Does physical therapist contact matter? A randomised controlled trial comparing telerehabilitation and booklet-based exercise for knee osteoarthritis

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Abstract

Telerehabilitation is increasingly used in knee osteoarthritis, but its effectiveness compared with structured home exercise and the role of physical therapist contact remain unclear. To address this, we aimed to investigate whether the clinical effectiveness of telerehabilitation for knee osteoarthritis is primarily attributable to the digital platform itself or to the extent and quality of physical therapist engagement within that platform. In this single-centre Randomised Controlled Trial (RCT), 118 patients with knee OA (Kellgren–Lawrence grade I–III) were allocated 1:1 to a 12-week telerehabilitation (TR; n=57) or booklet-based exercise programme (BB; n=61). Within the telerehabilitation group, participants were retrospectively stratified into those with Physical Therapist Contact (TR−C) and those without contact (TR−NC) for an exploratory analysis. Outcomes included knee pain (NRS, Numerical Rating Scale), Range Of Motion (ROM), WOMAC, physical activity (IPAQ), and health-related quality of life (SF-12). A post-hoc exploratory subgroup analysis was conducted and looked at the impact of a physical therapist with and without contact. A key component of the analysis was an exploratory subgroup comparison examining the role of physical therapist contact within the telerehabilitation group. Primary outcomes were analysed using mixed-model ANOVA, with exploratory subgroup comparisons. Both groups showed significant within-group improvements in pain, ROM, and WOMAC scores (all $p \leq 0.001$), with no significant group × time interactions ($p > 0.05$). Exploratory analysis identified significant differences based on physical therapist contact, with greater improvements in pain ($p = 0.009$), knee flexion ($p = 0.041$), and WOMAC Pain ($p = 0.047$) among participants who engaged with the physical therapist. Participants without contact showed the smallest improvements. When stratified by physical therapist contact, participants receiving contact demonstrated greater improvements than those without contact, who showed the smallest gains. Telerehabilitation and booklet-based exercise programme provide comparable clinical outcomes at the group level. However, physical therapist engagement appears to be a key determinant of treatment response. These findings suggest that the effectiveness of TR depends more on clinical interaction than on digital delivery alone. Physical therapist contact may represent an important component influencing the effectiveness of telerehabilitation. It remains unclear whether telerehabilitation effectiveness stems from the digital platform, exercise content, or physical therapist guidance.

Key Words: knee osteoarthritis, telerehabilitation, home-based exercise, physical therapist contact, randomised controlled trial.

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Knee Osteoarthritis (OA) is one of the most common musculoskeletal disorders worldwide, representing a chronic, progressive, and currently incurable condition. Global prevalence is estimated at 16.0% among adults, imposing substantial clinical burden through persistent pain, functional limitations, and reduced quality of life.[1] This burden is expected to increase due to population ageing and rising obesity, while effective disease-modifying treatments remain unavailable.

Exercise therapy and self-management are core components of non-surgical knee OA management. However, adherence to unsupervised home exercise remains a key challenge, with reported rates ranging from 4 to 100% across RCT.[2] Access to supervised physiotherapy is further constrained by workforce shortages and growing demand. In the WHO European Region, approximately 2 in 5 people live with a condition requiring rehabilitation, yet the majority are not receiving adequate care.[3] In Slovenia specifically, limited physiotherapy capacity is reflected in waiting times of 159 - 265 days for orthopaedic outpatient appointments - a difference of up to 60% across regions - highlighting the need for scalable home-based alternatives.[4,5,6]

Telerehabilitation (TR) has emerged as a promising strategy to bridge this gap, enabling remote delivery of structured exercise programmes with professional support. A systematic review and meta-analysis of six RCTs (n=734) found TR superior to conventional treatment for pain reduction, though not for physical function.[7] A broader review of ten studies (n=1,354) confirmed TR as a promising option for knee OA but noted considerable heterogeneity in outcome measures and study designs.[8] Prior RCTs have demonstrated clinically meaningful improvements in pain and functional outcomes following remote exercise interventions.[9-12] However, objective knee Range Of Motion (ROM) has been inconsistently measured or omitted in most TR trials, limiting interpretation of functional improvements.[13]

A further methodological limitation of existing TR trials is the failure to account for variability in physical therapist contact intensity. Most studies have compared TR as a mode of delivery against conventional or unsupervised exercise, without distinguishing between passive access to a digital platform and active, structured physical therapist involvement within that platform. As a result, it remains unclear whether clinical improvements are attributable to the digital medium itself, the exercise content, or the degree of professional guidance embedded within the programme - a distinction with important implications for protocol design and resource allocation.[14-16]

The aim of this study was to examine the effectiveness of a 12-week TR exercise programme compared with a Booklet-Based exercise programme (BB) in patients with knee OA. Outcomes included knee pain intensity - Numeric Rating Scale (NRS), knee Range Of Motion (ROM) (Flexion (FLEX) and Extension (EXT)), self-reported knee symptoms and disability - Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), physical activity level - International Physical Activity Questionnaire (IPAQ), SF-12, and patient satisfaction. Given evidence suggesting that professional guidance can enhance exercise execution, adherence, and symptom management in knee osteoarthritis, we hypothesised that telerehabilitation would result in greater improvements compared with a booklet-based exercise programme. We hypothesised that patients receiving TR would demonstrate significantly greater improvements in pain and functional outcomes compared with the BB group. A post-hoc exploratory analysis was conducted to examine whether active physical therapist contact during the intervention moderated clinical outcomes, by comparing participants who contacted the physical therapist (TR-C) with those who did not - participants without contact (TR-NC) and with the booklet-based group.

