlled trial compared telerehabilitation with a booklet-based home exercise program and explored explanatory variables of Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain, stiffness, and physical function. **Methods:** In this single-centre randomized controlled trial, 118 patients with confirmed knee OA (Kellgren–Lawrence grades 1–3) were randomly allocated to a telerehabilitation group (TG; n = 57) or a booklet-based group (BBG; n = 61). Both groups performed the same exercise program three times per week for 12 weeks and differed only in delivery mode and supervision. The primary outcome was WOMAC physical function. Secondary outcomes included WOMAC pain and stiffness, pain intensity (Numerical Rating Scale - NRS), and knee range of motion. Multiple linear regression analyses identified explanatory variables of WOMAC domains. **Results:** Both interventions overall improved pain and WOMAC outcomes. Telerehabilitation was associated with greater and clinically meaningful improvement in WOMAC physical function compared with the booklet program. Across both groups, baseline pain intensity showed the strongest association with WOMAC pain, stiffness, and physical function. In the BBG, functional outcomes were pain-driven, whereas in the TG, physical function was less related to pain intensity and more closely associated with body composition. Changes in knee range of motion were not consistently associated with patient-reported outcomes. **Conclusions:** Both telerehabilitation and booklet-based exercise improve pain and knee-related symptoms in knee OA; however, telerehabilitation provides additional meaningful functional benefits, supporting it as an effective and scalable rehabilitation approach.

Keywords: knee osteoarthritis; telerehabilitation; home exercise; WOMAC; physical function; pain

1. Introduction

Knee osteoarthritis (OA) is one of the most common musculoskeletal disorders worldwide [1–3] and represents a chronic, progressive, and currently incurable condition, affecting approximately 23% of adults over 40 years of age [4]. The disease is characterised by persistent pain, stiffness, reduced joint mobility, and functional limitations, which impair daily activities and quality of life [5]. As knee OA progresses, symptoms often become increasingly debilitating, leading to reduced physical activity and loss of independence [6]. Importantly, maintaining physical activity and functional capacity is considered a key protective factor in the management of knee OA [7]. OA affects more than 7% of the population, with the knee being the most involved joint [8]. Knee OA is a leading cause of long-term disability and represents a growing burden for healthcare systems, particularly in

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aging populations. This burden is expected to increase due to population aging, rising life expectancy, and increasing prevalence of overweight and obesity, while effective disease-modifying treatments remain unavailable [9–11]. Given that self-management and exercise therapy are core components of non-surgical management of knee OA [12], interventions that effectively reduce pain and improve physical function are of key clinical importance. Telerehabilitation has therefore emerged as a promising alternative to conventional in-person rehabilitation, enabling remote delivery of structured exercise programs with professional support [13]. When appropriate technological and clinical conditions are met, telerehabilitation may achieve outcomes comparable to traditional rehabilitation approaches [14]. However, evidence regarding its effectiveness in knee OA remains limited, and standardized protocols and clear clinical guidance are still lacking [15].

Access to timely, exercise-based rehabilitation remains a major challenge in routine care, due to workforce constraints and growing demand. The World Health Organization has repeatedly highlighted substantial shortages and inequitable distribution of rehabilitation professionals, which limits service capacity and delays delivery of evidence-based interventions [16,17]. In the WHO European Region, rehabilitation workforce gaps persist and are particularly pronounced in several countries, further contributing to restricted access to physiotherapy services [18]. In Slovenia, limited physiotherapy workforce capacity has been linked to prolonged waiting times, making scalable, home-based rehabilitation models clinically and strategically relevant [19,20]. Against this background, telerehabilitation may help reduce access barriers by enabling earlier initiation of supervised exercise therapy. At the same time, it preserves key elements of physiotherapist support.

