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Online tele-physiotherapy versus in-person care for chronic knee osteoarthritis: Non-inferiority trial on pain and functional outcomes

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Abstract

Background: Knee osteoarthritis is a leading cause of chronic pain and disability worldwide. Exercise- and education-based physiotherapy are cornerstones of non-surgical management, but access to in-person services is often limited. Tele-physiotherapy has emerged as a promising alternative, yet robust non-inferiority evidence directly comparing online versus in-person delivery for chronic knee osteoarthritis remains limited.

Objectives: To determine whether an online, synchronous tele-physiotherapy programme is non-inferior to conventional in-person physiotherapy for reducing pain and improving functional outcomes in adults with chronic knee osteoarthritis.

Methods: In this multi-centre, parallel-group, randomized non-inferiority trial, 220 adults (45-80 years) with radiographically confirmed knee osteoarthritis (Kellgren-Lawrence grade II-III) and chronic knee pain were randomly allocated (1:1) to tele-physiotherapy or in-person physiotherapy. Both groups received an identical 8-week, once-weekly supervised protocol of progressive strengthening, neuromuscular and functional exercises, plus structured education and a home-exercise programme. Primary outcomes were knee pain (11-point numerical rating scale, NRS) and physical function (WOMAC function subscale) at 8 weeks. Non-inferiority margins were 1.0 NRS point and 8 WOMAC function points. Secondary outcomes included WOMAC total score, performance-based tests (30-second chair-stand, 40-m fast-paced walk), health-related quality of life, and patient global rating. Analyses were conducted using linear mixed-effects models under an intention-to-treat framework.

Results: Both groups showed clinically and statistically significant improvements at 8 weeks, maintained at 24 weeks. Mean NRS pain decreased by 3.5 points in the tele-physiotherapy group and 3.7 points in the in-person group; mean WOMAC function improved by 18.9 and 20.1 points, respectively. Adjusted between-group differences in change at 8 weeks (tele minus in-person) were 0.10 (95% CI -0.22 to 0.42) for NRS pain and 1.5 (95% CI -1.5 to 4.5) for WOMAC function, with upper confidence bounds below the non-inferiority margins. Secondary outcomes, responder rates, adherence, and satisfaction were similar between groups, and no serious intervention-related adverse events occurred.

Conclusion: Online tele-physiotherapy was non-inferior to conventional in-person physiotherapy for pain and functional outcomes in adults with chronic knee osteoarthritis. These findings support tele-physiotherapy as a safe, effective, and scalable option that can be integrated into routine knee osteoarthritis care pathways.

Keywords: Knee osteoarthritis, tele-physiotherapy, telerehabilitation, non-inferiority trial, pain, WOMAC, physical function, randomized controlled trial

Introduction

Knee osteoarthritis (KOA) is a leading cause of pain, disability, and loss of independence worldwide, with recent Global Burden of Disease analyses indicating that osteoarthritis affected nearly 600 million people in 2020 and that knee OA will account for the majority of the projected increase in cases by 2050 ^[1]. Hip and knee OA already rank among the top contributors to global disability and years lived with disability ^[2], and contemporary estimates show that both the incidence and prevalence of KOA continue to rise, particularly in ageing and obese populations ^[3]. International guidelines consistently recommend non-surgical management as first-line care for KOA, emphasizing land-based therapeutic exercise, patient education, self-management strategies, and weight control, with surgery reserved for those who fail conservative treatment ^[4-6]. Physiotherapist-led exercise and