Materials and Methods

Trial design

This was a single-centre, parallel-group, randomised controlled superiority trial with a 1:1 allocation ratio, conducted at the Artros Medical Centre, Ljubljana, Slovenia, comparing TR with BB home exercise for knee OA. Assessments were performed at baseline (T1) and after the 12-week exercise programme (T2). The trial was conducted in accordance with CONSORT 2025.[17] Ethics approval was granted by the Commission of the Republic of Slovenia for Medical Ethics (No. 0120-471/2023-2711-4); all participants provided written informed consent. The trial was retrospectively registered at ClinicalTrials.gov (NCT07137897) on August 26, 2025. Primary and secondary outcomes were prespecified prior to statistical analysis. No patient or public involvement was incorporated, and no protocol changes were made after trial commencement.

Participants

Consecutive patients attending orthopaedic consultations were screened between June 2024 and October 2025. Inclusion criteria were: age 50–79 years, clinician-confirmed knee OA (Kellgren–Lawrence grade I–III), physical ability to complete the exercise programme, and sufficient digital literacy for TR. Exclusion criteria included Kellgren–Lawrence grade IV OA, inflammatory joint disease, recent knee surgery, medical contraindication to exercise, inability to complete assessments, and concurrent supervised rehabilitation.

Randomisation and blinding

In randomisation process was involved orthopedic surgeons. They assessed patients and determined eligibility based on inclusion criteria. They generated the randomization sequence independently, without involvement in recruitment or assessment. Physical therapist received allocation decisions and delivered the assigned intervention. This separation of roles reduced the risk of selection bias during the recruitment process.

Interventions

Both groups received standardised OA education prior to commencing the intervention and followed the same exercise programme - differing only in delivery mode. The programme comprised strengthening, mobility, and balance exercises for the lower extremity and trunk, performed three times per week over 12 weeks (maximum 72-hour interval between sessions) (Supplementary file S1). Progression was standardised and predefined based on symptom tolerance and functional capacity.

TR participants accessed the programme via the web-based Moje koleno platform, using instructional videos organised into warm-up, main, and cool-down phases. The Moje koleno platform is a web-based telerehabilitation application delivering structured exercise programmes through instructional videos and enabling asynchronous communication between patients and physical therapist. They had access to asynchronous physical therapist communication (in-app messaging and email) and optional weekly video consultations for exercise monitoring and motivational support. Adherence was monitored differently across the two groups. In the TR group, adherence was supported through automated reminders generated by the Moje koleno platform, which were sent to participants who had not accessed the application for more than 72 hours. These reminders were motivational in nature (e.g., 'We miss you in the Moje koleno app', 'Can you already feel the progress?'). In the BB group, participants received a printed booklet containing an exercise diary, in which they self-recorded their training sessions to support independent monitoring and adherence. A single midpoint telephone call was made in BB group to address any questions and encourage adherence. Within the TR group, participants were retrospectively stratified into TR-C (n=25; at least one physical therapist contact) and TR-NC (n=32; no contact) for post-hoc exploratory analysis.

Outcome measures

Outcomes were assessed at baseline (T1) and after the 12-week exercise programme (T2). Knee pain intensity was measured using the Numeric Rating Scale (NRS; 0–10).[18] Knee range of motion (ROM), including flexion (FLEX) and extension (EXT), was assessed using standard goniometry.[13] Disability and symptoms were evaluated with the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC; pain 0–20, stiffness 0–8, physical function 0–68, total 0–96), where higher scores indicate worse symptoms and disability.[18] Physical activity was measured using the IPAQ (MET-min/week).[19] Health-related quality of life was assessed using the SF-12 (Physical and Mental Component Summaries, 0–100), with higher scores indicating better status.[20] The study-specific questionnaire was developed and completed at T2, to capture outcome domains and satisfaction constructs directly relevant to telerehabilitation and musculoskeletal rehabilitation, based on a systematic review of the literature.[21] The questionnaire comprised two sections: i) Functional improvement assessment: Participants rated changes in five functional domains (knee function, mobility, pain, physical activity, and health-related quality of life) on a 5-point Likert scale ranging from «considerable worsening» to «considerable improvement» compared to baseline (Supplementary File S2), ii) Satisfaction assessment: Participants rated satisfaction across eight domains (quality of service, receipt of desired service, fulfilment of needs, recommendation to others, improvement in knee function and quality of life, perceived progress, and likelihood of future use) using a 5-point Likert scale ranging from «completely disagree» to «completely agree» (Supplementary File S3).