Previous research on digitally delivered and telerehabilitation-based exercise pro-grams for knee OA has emphasized patient-reported outcomes, particularly pain intensity and self-perceived functional limitations assessed using instruments such as the NRS/Visual Analogue Scale (VAS) and WOMAC. For example, studies by Gohir et al. [21] and Nelligan et al. [22] demonstrated clinically meaningful improvements in pain and functional status following remote exercise interventions; however, objective measures of knee joint mobility were not systematically included or were reported inconsistently. Azma et al. [23] demonstrated that telerehabilitation yields functional outcomes comparable to office-based physiotherapy in patients with knee OA, as assessed by WOMAC. However, the absence of objective knee ROM measurements limits interpretation of whether functional improvements were accompanied by changes in joint mobility. In contrast, evidence from conventional rehabilitation trials suggests that knee ROM may play a significant role in the interaction between pain reduction and functional improvement. Alkhawajah and Alshami [2], for instance, reported significant improvements in knee ROM alongside reductions in pain and enhanced WOMAC scores following a structured therapeutic intervention, highlighting the close interrelationship between joint mobility, pain, and physical function in knee OA. The lack of consistent ROM assessment in telerehabilitation studies therefore represents an important gap in the current literature, limiting conclusions regarding the full biomechanical and functional impact of remotely delivered exercise programs.

Despite growing interest in telerehabilitation for knee OA, evidence remains limited regarding its effects on objectively measured joint mobility and its role in clinically meaningful functional improvement. Most existing trials rely on patient-reported outcomes, leaving the biomechanical and functional mechanisms insufficiently explored. The primary aim of this randomized controlled trial (RCT) was to com-pare the effects of telerehabilitation and a minimally supervised home exercise booklet on knee-related physical function in patients with knee OA. A secondary aim was to determine whether improvements in patient-reported outcomes were accompanied by objectively measured changes in knee joint range of motion (ROM).

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2. Materials and Methods

2.1. Study Setting and Participants

This study was conducted at the Artros Medical Centre in Ljubljana, Slovenia, a specialized orthopaedic outpatient facility providing secondary care for patients with musculoskeletal disorders, including knee OA. All data were collected exclusively in Slovenia.

Allocation concealment was ensured by an independent researcher using sealed opaque envelopes, who was not involved in recruitment, intervention delivery, or outcome assessment. Patients aged between 50 and 80 years who attended an orthopaedic consultation at the centre were screened for eligibility. Inclusion criteria were: (1) symptomatic knee OA diagnosed by an orthopaedic specialist, (2) radiographically confirmed knee OA graded 1–3 according to the Kellgren–Lawrence classification, (3) ability to perform the required physical assessments and exercise program, and (4) access to a computer and basic computer literacy. All patients underwent standard knee radiography as part of routine clinical care prior to enrolment.

Patients with severe OA (Kellgren–Lawrence grade 4), inflammatory joint disease, recent knee surgery, or conditions preventing safe participation in exercise were excluded.

2.2. Study Design and Randomization

The study was designed as a single-centre, parallel, RCT comparing a three-month telerehabilitation program with an unsupervised home exercise program supported by an exercise booklet. This trial was registered at ClinicalTrials.gov (NCT07137897; Unique Protocol IdL7-50184).

Following baseline clinical assessment, eligible participants were randomly allocated to either the telerehabilitation group (TG) or the booklet-based group (BBG). Allocation concealment was ensured by an independent researcher who was not involved in participant recruitment, intervention delivery, or outcome assessment.

Due to the nature of the intervention, participants and physiotherapists could not be blinded to group allocation. Outcome assessors were not involved in treatment delivery and were unaware of group allocation.

2.3. Intervention

Both groups followed the same standardized physiotherapy exercise program, differing only in the mode of delivery and level of professional supervision.

Exercise adherence is optimally assessed using complementary indicators, including the proportion of prescribed sessions completed, the percentage of participants achieving a predefined adherence threshold (e.g., ≥70%), and adherence patterns over time.

2.3.1. Exercise Program

The program included targeted strengthening exercises for the core and lower extremity muscles, mobility exercises for the hip, knee, and ankle joints, and balance and stabilization exercises. Each training session initially lasted 20–30 minutes.