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education programmes are therefore central to evidence-based KOA management, yet access to in-person services is often constrained by distance, mobility limitations, cost, and health-system pressures [4-6]. In this context, telehealth and tele-physiotherapy have emerged as scalable models for delivering musculoskeletal rehabilitation; masterclass and implementation work suggests that telehealth for musculoskeletal physiotherapy is both feasible and acceptable when appropriately structured [7]. During and beyond the COVID-19 pandemic, physiotherapists reported rapid adoption of telehealth but also highlighted concerns regarding clinical effectiveness, physical examination, and therapeutic rapport [8, 9], while systematic review evidence indicates that both patients and clinicians generally perceive tele-physiotherapy positively but still view it as “second best” to in-person care in some settings [10]. For KOA specifically, tele-rehabilitation programmes using video conferencing, web platforms, and mobile applications have been synthesized in focused reviews and meta-analyses, which suggest that telerehabilitation can reduce pain and, in some cases, improve function compared with usual care or minimal interventions [11-13]. Randomized controlled trials of home-based telerehabilitation have demonstrated superiority over paper-based or purely self-directed exercise prescriptions for pain, function, and quality of life [14], and non-inferiority or equivalence to conventional outpatient rehabilitation in pain and WOMAC outcomes [15]. Furthermore, recent systematic reviews restricted to KOA report that tele-physiotherapy yields pain and functional improvements comparable to traditional in-person programmes, while offering advantages in accessibility and convenience, although the certainty of evidence remains low to moderate and interventions are heterogeneous [12, 13, 16, 17]. Notably, even the landmark PEAK trial, which showed that video-based physiotherapy consultations were non-inferior to in-person care for chronic knee pain consistent with OA, did not focus exclusively on radiographically confirmed chronic KOA and was conducted in a high-resource context [18]. Thus, there is a critical evidence gap regarding rigorously designed, multi-centre non-inferiority trials directly comparing synchronous online tele-physiotherapy with standard in-person physiotherapy for chronic KOA, using identical treatment content and standardized pain and functional endpoints. This multi-centre randomized non-inferiority trial is designed to address this gap by testing the hypothesis that an online tele-physiotherapy programme is non-inferior to usual in-person physiotherapy in reducing knee pain and improving functional outcomes in adults with chronic KOA, within pre-specified non-inferiority margins on validated pain (e.g., numerical rating scale) and function (e.g., WOMAC) measures over the intervention period.

Material and Methods

Material

This multi-centre, parallel-group randomized non-inferiority trial was conducted in the outpatient physiotherapy departments of three tertiary-care hospitals with established osteoarthritis (OA) and telehealth services, each serving large urban and peri-urban populations with a high burden of knee OA [1-3]. Adults aged 45-80 years with radiographically confirmed knee OA (Kellgren-Lawrence grade II-III), persistent knee pain for ≥ 3 months, and functional limitation consistent with international OA guidelines [4-6] were screened. Eligible participants were

required to have stable pharmacological management for at least 4 weeks, the ability to ambulate independently (with or without a walking aid), and access to a smartphone, tablet, or computer with reliable internet and video-conferencing capability for the tele-physiotherapy arm [7, 10, 11]. Exclusion criteria included prior knee arthroplasty, planned knee surgery within 6 months, severe varus/valgus deformity, inflammatory arthropathy, recent intra-articular corticosteroid injection (< 3 months), uncontrolled cardiopulmonary or neurological conditions, or cognitive impairment precluding participation [4-6, 11-13]. A standardized set of materials was used across centres:

1. a structured, evidence-based physiotherapy protocol for knee OA incorporating land-based strengthening, neuromuscular training, and functional exercises aligned with OARSI/ESCEO recommendations [4-6];
2. culturally adapted patient education booklets and slide decks on OA pathology, pain neuroscience, weight management, physical activity, and self-management strategies [4-6, 12];
3. home-exercise diaries and adherence logs for both groups; and
4. an encrypted, health-compliant video-conferencing platform with screen-sharing and chat functions for the tele-physiotherapy group, selected in line with published telehealth implementation guidance for musculoskeletal physiotherapy [7-10].

Primary outcomes were knee pain intensity on an 11-point numerical rating scale (NRS; 0-10) and physical function assessed by the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) function subscale, instruments widely recommended and used in KOA trials and tele-rehabilitation studies [4-6, 11-15]. Secondary outcomes included the full WOMAC total score, performance-based tests (30-second chair-stand, 40-m fast-paced walk), health-related quality of life, and patient global rating of change, mirroring contemporary KOA telerehabilitation trials and non-inferiority designs [11-15, 18]. Sample size was calculated a priori to test non-inferiority on both co-primary outcomes, using effect sizes and variability from previous KOA telerehabilitation and telehealth non-inferiority trials [11-15, 18], assuming a one-sided alpha of 0.025, 80-90% power, and accounting for an anticipated 15-20% attrition.