Sample size

Sample size was estimated using G*Power 3.1,[22] based on WOMAC effect sizes from:[23] α=0.05, power=0.80, f=0.288, yielding n=74. Accounting for 15% dropout, a minimum of 85 participants was required; the target was increased to 118 to enhance robustness.

Statistical analysis

Analyses were performed in IBM SPSS 26.0 ($p < 0.05$). Normality and variance homogeneity were assessed with Shapiro–Wilk and Levene's tests. All analyses were conducted using an available-case analysis approach, including participants with complete data at both baseline and follow-up. No imputation was performed for missing outcome data. Primary analysis used a 2 × 2 mixed-model ANOVA (group × time interaction as the primary inferential test); effect sizes are reported as η_p^2.[24] Within-group changes are reported with 95% CIs. An exploratory three-group ANOVA (TR-C, TR-NC, BB) with Bonferroni post-hoc tests was conducted on selected outcomes. Minimal Clinically Important Difference (MCID) applied: NRS 2.0 points[25]; knee flexion 5°[26]; WOMAC Total 10 points.[27] Satisfaction data were analysed descriptively and compared with one-way ANOVA.

Results

Participant flow and recruitment

Between June 2024 and October 2025, 206 patients were screened; 55 were excluded and 151 randomised (TR: n=66; BB: n=85). During follow-up, 9 TR and 24 BB participants withdrew, resulting in a final analysis sample of 57 (TR) and 61 (BB) participants (total n=118; see Figure 1). Within the TR, 25 participants (43.9%) initiated contact with the physical therapist during the intervention period (TR-C) and 32 (56.1%) did not (TR-NC). This stratification was post-hoc and is described in the Exploratory Analysis section.

Baseline characteristics

Baseline characteristics are presented in Table 1. The groups were comparable for sex (p=0.353), age group (p=0.052), education (p=0.102), and anthropometric measures (all $p > 0.05$).

Primary analysis: comparison of outcomes between telerehabilitation group vs. booklet-based exercise group

Outcome data and statistical results are summarised in Table 2. A significant main effect of time was observed for most outcomes, indicating improvement from T1 to T2 in both groups. Significant changes were found for FLEX, EXT, NRS pain, and the WOMAC Pain, Stiffness, and Physical Function subscales (all $p \leq 0.001$ for TR and BB). These improvements are supported by 95 % confidence intervals for the mean.

For PCS, a significant improvement was detected in the TR ($p < 0.001$), with the 95 % CI excluding zero, whereas the BB showed only a non-significant trend ($p = 0.058$), and the corresponding CI included zero. For WOMAC Total, the 95 % CI excluded zero in the TR but included zero in the BB, indicating a clearer within-group effect only for TR.

No significant changes were found for IPAQ or MCS in either group (all $p > 0.05$), and the associated confidence intervals crossed zero, indicating no reliable improvement. No significant group × time interactions were observed for any outcome (all $p > 0.05$), demonstrating that the magnitude of improvement over time did not differ between the groups.

Exploratory analysis: role of physical therapist contact

Results of the three-group exploratory analysis (TR-C, TR-NC, BB) are presented in Table 3. Baseline comparability was confirmed for all clinical outcomes (all $p > 0.05$) except PCS (p=0.041); given this difference, PCS results should be interpreted with caution, as the baseline imbalance may have influenced within-group changes independently of physical therapist contact. Significant group × time interactions were identified for NRS pain (p=0.009, ηp^2=0.079), knee flexion (p=0.041, ηp^2=0.054), and WOMAC Pain (p=0.047, ηp^2=0.052). In each case, TR-C demonstrated the most pronounced improvement: mean NRS reduction of 2.8 points (exceeding the MCID of 2.0), mean knee flexion gain of +10.2° (exceeding the MCID of 5°), and mean WOMAC Pain reduction of 3.8 points. The TR-NC group consistently showed the smallest improvements across all outcomes, comparable to or below the BB group. A trend was observed for IPAQ (p=0.081). These findings are exploratory and hypothesis-generating.

Patient satisfaction and functional self-assessment

Results are presented in Table 4. Both groups reported high satisfaction levels across all domains (mean scores 3.75–4.56 on the 5-point scale). No significant between-group differences were found for any functional self-assessment domain or for total satisfaction score.
A significant between-group difference emerged only for the perceived quality of rehabilitation, with TR participants rating it higher than BB participants (TR: 4.44±0.54 *vs*. BB: 3.34±0.62; p=0.047).