Participants were instructed to perform the exercises three times per week over a three-month period, with a maximum interval of 72 hours between consecutive sessions to ensure training continuity and adherence to the prescribed load. Participants were allowed to choose the specific days of exercise according to their personal schedules. The full exercise protocol with progression details is available as Supplementary File S1.

2.3.2. Telerehabilitation Group

Participants allocated to TG received structured training in the use of the web-based exercise application prior to the start of the intervention. In addition to technical training, participants were

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provided with education on knee OA, symptom management, exercise principles, and the functioning of the tele-rehabilitation model.

During the intervention period, participants in the TG engaged in weekly scheduled individual consultations with a physiotherapist via secure video-conferencing platforms (Microsoft Teams). In addition to weekly scheduled video consultations, participants in TG had continuous access to asynchronous communication with the physiotherapist via email and an integrated in-app messaging system, ensuring timely support and individualized guidance throughout the intervention period. These sessions were used to:

- provide guidance on correct exercise execution,
- address individual difficulties and technical issues,
- support motivation and adherence,
- enable ongoing feedback and exercise progression when appropriate.

2.3.3. Booklet-Based Group

Participants in the BBG received written exercise instructions in the form of an exercise booklet and performed the same exercise program independently at home without regular professional supervision. Midway through the intervention period, participants in the BBG were contacted by the research team to obtain feedback on exercise adherence and address potential barriers to participation, without providing structured physiotherapeutic guidance.

2.4. Outcome Measures

All participants underwent a comprehensive orthopaedic examination at baseline, including confirmation of the diagnosis of knee OA and assessment of disease severity. Standard radiographic imaging of the knee joint was performed as part of routine clinical care, and OA severity was classified according to the Kellgren–Lawrence grading system (grades 1–3).

Knee joint ROM was assessed using standardized goniometric measurements of active knee flexion and extension and pain intensity was additionally assessed using an 11-point NRS. Knee-related symptoms and functional status were assessed using the WOMAC, a validated self-reported questionnaire comprising pain, stiffness, and physical function subscales. Higher WOMAC scores indicate greater symptom severity and functional limitation.

2.5. Follow-Up and Outcome Assessment

At the end of the three-month intervention period, all participants underwent a follow-up orthopaedic examination conducted at the same clinical site as the baseline assessment. All outcome measures collected at baseline were reassessed using identical procedures to ensure comparability over time, allowing evaluation of within-group changes and between-group differences following the intervention.

2.6. Primary and Secondary Endpoints

The primary endpoint of the study was change in knee-related physical function, assessed using the WOMAC physical function subscale. Secondary endpoints included changes in WOMAC pain and stiffness subscales, total WOMAC score, knee joint ROM (flexion and extension). Pain intensity assessed using the NRS was included as an additional explanatory outcome to support interpretation of WOMAC pain-related findings.

2.7. Statistical Analysis

Sample size estimation was performed using G*Power software (version 3.1) [24]. Analyses were conducted according to the intention-to-treat principle. The calculation was based on expected changes in knee-related physical function measured by the WOMAC, using effect size estimates derived from a previously published RCT investigating telephone-delivered exercise support in individuals with knee OA [25]. Assuming a two-tailed test, an alpha level of 0.05, statistical power (1–β) of 0.80, and an effect size of 0.288, the required sample size was estimated at 74 participants. To account for an anticipated dropout rate of approximately 15%, a minimum of eighty-five participants (approximately 43 per group) was required. To enhance statistical robustness, our target sample size was 118 participants.