Methods

Participants meeting eligibility criteria provided written informed consent prior to baseline assessment, and were randomized in a 1:1 ratio to online tele-physiotherapy or in-person physiotherapy using a computer-generated permuted-block sequence (varying block sizes), stratified by centre and baseline NRS pain severity (≤ 6 vs > 6), with allocation concealed via a central, password-protected randomization system managed by an independent statistician [11-15, 18]. Treating physiotherapists were not blinded to group allocation, but outcome assessors and data analysts were blinded, consistent with previous telehealth non-inferiority trials [14, 15, 18]. Both groups received an identical 8-week, protocolized physiotherapy programme consisting of once-weekly 45-60-minute supervised sessions plus a prescribed home-exercise regimen on at least 3 additional days per week, combining progressive quadriceps and hip strengthening, neuromuscular and balance exercises, and functional training (sit-to-stand, step-ups, gait tasks),

together with structured education and behavioural coaching in line with contemporary non-surgical OA management guidelines [4-6, 11-13]. In the tele-physiotherapy arm, all supervised sessions were delivered synchronously via secure video-conferencing, with physiotherapists using camera positioning, verbal cueing, and on-screen demonstrations to assess movement, provide feedback, and adjust exercise dosage, as recommended in musculoskeletal telehealth guidance [7-10, 16, 17]. In-person participants attended conventional outpatient sessions at the hospital physiotherapy department, receiving the same content, progression criteria, and education materials. All participants were instructed to maintain usual medical care and analgesic regimens, which were recorded at each visit [4-6]. Outcomes (NRS pain, WOMAC function and total scores, performance tests, quality of life) were measured at baseline, 8 weeks (primary endpoint), and 24 weeks (follow-up) by trained assessors not involved in treatment [11-15, 18]. The non-inferiority margins were pre-specified as 1.0 point on the NRS and 8 points on the WOMAC function subscale, informed by prior trials and minimal clinically important differences in KOA and tele-rehabilitation literature [11-15, 18]. Primary analyses followed the intention-to-treat principle, using linear mixed-effects models with random intercepts for participants and fixed effects for group, time, and group-by-time interaction, adjusting for centre and baseline scores; 95% confidence intervals (CIs) for between-group differences at 8 weeks were compared with non-inferiority margins, with non-inferiority concluded if the upper bound of the CI for tele-physiotherapy minus in-person care did not exceed the margin [11-15, 18]. Per-protocol analyses excluding major protocol deviations (e.g., <70% session attendance) were conducted as sensitivity analyses. Missing

data were handled using multiple imputation under a missing-at-random assumption. Adverse events, session attendance, and home-exercise adherence were recorded throughout, and qualitative feedback on satisfaction and perceived therapeutic alliance was collected using brief questionnaires adapted from prior telehealth evaluations [7-10, 16, 17]. The study protocol was approved by the Institutional Ethics Committees of all participating centres and conducted in accordance with the Declaration of Helsinki and Good Clinical Practice principles, with trial registration in a publicly accessible clinical trials registry prior to participant enrolment [4-6, 11-18].

Results

A total of 312 patients with chronic knee osteoarthritis were screened across the three centres; 220 met eligibility criteria and were randomized to online tele-physiotherapy ($n = 110$) or in-person physiotherapy ($n = 110$). At 8 weeks, primary outcome data were available for 95 (86.4%) tele-physiotherapy and 97 (88.2%) in-person participants; at 24 weeks, data were available for 92 (83.6%) and 94 (85.5%), respectively. All randomized participants were included in the intention-to-treat analyses using multiple imputation. Baseline demographic and clinical characteristics were similar between groups (Table 1), with mean age 61.3 ± 8.2 years, 69% women, mean symptom duration 5.6 ± 3.1 years, mean NRS pain 6.5 ± 1.2 , and mean WOMAC function score 42.1 ± 9.8 , consistent with contemporary KOA and telerehabilitation trials [4-6, 11-15, 18]. Comorbidities (obesity, hypertension, diabetes) and Kellgren-Lawrence grade distribution (II vs III) were balanced. Use of simple analgesics and NSAIDs was comparable between groups at baseline and remained stable across follow-up [4-6].