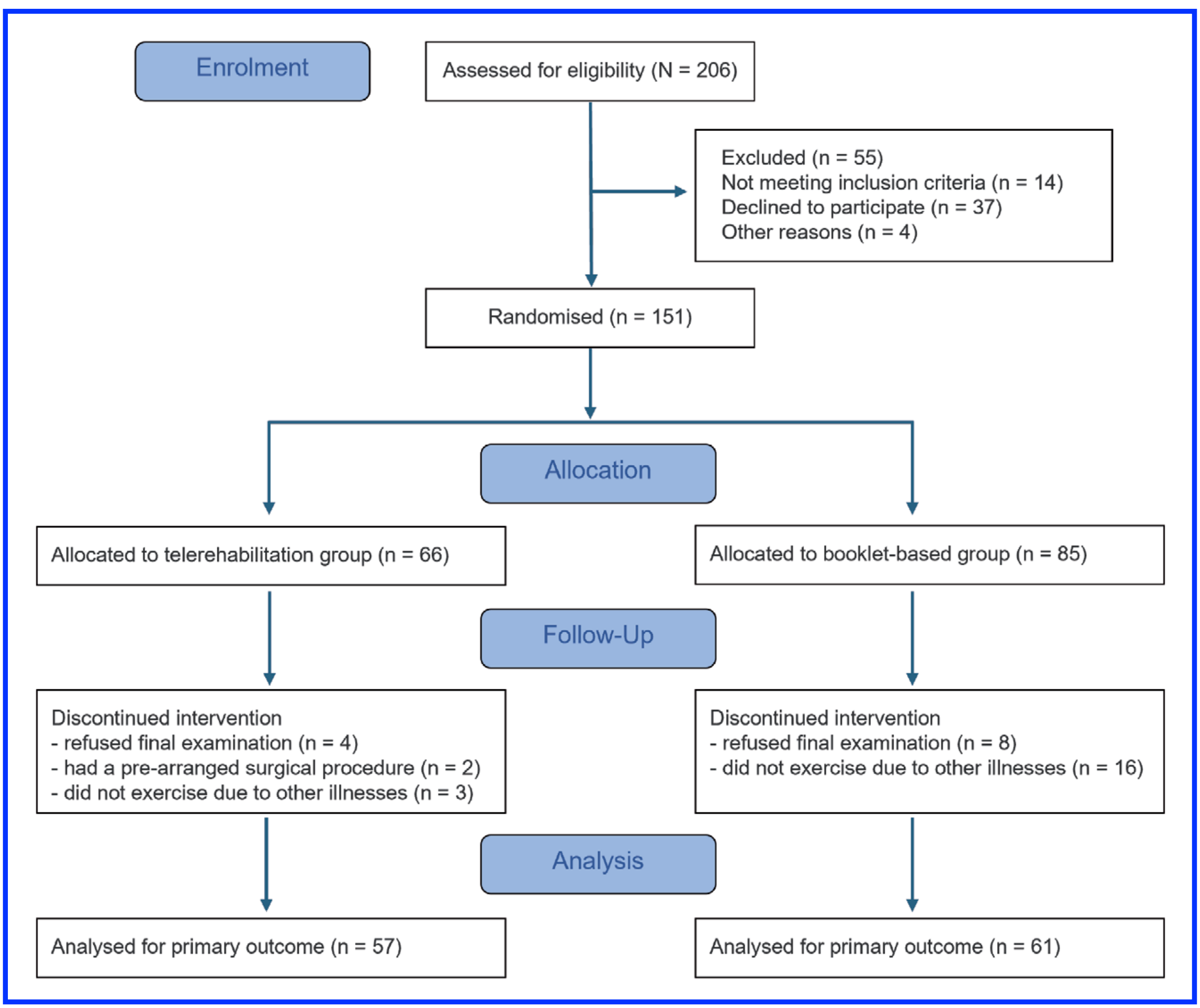

Figure 1. *CONSORT flow diagram illustrating participant screening, randomisation, follow-up, and analysis.*

Table 1. *Baseline demographic and anthropometric.*

Characteristic	TR (n=57) n (%) or mean±SD	BB (n=61) n (%) or mean±SD	*p*-value
Demographic characteristics			
Sex: female, n (%)	41 (71.9%)	39 (63.9%)	.353
Age group, n (%)			.052
50–59 years	23 (40.4%)	13 (21.3%)	
60–69 years	22 (38.6%)	26 (42.6%)	
70–79 years	12 (21.1%)	22 (36.1%)	
Anthropometric measures			
Body weight [kg]	82.68±15.49	83.51±17.91	.790
Height [cm]	168.72±10.89	169.48±9.56	.689
BMI [kg/m²]	28.88±4.87	28.93±5.02	.959

SD, standard deviation; TR, telerehabilitation group (n=57); BB, booklet-based exercise group (n=61); BMI, body mass index. Between-group comparisons: independent-samples t-tests for continuous variables; chi-square (χ^2) tests for categorical variables.