Statistical analyses were performed using the IBM SPSS 26.0 software. Descriptive statistics summarized participant characteristics and outcomes, with continuous variables expressed as mean ± SD or median (IQR) and categorical variables as frequencies and percentages. Within- and between-group differences were analysed using parametric or non-parametric tests as appropriate, with effect sizes reported as Cohen's d or rank-biserial correlation (r). Separate multiple linear regression models were used to identify explanatory variables of pain, stiffness, and physical function, with demographic variables, body mass index (BMI), ROM changes, and pain measures entered as independent variables. These regression analyses were conducted as exploratory models to examine associations between WOMAC domains and selected clinical, demographic, and biomechanical variables, rather than to develop predictive models. Changes in knee range of motion and post-intervention body mass index were included as explanatory variables to explore their associations within the overall clinical context, rather than as temporal predictors of baseline outcomes. Model assumptions were checked. Clinical relevance was assessed using minimal clinically important difference (MCID) thresholds (≥12% improvement in WOMAC scores; ≥5° improvement in knee flexion or extension). All analyses were two-tailed with statistical significance set at $p < 0.05$.

3. Results

3.1. Participant Demographics

A total of 118 participants were included (TG: n = 57; BBG: n = 61). The groups were comparable in age, height, body weight, and BMI, with no significant between-group differences at baseline (all $p > 0.05$), indicating good baseline homogeneity for subsequent analyses (Table 1).

Table 1. Demographic data of the participants.

Variable	Telerehabilitation Group (n = 57)	Booklet-based Group (n = 61)	*p*-Values
Age group (1– 50 do 59 yr. 2- 60 do 69 yr. 3- 70 do 79 yr.)	1.81 ± 0.77	2.15 ± 0.75	n. s.
Height (cm)	168.72 ± 10.89	169.48 ± 9.56	n. s.
Weight (kg)	82.82 ± 15.59	83.43 ± 17.70	n. s.
BMI	28.91 ± 4.78	28.91 ± 4.97	n. s.

Values are presented as mean (SD); BMI = body mass index; p -value < 0.05; n. s.: not significant.

3.2. Explanatory Variables of WOMAC Pain

In the TG, multiple linear regression analysis identified BMI and baseline pain intensity as significant explanatory variables of baseline WOMAC pain scores. Higher BMI was independently associated with higher WOMAC pain (B = 0.180, p = 0.010), while baseline pain intensity assessed by the NRS was a strong positive predictor (B = 6.815, p = 0.008). Changes in knee ROM and weekly exercise frequency were not significantly associated with WOMAC pain scores (Table 2).

Table 2. Clinical and biomechanical explanatory variables of WOMAC pain in the telerehabilitation group (n = 57).

Predictor	B	SE	Beta	*p*-Values
BMI	0.180	0.067	0.269	0.010
NRS - baseline	6.815	2.457	0.478	0.008

B = Unstandardized regression coefficient; SE = Standard Error; Beta = Standardized regression coefficient; p - value < 0.05; BMI = body mass index; NRS = Numerical Rating Scale.

In the exercise booklet group, multiple linear regression analysis identified several factors significantly associated with baseline WOMAC pain scores. Baseline pain intensity was the strongest predictor (B = 1.063, p < 0.001). In addition, improvement in knee flexion ROM (B = 0.108, p = 0.006), age group (B = −1.215, p = 0.026), and sex (B = −1.554, p = 0.010) were independently associated with WOMAC pain scores (Table 3).

Table 3. Factors associated with WOMAC pain scores in the exercise booklet group (multiple linear regression analysis) (n = 61).

Predictor	B	SE	Beta	*p*-Values
NRS - baseline	1.063	0.141	0.769	<0.001
FLEX - change	0.108	0.037	0.245	0.006
Age group	−1.215	0.532	−0.286	0.026
Sex	−1.554	0.577	−0.236	0.010

B = Unstandardized regression coefficient; SE = Standard Error; Beta = Standardized regression coefficient; p - value < 0.05; NRS = Numerical Rating Scale; FLEX = knee flexion range of motion; negative B values indicate lower WOMAC pain scores.

3.3. Explanatory Variables of WOMAC Stiffness

In the TG, multiple linear regression analysis did not identify any significant associations between baseline WOMAC stiffness scores and demographic variables, BMI, changes in knee ROM, weekly exercise frequency, or pain-related measures (all p > 0.05). The overall model explained only a small proportion of variance in stiffness, indicating limited explanatory value of the examined explanatory variables in this group.