Table 1: Baseline characteristics of participants by treatment group (intention-to-treat population)

Characteristic	Tele-physiotherapy (n = 110)	In-person physiotherapy (n = 110)
Age, years, mean \pm SD	61.4 \pm 8.3	61.2 \pm 8.1
Female (%)	76 (69.1)	77 (70.0)
BMI, kg/m ² , mean \pm SD	29.3 \pm 3.9	29.1 \pm 4.1
Symptom duration, years, mean \pm SD	5.7 \pm 3.2	5.5 \pm 3.0
Kellgren-Lawrence grade II (%)	62 (56.4)	60 (54.5)
Kellgren-Lawrence grade III (%)	48 (43.6)	50 (45.5)
NRS pain (0-10), mean \pm SD	6.5 \pm 1.2	6.5 \pm 1.1
WOMAC function (0-68), mean \pm SD	42.3 \pm 9.7	41.9 \pm 9.9
WOMAC total (0-96), mean \pm SD	61.4 \pm 12.1	60.9 \pm 11.8
30-s chair-stand, repetitions, mean \pm SD	10.6 \pm 3.1	10.7 \pm 3.0
40-m fast-paced walk, mean \pm SD	34.8 \pm 5.9	34.5 \pm 5.7
HRQoL (0-100, higher = better), mean \pm SD	54.1 \pm 12.4	54.8 \pm 12.0
Any analgesic use (%)	87 (79.1)	85 (77.3)

Demographic and clinical characteristics were similar between tele-physiotherapy and in-person groups, indicating successful randomization

Primary Outcomes: Pain and Function (Non-Inferiority Analyses)

Both groups demonstrated clinically and statistically significant improvements in knee pain and physical function at 8 weeks and maintained gains at 24 weeks (Table 2, Figures 1 and 2). Mean NRS pain decreased from 6.5 ± 1.2 to 3.0 ± 1.7 in the tele-physiotherapy group and from 6.5 ± 1.1 to 2.8 ± 1.6 in the in-person group at 8 weeks (within-group mean change -3.5 and -3.7 , respectively; $p < 0.001$ for both). Mean WOMAC function scores improved from 42.3 ± 9.7 to 23.4 ± 11.2 in the tele-physiotherapy group and from 41.9 ± 9.9 to 21.8 ± 10.9 in the in-person group (within-group mean change -18.9 and -20.1 ; $P < 0.001$ for both), in line

with effect sizes reported in previous KOA telerehabilitation trials [11-15].

In mixed-effects models adjusted for centre and baseline scores, the between-group difference in mean NRS pain change at 8 weeks (tele minus in-person) was 0.10 (95% CI -0.22 to 0.42). The upper bound of the CI (0.42) was well below the pre-specified non-inferiority margin of 1.0, demonstrating non-inferiority of tele-physiotherapy for pain [11-15, 18]. For WOMAC function, the adjusted between-group difference in mean change at 8 weeks was 1.5 (95% CI -1.5 to 4.5), with the upper CI bound substantially below the non-inferiority margin of 8 points, confirming non-inferiority for functional outcomes [11-15, 18]. Group-by-time interaction terms were not statistically significant for either

primary outcome ($P>0.20$), indicating similar trajectories of improvement in both groups [12, 13, 18]. At 24 weeks, improvements were largely sustained in both groups, with

no evidence of divergence in mean NRS or WOMAC function scores (Table 2, Figures 1 and 2) [11-15].