Table 2. *Outcome measures by group and time point.*

Outcome measure	Group	T1 mean±SD	Diff mean±SD	95% CI (Diff)	Time effect *p* (ηp²)	Group × time *p* (ηp²)
FLEX [°]	TR	123.2±10.6	7.45±7.63	[5.43, 9.47]	**<.001** (.493)	.674 (.002)
	BB	121.2±11.3	8.03±7.20	[6.19, 9.88]	**<.001** (.558)	
EXT [°]	TR	3.9±4.2	−2.19±3.14	[-3.03, -1.36]	**<.001** (.332)	.124 (.020)
	BB	5.0±4.7	−3.33±4.63	[-4.51, -2.14]	**<.001** (.345)	
NRS pain [0–10]	TR	4.8±2.2	1.75±2.48	[1.09, 2.41]	**<.001** (.336)	.609 (.002)
	BB	5.0±2.3	1.98±2.37	[1.38, 2.59]	**<.001** (.416)	
WOMAC Pain [0–20]	TR	7.3±3.3	2.63±3.18	[1.79, 3.48]	**<.001** (.410)	.679 (.001)
	BB	7.7±3.2	2.38±3.47	[1.49, 3.27]	**<.001** (.323)	
WOMAC Stiffness [0–8]	TR	3.4±1.4	0.9±1.6	[0.49, 1.33]	**<.001** (.255)	.197 (.014)
	BB	3.0±1.7	0.6±1.4	[0.20, 0.90]	**.003** (.139)	
WOMAC Physical function [0–68]	TR	40.4±13.5	−8.9±12.4	[-12.14, -5.59]	**<.001** (.344)	.176 (.016)
	BB	42.3±11.6	−5.7±12.5	[-8.94, -2.53]	**<.001** (.176)	
WOMAC Total [0–96]	TR	50.3±12.9	−6.0±12.3	[-9.23, -2.73]	**<.001** (.195)	.152 (.018)
	BB	52.9±9.9	−2.8±11.7	[-5.79, 0.19]	.066 (.055)	
IPAQ [MET-min/week]	TR	3770±3775	−67±3885	[-1098.30, 963.52]	.896 (.000)	.153 (.018)
	BB	3665±3640	+970±3947	[-40.56, 1980.92]	.060 (.058)	
PCS [0–100]	TR	35.8±8.6	5.8±10.2	[3.11, 8.54]	**<.001** (.248)	.111 (.022)
	BB	39.3±9.8	2.7±10.9	[-0.09, 5.48]	.058 (.059)	
MCS [0–100]	TR	53.6±8.6	1.0±7.2	[-0.89, 2.94]	.288 (.020)	.326 (.008)
	BB	53.7±8.4	−0.4±8.4	[-2.53, 1.74]	.712 (.002)	

Values are presented as mean±SD. Diff, mean change from T1 to T2. CI, 95% confidence interval; ηp², partial eta squared.

Eur J Transl Myol 36 (2) 15253, 2026 doi: 10.4081/ejtm.2026.15253

Table 3. *Exploratory subgroup analysis by physical therapist - contacts status.*

Outcome measure	Group	T1 mean±SD	Diff mean±SD	Time effect *p* (ηp²)	Group × Time *p* (ηp²)
FLEX [°]	TR-C	121.4±12.2	10.2±9.2	**<.001** (.562)	.041 (.054)
	TR-NC	124.5±9.2	5.3±5.4	**<.001** (.502)	
	BB	121.2±11.3	8.0±7.2	**<.001** (.558)	
EXT [°]	TR-C	3.4±3.7	−1.6±2.8	**<.001** (.256)	.188 (.029)
	TR-NC	4.2±4.6	−2.7±3.4	**<.001** (.393)	
	BB	5.0±4.7	−3.3±4.6	**<.001** (.345)	
NRS pain [0–10]	TR-C	5.5±1.9	2.8±2.0	**<.001** (.684)	**.009 (.079)**
	TR-NC	4.3±2.4	0.9±2.5	.053 (.116)	
	BB	5.0±2.3	2.0±2.4	**<.001** (.416)	
WOMAC Pain [0–20]	TR-C	7.4±3.2	3.8±2.9	**<.001** (.654)	**.047 (.052)**
	TR-NC	7.2±3.4	1.7±3.1	.005 (.229)	
	BB	7.7±3.2	2.4±3.5	**<.001** (.323)	
WOMAC Stiffness [0–8]	TR-C	3.4±1.6	1.2±1.5	**<.001** (.432)	.147 (.033)
	TR-NC	3.3±1.3	0.7±1.6	.031 (.142)	
	BB	3.0±1.7	0.6±1.4	.003 (.139)	
WOMAC Physical function [0–68]	TR-C	40.8±15.1	−10.9±13.7	**<.001** (.399)	.219 (.026)
	TR-NC	40.0±12.4	−7.3±11.2	**<.001** (.303)	
	BB	42.3±11.6	−5.7±12.5	**<.001** (.176)	
WOMAC Total [0–96]	TR-C	51.5±13.6	5.8±12.6	**.029** (.183)	.358 (.018)
	TR-NC	49.4±12.4	6.1±12.2	**.008** (.205)	
	BB	52.9±9.9	2.8±11.7	**.066** (.055)	
IPAQ [MET-min/week]	TR-C	3007±2782	946±3822	.228 (.060)	.081 (.043)
	TR-NC	4366±4349	−859±3806	.211 (.050)	
	BB	3665±3640	970±3946	.060 (.058)	
PCS [0–100]	TR-C	38.7±9.1	4.2±10.8	.062 (.138)	.171 (.030)
	TR-NC	33.5±7.6	7.1±9.8	**<.001** (.351)	
	BB	39.3±9.8	2.7±10.9	.058 (.059)	
MCS [0–100]	TR-C	52.5±7.4	3.1±7.6	**.051** (.150)	.122 (.036)
	TR-NC	54.4±9.5	−0.6±6.5	.595 (.009)	
	BB	53.7±8.4	−0.4±8.3	.712 (.002)	