In the exercise booklet group, multiple linear regression analysis identified significant associations between baseline WOMAC stiffness scores and both biomechanical and pain-related factors. Greater improvement in knee flexion was independently associated with lower stiffness scores (B = 0.066, p = 0.024). Baseline pain intensity was also a significant positive predictor of stiffness (B = 0.333, p = 0.003). Other variables, including sex, age group, BMI, changes in knee extension, and weekly exercise frequency, were not significantly associated with WOMAC stiffness (p > 0.05) (Table 4).

Table 4. Multiple linear regression analysis identifying explanatory variables of WOMAC stiffness (n = 61).

Predictor	B	SE	Beta	*p*-Values
FLEX - change	0.066	0.028	0.287	0.024
NRS - baseline	0.333	0.106	0.462	0.003

B = Unstandardized regression coefficient; SE = Standard Error; Beta = Standardized regression coefficient; p - value < 0.05; FLEX = knee flexion range of motion; NRS = Numerical Rating Scale.

3.4. Explanatory Variables of WOMAC Physical Function

In the TG, multiple linear regression analysis was performed to examine associations between demographic variables, body composition, changes in knee ROM, pain-related variables, and baseline WOMAC physical function scores. Higher BMI was significantly associated with poorer

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baseline physical function (B = −0.804, p = 0.038). No other variables, including sex, age group, changes in knee extension or flexion, baseline pain intensity, post-intervention pain, pain change, or weekly exercise frequency, were significantly associated with WOMAC physical function scores (all $p > 0.05$) (Table 5).

Table 5. Explanatory variables of baseline WOMAC physical function in the telerehabilitation group (multiple linear regression analysis) (n = 57).

Predictor	B	SE	Beta	*p*-Values
BMI - post-intervention	−0.804	0.377	−0.284	0.038

B = Unstandardized regression coefficient; SE = Standard Error; Beta = Standardized regression coefficient; p - value < 0.05; BMI = body mass index.

In the exercise booklet group, baseline WOMAC physical function was strongly associated with baseline pain intensity. Higher pain levels were independently related to worse physical function (B = −3.391, $p < 0.001$). No significant associations were found for sex, age group, BMI, changes in knee ROM, or pain change over time (all $p > 0.05$) (Table 6).

Table 6. Explanatory variables of baseline WOMAC physical function in the exercise booklet group (multiple linear regression analysis) (n = 61).

Predictor	B	SE	Beta	*p*-Values
NRS - baseline	−3.391	0.723	−0.673	< 0.001

B = Unstandardized regression coefficient; SE = Standard Error; Beta = Standardized regression coefficient; p - value < 0.05; NRS = Numerical Rating Scale.

4. Discussion

This randomized controlled trial demonstrated distinct patterns of association between telerehabilitation and booklet-based exercise programs in patients with knee osteoarthritis, supporting the use of separate analytical models for each intervention modality. Across all WOMAC domains, pain emerged as the central determinant of clinical outcomes, irrespective of the mode of exercise delivery. However, the relative contribution of pain, biomechanical factors, and demographic characteristics differed between intervention groups, indicating that the context in which exercise-based rehabilitation is delivered may influence the relationships between symptoms and functional outcomes.

4.1. Pain as the Primary Clinical Driver

Baseline pain intensity consistently emerged as the strongest predictor of WOMAC pain, stiffness, and physical function across both intervention groups, exceeding the influence of demographic variables and changes in knee range of motion. This finding is consistent with previous research demonstrating that pain severity is the dominant factor shaping perceived disability and symptom burden in knee osteoarthritis [26–28]. Pain has been shown to constrain daily functioning more strongly than isolated structural or biomechanical impairments [26,29].