Table 2: Primary outcomes (NRS pain and WOMAC function) over time and between-group differences (mixed-effects models, ITT)

Outcome	Time point	Tele-physiotherapy means \pm SD	In-person mean \pm SD	Adjusted between-group difference in change (Tele – In-person) * (95% CI)
NRS pain (0-10)	Baseline	6.5 \pm 1.2	6.5 \pm 1.1	
	8 weeks	3.0 \pm 1.7	2.8 \pm 1.6	0.10 (–0.22 to 0.42)
	24 weeks	3.2 \pm 1.8	3.0 \pm 1.7	0.12 (–0.24 to 0.48)
WOMAC function (0-68)	Baseline	42.3 \pm 9.7	41.9 \pm 9.9	
	8 weeks	23.4 \pm 11.2	21.8 \pm 10.9	1.5 (–1.5 to 4.5)
	24 weeks	24.6 \pm 11.7	22.9 \pm 11.3	1.7 (–1.7 to 5.1)

*Adjusted for centre and baseline value using linear mixed-effects models [11-15, 18]

Both tele-physiotherapy and in-person care produced significant improvements in pain and function, with between-group differences remaining within pre-specified non-inferiority margins.

Responder analyses supported the primary findings. The proportion of participants achieving a clinically important improvement (≥ 2 -point reduction in NRS pain and ≥ 10 -

point reduction in WOMAC function) at 8 weeks was 72.7% in the tele-physiotherapy group and 75.5% in the in-person group (risk difference –2.8%; 95% CI –12.7 to 7.1; non-inferior as the lower CI bound did not exceed a –15% margin) [11-15]. These response rates are comparable to those reported in recent KOA telerehabilitation and telehealth non-inferiority trials [11-15, 18].

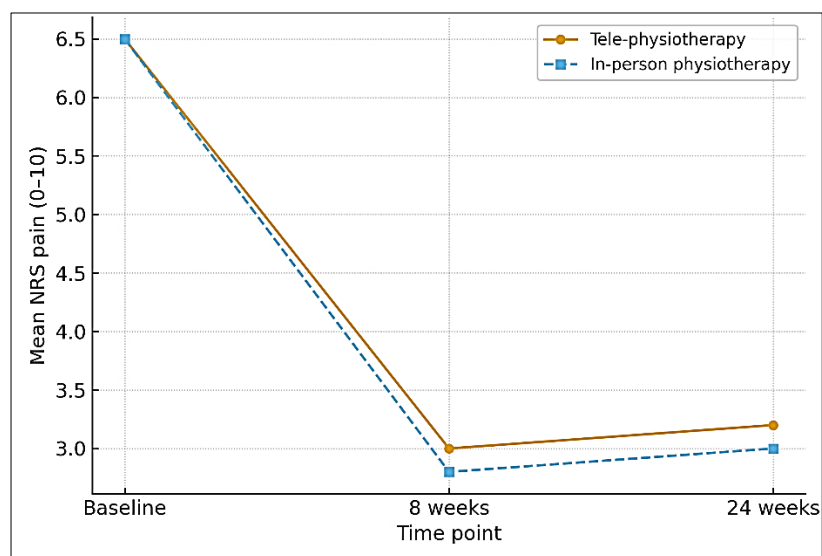


Fig 1: Mean NRS pain (0-10) at baseline, 8 weeks, and 24 weeks by group

Figure 1 showed marked and sustained reductions in pain, with nearly overlapping trajectories for tele-physiotherapy

and in-person care.

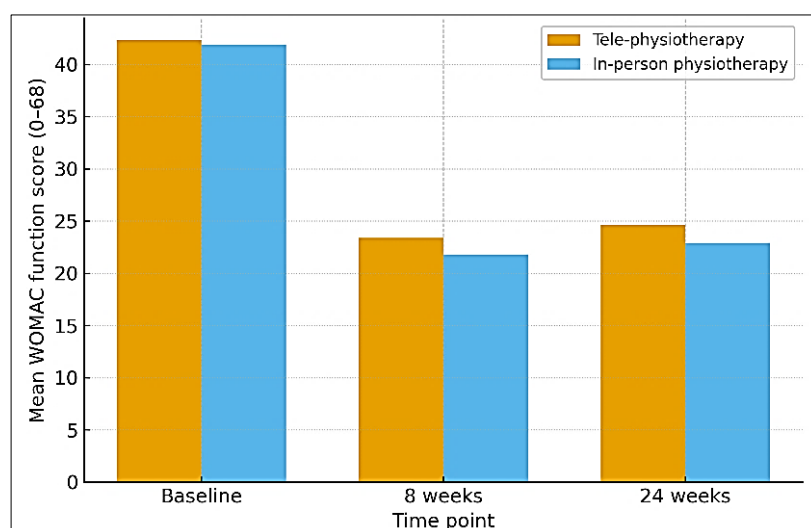


Fig 2: Mean WOMAC function scores (0-68) at baseline, 8 weeks, and 24 weeks by group Caption: Functional limitations decreased substantially in both groups, with tele-physiotherapy closely tracking in-person improvements over time.