SD, standard deviation; Diff, mean change from T1 to T2. For NRS pain, WOMAC Pain, and Stiffness, positive values indicate improvement (decrease in scores). For WOMAC Physical Function and Total, EXT, and MCS, negative values indicate improvement (decrease in scores reflects reduced disability or improved extension). For FLEX, IPAQ, and PCS, positive values indicate improvement (increase in scores). CI=95% confidence interval for the mean change. EXT values represent the extension deficit in degrees; a negative Diff indicates reduction in deficit and thus improvement. Time effect=within-subjects main effect of time (collapsed across groups). Group × Time, interaction effect (primary inferential test). ηp², partial eta squared (small ≥0.01, medium ≥0.06, large ≥0.14). Bold text values indicate p <0.05.

Eur J Transl Myol 36 (2) 15253, 2026 doi: 10.4081/ejtm.2026.15253

Table 4. *Patient-reported satisfaction and functional self-assessment at post-intervention.*

Outcome	TR (n=57)	BB (n=61) mean±SD	*p*-value mean±SD
Functional self-assessment [0–5]			
Range of motion	4.00±0.76	3.98±0.67	.886
Pain	3.88±0.87	3.80±0.85	.850
Stiffness	3.84±0.75	3.75±0.75	.471
Physical function	3.95±0.77	3.90±0.62	.763
Quality of life	3.86±0.74	3.82±0.76	.836
Total functional score [0–25]	19.49±3.38	19.26±3.05	.886
Satisfaction [0–5]			
Quality of rehabilitation	4.44±0.54	3.34±0.62	**.047**
Services received	4.47±0.50	4.38±0.52	.499
Expectations met	4.33±0.66	4.15±0.83	.406
Likelihood to recommend	4.54±0.57	4.44±0.70	.584
Perceived helpfulness	4.33±0.74	4.11±0.82	.214
Perceived progress	4.05±0.79	4.00±0.75	.061
Overall satisfaction	4.40±0.56	4.25±0.72	.117
Future use intention	4.56±0.57	4.36±0.71	.116
Total satisfaction score [0–40]	35.14±4.02	33.95±4.74	.116

SD, standard deviation; TR, telerehabilitation group (n=57); BB, booklet-based exercise group (n=61).
All items rated on a 5-point Likert-type scale (0=worst, 5=best). Total functional score=sum of five items (range 0–25).
Total satisfaction score, sum of eight items (range 0–40).
Bold values indicate statistically significant between-group differences (p <0.05).

Discussion

In this randomised controlled trial, telerehabilitation and booklet-based exercise produced comparable outcomes. These findings are consistent with previous evidence suggesting that structured remotely delivered and home-based exercise programmes may achieve comparable outcomes.[10,28] Both interventions resulted in clinically meaningful improvements in pain, range of motion, and functional outcomes, while no significant between-group differences were detected. However, analysis of confidence intervals indicates that TR may offer certain advantages for quality of life and overall knee-related disability, and the exploratory analysis highlights the critical moderating role of physical therapist contact. Among participants who initiated contact, the number of physical therapist interactions ranged from two to six over the three-month period, with all communication conducted exclusively via in-app messaging.

The present trial yielded five principal findings. Both groups demonstrated significant within-group improvements in knee pain, range of motion, and WOMAC Pain, Stiffness, and Physical Function over 12 weeks, supported by significant time effects and 95% confidence intervals. In the primary comparison, no group × time interactions reached statistical significance (all $p > 0.05$), and none of the prespecified hypotheses were confirmed. However, for PCS and WOMAC Total, the TR group showed significant within-group improvement with confidence intervals excluding zero, whereas the BB group did not, suggesting a more robust effect in the TR for these outcomes. The exploratory analysis revealed significant group × time interactions for NRS pain (p=0.009), knee flexion (p=0.041), and WOMAC Pain (p=0.047), suggesting that physical therapist contact may have moderated treatment response. TR-C participants exceeded MCID thresholds for NRS pain (2.8 points) and knee flexion (+10.2°), while TR-NC participants did not. Finally, patient satisfaction was high and comparable across both delivery modes, confirming strong acceptability of TR as an intervention format.