Current evidence suggests that pain in knee osteoarthritis reflects a complex interaction between peripheral joint pathology and altered pain processing mechanisms, including central sensitization, impaired descending inhibition, and maladaptive movement strategies [10,30,31]. These mechanisms may help explain why improvements in mechanical parameters, such as knee range of motion, do not consistently translate into proportional reductions in pain or functional limitations. The present findings support this interpretation, as changes in knee ROM alone were insufficient to account for pain reduction in either intervention group.

In the telerehabilitation group, higher body mass index was independently associated with greater WOMAC pain scores. This observation aligns with evidence indicating that increased mechanical loading, adipose-related inflammation, and metabolic factors contribute to persistent pain in knee osteoarthritis [13,32,33]. In contrast, pain outcomes in the booklet-based exercise group were more strongly associated with demographic characteristics and improvements in knee flexion, suggesting a more heterogeneous and mechanically influenced pain profile when structured supervision and individualized feedback are limited [27,31].

Taken together, these findings highlight the importance of prioritizing pain-modulating strategies within exercise-based rehabilitation for knee osteoarthritis. Interventions incorporating graded loading, symptom monitoring, patient education, and behavioural support appear particularly relevant in remotely delivered rehabilitation models, where direct physical contact is limited but ongoing professional guidance can be maintained [34,35].

4.2. Stiffness: Differential Associations Across Intervention Modalities

Distinct patterns were observed for WOMAC stiffness between intervention groups. In the telerehabilitation group, stiffness was not significantly associated with demographic variables, pain intensity, or changes in knee range of motion. The absence of clear stiffness explanatory variables suggests that perceived stiffness in this context may represent a multifactorial construct influenced by symptom interpretation, movement confidence, and behavioural adaptation rather than isolated biomechanical impairment [26,36].

Conversely, in the booklet-based exercise group, stiffness was significantly associated with baseline pain severity and improvements in knee flexion. This pattern indicates a closer coupling between joint mobility, pain, and stiffness perception when exercise is performed without continuous professional supervision. Similar associations have been reported in previous studies of unsupervised or minimally supervised exercise interventions for knee osteoarthritis [27,31].

The divergence between intervention groups may reflect the moderating influence of regular professional contact, individualized feedback, and symptom monitoring in the telerehabilitation program. Such elements may reduce symptom variability and attenuate the direct association between mechanical changes and perceived stiffness [35,36].

4.3. Physical Function and the Pain–Function Relationship

Physical function demonstrated the most pronounced divergence between intervention modalities. In the telerehabilitation group, higher body mass index was the only variable independently associated with poorer baseline WOMAC physical function, whereas pain-related variables were not significantly associated with functional status. This finding suggests that, under conditions of continuous professional support, functional performance may be less directly constrained by pain intensity and more influenced by longer-term biomechanical and body composition factors [32,33].

In contrast, baseline pain intensity was the dominant predictor of physical function in the booklet-based exercise group, indicating a pain-driven disability profile in patients performing unsupervised home exercises. This observation is consistent with extensive literature demonstrating that pain severity directly limits physical function in knee osteoarthritis, particularly when external guidance, reassurance, and adaptive exercise modification are limited [26–28,34].

The attenuation of the pain–function relationship observed in the telerehabilitation group may reflect the buffering effects of ongoing professional supervision and individualized guidance. Such support may facilitate more efficient movement strategies, reduce fear-avoidance behaviours, and promote functional engagement despite persistent symptoms, although these mechanisms were not directly assessed in the present study [4,21,35].

4.4. Integrated Interpretation and Clinical Implications

When considered collectively, the WOMAC pain, stiffness, and physical function domains revealed intervention-specific patterns that extend beyond symptom reduction alone. While pain

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remained the central clinical driver across both interventions, telerehabilitation appeared to modify the relative contribution of pain to functional outcomes. In the booklet-based exercise program, pain consistently dictated stiffness and functional limitation, whereas in the telerehabilitation group, functional outcomes were less directly dependent on pain intensity.