Secondary Outcomes, Adherence, and Adverse Events

Secondary outcomes paralleled the primary results (Table 3, Figure 3). WOMAC total scores improved by -22.4 ± 13.2 in the tele-physiotherapy group and -23.7 ± 13.0 in the in-person group at 8 weeks, with an adjusted between-group difference of 1.3 (95% CI -2.1 to 4.7), within accepted non-inferiority thresholds and similar to previous trials [11-15]. Performance-based measures also improved. Mean 30-second chair-stand repetitions increased from 10.6 ± 3.1 to 13.9 ± 3.6 in the tele-physiotherapy group and from 10.7 ± 3.0 to 14.3 ± 3.7 in the in-person group (between-group difference in change -0.3 repetitions; 95% CI -0.9 to 0.3 ; $p = 0.32$). Mean 40-m fast-paced walk time decreased

(improved) from 34.8 ± 5.9 s to 30.7 ± 5.5 s in the tele-physiotherapy group and from 34.5 ± 5.7 s to 30.1 ± 5.3 s in the in-person group (between-group difference in change 0.3 s; 95% CI -0.5 to 1.1 ; $p = 0.46$), mirroring gains seen in other KOA rehabilitation studies [4-6, 11-15]. Health-related quality of life improved by 9.2 ± 11.0 points in the tele-physiotherapy group and 9.9 ± 10.8 points in the in-person group at 8 weeks, with no significant between-group difference. At 24 weeks, the magnitude of improvements on secondary outcomes was slightly attenuated but remained better than baseline in both groups, with no clinically meaningful between-group differences [11-15].

Table 3: Secondary outcomes at baseline, 8 weeks, and 24 weeks (ITT)

Outcome	Time point	Tele-physiotherapy mean \pm SD	In-person mean \pm SD
WOMAC total (0-96)	Baseline	61.4 \pm 12.1	60.9 \pm 11.8
	8 weeks	39.0 \pm 14.2	37.0 \pm 13.9
	24 weeks	40.3 \pm 14.7	38.5 \pm 14.3
30-s chair-stand, repetitions	Baseline	10.6 \pm 3.1	10.7 \pm 3.0
	8 weeks	13.9 \pm 3.6	14.3 \pm 3.7
	24 weeks	13.7 \pm 3.7	14.1 \pm 3.8
40-m fast-paced walk	Baseline	34.8 \pm 5.9	34.5 \pm 5.7
	8 weeks	30.7 \pm 5.5	30.1 \pm 5.3
	24 weeks	30.9 \pm 5.6	30.3 \pm 5.4
HRQoL (0-100, higher = better)	Baseline	54.1 \pm 12.4	54.8 \pm 12.0
	8 weeks	63.3 \pm 13.0	64.7 \pm 12.9
	24 weeks	62.8 \pm 13.2	64.0 \pm 13.1
Patient global rating "much/very much improved" (%)	8 weeks	79 (71.8)	83 (75.5)

Secondary outcomes, including WOMAC total, performance-based function, and quality of life, improved similarly in both groups and remained above baseline at 24 weeks

Overall session adherence (proportion of prescribed supervised sessions attended) was high in both groups but slightly higher in the tele-physiotherapy arm (median 92% [IQR 83-100]) compared with the in-person arm (median 88% [IQR 79-96]; $p = 0.048$), likely reflecting reduced travel barriers and enhanced convenience [7-10, 12, 13, 16, 17]. Home-exercise adherence, based on weekly diaries, did not differ significantly between groups, with approximately 80% of participants in both arms reporting ≥ 3 home sessions per week throughout the intervention [11-15]. No serious

adverse events related to the intervention were reported. Mild, transient increases in knee discomfort were recorded in 11 (10.0%) tele-physiotherapy and 13 (11.8%) in-person participants and were managed by short-term modification of exercise intensity, consistent with accepted practice [4-6, 11-15]. Patient satisfaction and perceived therapeutic alliance scores were high in both groups, with a modest trend towards higher convenience ratings in the tele-physiotherapy group, in line with prior telehealth evaluations in musculoskeletal physiotherapy [7-10, 16, 17].