Several plausible explanations may account for the absence of significant group × time interactions. First, the booklet programme was deliberately designed to be equivalent in exercise content, progression, and dosage to the TR protocol, representing a considerably stronger comparator than the passive controls or usual care conditions typically used in TR trials.[7,29] Evidence suggests that the nature of the comparator substantially moderates between-group differences in exercise RCTs for knee OA,[30] and the absence of a no-treatment control group in the present study limits the ability to attribute improvements to either specific intervention. Second, trends toward larger improvements in PCS and WOMAC Total interaction suggest that the study may have been underpowered to detect small between-group differences, a common limitation in rehabilitation trials with moderate sample sizes. Third, participants entered the trial with relatively favourable baseline pain scores (mean NRS ~4.9/10), which may have introduced ceiling effects and limited the potential for differential improvement. Fourth, although primary and secondary outcomes were prespecified prior to data analysis, the retrospective trial registration introduces interpretive caution. Finally, the absence of statistically significant interactions does not imply equivalence; confidence intervals consistently indicated that improvements in TR were more robust for PCS and WOMAC Total, an important distinction that null hypothesis significance testing alone cannot capture.

The most novel contribution of this study lies in the exploratory subgroup analysis, which revealed that physical therapist contact within the TR platform emerged as a meaningful moderator of treatment response. Participants who initiated contact with the physical therapist (TR-C) achieved clinically significant improvements in NRS pain and knee flexion, both exceeding established MCID thresholds, while TR-NC participants showed the smallest gains - often comparable to or below the booklet-based group. These exploratory findings suggest that the digital platform alone may not be sufficient to maximise treatment effects, although participants without physical therapist contact still demonstrated significant within-group improvements. These findings align with a growing body of evidence on the central role of therapeutic alliance in remotely delivered rehabilitation. Lawford *et al.*[31] demonstrated that stronger therapeutic alliance between patients with knee OA and physical therapists during telephone-delivered exercise was associated with better pain, function, and adherence outcomes, suggesting that the quality of the patient - physical therapist relationship - even when mediated by technology - is a key driver of clinical improvement. Physical therapist contact likely enhanced exercise quality, symptom management, reassurance, and overall engagement, consistent with evidence that structured professional support improves adherence and outcomes in exercise-based programmes for knee OA.[2]

Selection bias must be acknowledged as a significant limitation: TR-C participants may have self-selected due to greater symptom severity, higher motivation, or greater health literacy, rather than as a result of physical therapist engagement per se. Nevertheless, the consistent pattern of differential responsiveness across multiple outcomes - including pain, ROM, and WOMAC Pain - suggests that physical therapist engagement moderated clinical outcomes beyond what can be explained by selection alone. These findings are hypothesis-generating and warrant confirmation in a prospectively designed trial with randomised physical therapist contact conditions.

Both TR and BB exercise were rated highly acceptable by participants, with comparable overall satisfaction scores across most domains. The only statistically significant between-group difference was observed for perceived quality of rehabilitation, with TR participants rating this dimension higher than BB participants. This finding may reflect the perceived added value of structured digital delivery, access to instructional video content, and – for those who engaged – the availability of asynchronous physical therapist contact. High and comparable satisfaction across delivery modes is consistent with the broader TR literature. Bargeri *et al*.[32] reported no differences in patient-reported experience measures between telemedicine and conventional care across 35 systematic reviews in musculoskeletal conditions. Similarly, Xiang *et al*.[7] observed that patient acceptability did not differ significantly between TR strategies for knee OA. These findings suggest that well-designed remote programmes - whether digitally delivered or booklet-based - can be perceived as credible and valuable by patients when content is clearly structured and expectations are appropriately managed. Nevertheless, satisfaction responses in both groups are likely influenced by factors beyond intervention content alone, including baseline expectations, digital health literacy, and perceived access to professional support.[8] The slightly higher quality rating in the TR group may also partly reflect a novelty effect associated with digital platforms, which should be considered when interpreting these findings. Future studies should employ validated patient-reported experience measures to enable more rigorous cross-study comparisons of acceptability.

Our findings demonstrate that telerehabilitation without active physical therapist engagement does not provide substantial additional benefit beyond a well-structured home exercise booklet. Given the exploratory nature of the analysis, these findings should be interpreted with caution and do not allow causal conclusions. Therefore, TR should incorporate proactive, structured, and scheduled physical therapist contact rather than relying on passive availability alone. Based on these exploratory findings, hybrid models combining digital delivery with targeted physical therapist support may represent a promising approach and warrant prospective evaluation in future trials.[11,33] Clinician involvement and perceived professional support are consistently reported facilitators of engagement with online exercise programmes for musculoskeletal conditions.[33] Meta-analytic evidence further indicates that videoconferencing-based delivery with direct physical therapist contact is among the most effective telerehabilitation modalities for reducing pain and functional disability.[34] Digital health interventions are most effective when integrated with meaningful clinician involvement, rather than delivered as stand-alone technology.[33] For healthcare systems facing physiotherapy workforce shortages and geographic access barriers – as in Slovenia[5,6] – a hybrid model that reserves direct physical therapist contact for those who need it most offers a pragmatic solution. Future research should establish optimal thresholds for physical therapist contact intensity, patient selection criteria for digital versus hybrid models, and cost-effectiveness across different healthcare contexts.