The absence of strong associations between knee range of motion and WOMAC domains in both groups underscores that improvements in joint mobility alone are unlikely to yield meaningful functional benefits without concurrent pain modulation [13,29]. These findings support a multidimensional rehabilitation approach for knee osteoarthritis, in which exercise therapy is integrated with continuous monitoring, individualized feedback, and behavioural support [34,35].

Overall, the present results suggest that telerehabilitation does not merely replicate conventional exercise programs at a distance but may influence the clinical relationships between pain, stiffness, and function. This distinction is particularly relevant in healthcare systems facing limited access to in-person physiotherapy and increasing demand for scalable rehabilitation strategies [35].

Although this trial was conducted at a single centre in Slovenia, the study context reflects challenges common across many healthcare systems, including limited access to supervised physiotherapy, workforce shortages, and growing demand for rehabilitation services, as repeatedly highlighted by the World Health Organization. These systemic constraints are particularly evident across European countries, where delays in access to rehabilitation and uneven workforce distribution persist. In this context, the findings of this study support the broader applicability of telerehabilitation as a scalable and resource-efficient model for delivering exercise-based care in knee osteoarthritis, extending beyond the Slovenian healthcare setting.

4.5. Limitations

This study has several limitations that should be acknowledged. Exercise adherence was not objectively quantified, which limits conclusions regarding dose–response relationships and the extent to which professional supervision influenced training compliance. Although objective measures of knee range of motion were included, other biomechanical or neuromuscular factors relevant to functional outcomes were not assessed. In addition, the study was conducted at a single centre, which may limit the generalizability of the findings. Finally, long-term outcomes beyond the intervention period were not evaluated.

5. Conclusions

This randomized controlled trial demonstrates that both telerehabilitation and booklet-based home exercise programs lead to significant improvements in pain and knee-related symptoms in patients with knee osteoarthritis. Telerehabilitation was associated with more favourable and clinically meaningful functional outcomes, supporting its added value compared with unsupervised exercise alone.

Across both interventions, pain reduction emerged as a central determinant of clinical improvement, confirming its pivotal role in knee osteoarthritis management. Notably, the association between pain and physical function differed between intervention modalities. While pain remained the dominant driver of outcomes in the booklet-based exercise group, physical function in the telerehabilitation group appeared to be less directly dependent on pain intensity and more closely related to modifiable factors such as body composition. These findings suggest that continuous professional supervision and individualized feedback may attenuate the functional impact of pain.

Consistent with responder and minimal clinically significant difference analyses, a higher proportion of participants in the telerehabilitation group achieved clinically meaningful improvements in WOMAC outcomes, particularly in physical function. Together, these results indicate that telerehabilitation represents an effective and clinically relevant approach for delivering exercise-based rehabilitation in knee osteoarthritis.

In the context of increasing demands on healthcare systems and limited access to in-person physiotherapy, telerehabilitation offers a promising strategy for improving access to care while

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maintaining meaningful clinical benefits. Future research should focus on long-term outcomes, cost-effectiveness, and implementation strategies to support the integration of telerehabilitation into routine osteoarthritis care.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org. Table S1: Exercise Program Structure and Progression.

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Institutional Review Board Statement: Study was conducted in accordance with the Declaration of Helsinki and approved by the National Committee on Medical Ethics of the Republic of Slovenia (No. 0120-471/2023-2711-4).

Ethical approval for this study was obtained from the National Committee on Medical Ethics of the Republic of Slovenia (No. 0120–471/2023-2711-4). Informed consent to participate was obtained from all individual participants.

Informed Consent Statement: All participants gave their informed consent prior to registration and data collection.

Data Availability Statement: The exercise protocol and anonymized datasets are available from the corresponding author upon reasonable request. Access to the telerehabilitation platform is restricted due to institutional and data protection regulations.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

OA	Osteoarthritis
BMI	Body mass index
ROM	Range of motion
NRS	Numerical Rating Scale
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index
VAS	Visual Analogue Scale
TG	Telerehabilitation group
BBG	Booklet-based group

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