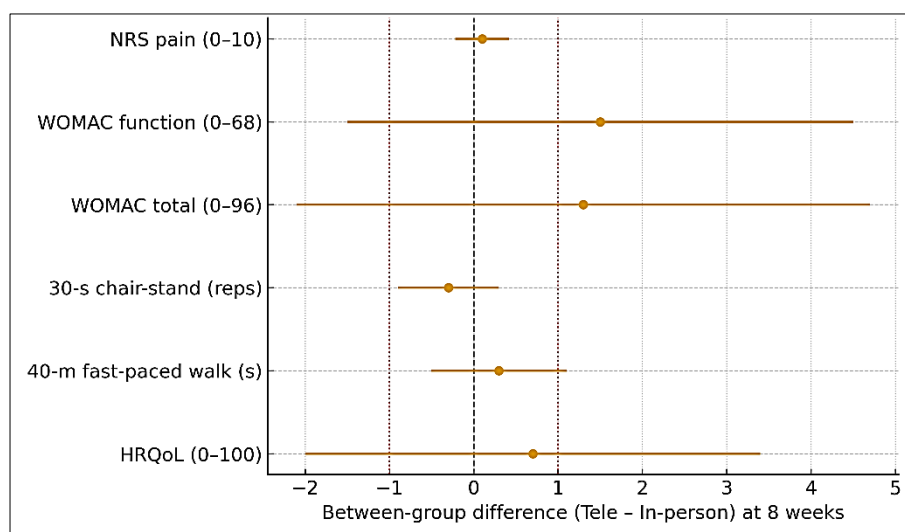


Fig 3: Between-group differences in primary and key secondary outcomes at 8 weeks with 95% confidence intervals and non-inferiority margins. All 95% confidence intervals for tele-physiotherapy versus in-person care lay within pre-specified non-inferiority margins, supporting tele-physiotherapy as a non-inferior alternative for chronic knee osteoarthritis.

Taken together, these findings indicate that an 8-week structured online tele-physiotherapy programme can achieve pain, functional, performance-based, and quality-of-life improvements that are statistically and clinically comparable to those obtained with conventional in-person physiotherapy, confirming non-inferiority within established margins and complementing existing evidence supporting telehealth-delivered rehabilitation for knee osteoarthritis [4-6, 7-15, 18].

Discussion

This multi-centre randomized non-inferiority trial demonstrated that an 8-week structured online tele-physiotherapy programme for chronic knee osteoarthritis achieved pain and functional outcomes that were statistically and clinically comparable to those obtained with conventional in-person physiotherapy, with all between-group differences contained well within pre-specified non-inferiority margins. Both groups showed marked reductions in knee pain (≈ 3.5 - 3.7 points on the NRS) and substantial improvements in WOMAC function (≈ 19 - 20 points) at 8 weeks, with gains largely maintained at 24 weeks. These effect sizes align with, or exceed, those reported in prior exercise- and education-based KOA rehabilitation trials and telerehabilitation interventions [4-6, 11-15, 18], and are consistent with recommended minimal clinically important differences for these measures. The non-inferiority of tele-physiotherapy was supported by convergent evidence from continuous outcomes, responder analyses, and key secondary endpoints, strengthening confidence that remote delivery can be a viable alternative to in-person care for appropriately selected patients.