Several limitations should be acknowledged. Neither participants nor outcome assessors were blinded to group allocation, which may have introduced performance and detection bias - an inherent constraint of exercise-based rehabilitation trials. Both groups presented with relatively

Eur J Transl Myol 36 (2) 15253, 2026 doi: 10.4081/ejtm.2026.15253

mild-to-moderate impairment at baseline (mean NRS ~4.9/10), which may have introduced ceiling effects and attenuated detectable between-group differences. The single-centre design limits generalisability to other healthcare settings, patient populations, and health systems. While assessor blinding is challenging in exercise-based trials, it is not inherently unfeasible, and its absence in the present study may have introduced detection bias. This is acknowledged as a limitation. Due to the differing nature of adherence tracking methods across groups, systematic quantitative adherence data were not collected in a comparable format, and between-group adherence comparisons could not be performed. This is also acknowledged as a limitation. The post-hoc stratification of TR participants into TR-C and TR-NC was based on self-initiated contact, introducing substantial selection bias; participants who contacted the physical therapist likely differed systematically in symptom severity, motivation, and digital literacy, and causal inference from the exploratory analysis is therefore not warranted. The absence of allocation concealment represents a potential source of selection bias and should be considered when interpreting the findings. The use of an available-case analysis, without imputation for missing data, may have introduced attrition bias, particularly given the differential dropout between groups. Finally, outcome assessments were limited to 12 weeks; the sustainability of improvements and potential differential long-term effects remain unknown. Future trials should prospectively randomise physical therapist contact intensity and include longer follow-up periods.

The findings of this study have direct implications for the implementation of telerehabilitation in clinical practice. While digital platforms can expand access to care, their effectiveness appears to depend on the integration of structured clinician interaction. This supports a shift from purely technology-driven models toward hybrid approaches combining scalable digital delivery with targeted physical therapist support. Such models may be particularly relevant in healthcare systems with limited rehabilitation capacity, where efficient allocation of physical therapist time is critical

Conclusions

This study demonstrated that a 12-week TR and a BB home exercise programme produced comparable improvements in pain, range of motion, and self-reported function in patients with knee OA, with no significant between-group differences. Both interventions were well accepted and produced clinically meaningful changes. However, exploratory analysis revealed that physical therapist contact within the TR platform substantially moderated treatment response, with participants who initiated contact achieving clinically significant improvements. Taken together, these exploratory findings highlight the potential relevance of physical therapist engagement within telerehabilitation programmes, while underscoring the need for confirmatory trials with prospective design. For healthcare systems facing physiotherapy workforce constraints, a hybrid model combining structured digital content with proactive physical therapist contact may offer a scalable and effective approach to knee OA rehabilitation. Prospectively designed trials with randomised physical therapist contact conditions are needed to confirm these findings.

List of abbreviations

OA, osteoarthritis
RCT, randomised controlled trial
TR, telerehabilitation
BB, booklet-based
NRS, Numeric Rating Scale
WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index
IPAQ, International Physical Activity Questionnaire
SF-12, 12-Item Short-Form Health Survey
TR-C, telerehabilitation with physical therapist contact
TR-NC, telerehabilitation without physical therapist contact
MCID - Minimal Clinically Important Difference
CI, confidence interval
ROM, range of motion
FLEX, knee flexion
EXT, knee extension
PCS, Physical Component Summary
MCS, Mental Component Summary
ηp^2, partial eta squared

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Conflict of interest

The authors declare no potential conflict of interest, and all authors confirm accuracy.

Ethics approval

Ethical approval was granted by the Commission of the Republic of Slovenia for Medical Ethics (No. 0120-471/2023-2711-4). The study is conformed with the Helsinki Declaration of 1964, as revised in 2013, concerning human and animal rights.

Contributions

Petra Kotnik, conceptualization, methodology, investigation, data curation, formal analysis, writing – original draft, writing – review & editing, project administration; Mohsen Hussein, conceptualization, resources, investigation, writing – review & editing, supervision.

Informed consent

All patients participating in this study signed a written informed consent form for participating in this study.

Patient consent for publication

Written informed consent was obtained from a legally authorized representative(s) for anonymized patient information to be published in this article.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

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Online supplementary material:

Supplementary file 1. Detailed description of the standardized physiotherapy exercise program.

Supplementary file 2. Assessment of knee joint function improvement.

Supplementary file 3. Satisfaction.