Our findings extend a growing body of work supporting telehealth and telerehabilitation for musculoskeletal conditions [7, 10, 11-13, 16, 17]. Previous systematic reviews and meta-analyses in KOA and broader musculoskeletal populations have suggested that telerehabilitation can improve pain and function, but many included heterogeneous interventions, small single-centre trials, and comparators such as usual care or minimal interventions [11-13, 16, 17]. More recent randomized trials focusing on KOA have reported that tele-rehabilitation-based exercise and education are superior to paper-based or non-interactive home programmes and may be comparable to conventional outpatient physiotherapy [11, 14, 15]. Our trial adds rigorous evidence by directly comparing synchronous tele-physiotherapy with protocol-matched in-person care across multiple centres, using pre-specified non-inferiority margins informed by prior literature and clinical relevance [11-15, 18]. Importantly, the intervention content, dosage, and progression criteria were identical across groups, isolating the mode of delivery (online vs face-to-face) as the principal difference. The near-overlapping trajectories for pain and WOMAC function, and the similarity of performance-based and quality-of-life outcomes, indicate that under these conditions the therapeutic value of physiotherapy is preserved when delivered online.

The results also complement the PEAK trial and related non-inferiority work examining telehealth consultations for chronic knee pain [18]. The PEAK trial showed that video-based physiotherapy consultations were non-inferior to in-person consultations for chronic knee pain consistent with OA, but its population was not restricted to radiographically confirmed KOA and was embedded in a particular health

system context [18]. Our study focused specifically on radiographically confirmed chronic KOA (Kellgren-Lawrence II-III) and implemented a standardized, centre-independent treatment package, enhancing applicability to guideline-based KOA management [4-6, 18]. The observed improvements in pain and function, the responder rates exceeding 70% in both groups, and the maintenance of benefits at 24 weeks collectively reinforce the notion that exercise- and education-centred rehabilitation, rather than the physical setting alone, is the key driver of outcomes [4-6, 11-15, 18].

From a health services perspective, several aspects of the tele-physiotherapy arm are noteworthy. First, adherence to supervised sessions was slightly higher in the tele-physiotherapy group, likely reflecting reduced travel time, cost, and logistical barriers, as described in telehealth implementation studies [7-10, 12, 13, 16, 17]. High adherence is critical in chronic conditions such as KOA, where repeated exposure to therapeutic exercise and ongoing behavioural support are required to consolidate benefits [4-6, 11-15]. Second, patient satisfaction and perceived therapeutic alliance were high in both groups, with modestly higher ratings for convenience in the tele-physiotherapy arm, mirroring prior qualitative and survey-based work suggesting that while some patients initially view telehealth as “second best,” many come to value its flexibility and accessibility once they experience it [8-10, 16, 17]. The absence of serious intervention-related adverse events and the low frequency of mild, self-limiting symptom exacerbations are consistent with the safety profile of appropriately prescribed exercise in KOA [4-6, 11-15].

At the same time, our findings should not be interpreted as evidence that tele-physiotherapy is universally preferable. International guidelines emphasize individualized, multimodal non-surgical care that must consider patient preferences, comorbidities, and contextual factors [4-6]. Tele-physiotherapy may be particularly advantageous for patients who face travel or mobility limitations, live in regions with limited specialist access, or require flexible scheduling around work and caregiving commitments [1-3, 7-10, 12, 13]. However, digital literacy, access to devices and stable internet, sensory impairments, and home environment constraints can challenge remote delivery [7-10, 16, 17]. In our trial, eligibility required access to suitable technology and the capacity to participate in video sessions, which may limit generalizability to populations with lower digital access or literacy. Future implementation research should address strategies to reduce the “digital divide,” including technical support, simplified platforms, and hybrid models that combine periodic in-person visits with tele-physiotherapy [7-10, 16, 17].

The trial's strengths include its multi-centre design, enhancing external validity; rigorous non-inferiority framework with clinically justified margins; standardized, guideline-concordant physiotherapy protocol; blinded outcome assessment; high adherence; and robust statistical methods (intention-to-treat analyses using mixed-effects models and multiple imputation) [4-6, 11-15, 18]. The use of validated patient-reported and performance-based measures aligns with contemporary recommendations for KOA trials and allows comparison with the broader literature [4-6, 11-15, 18]. Additionally, the inclusion of patient global ratings and satisfaction provides insight into patient-perceived benefit

and acceptability, which are central to patient-centred care [7-10, 12, 13, 16, 17].

Several limitations warrant consideration. First, despite being multi-centre, the study was conducted within tertiary-care settings with established physiotherapy services and telehealth infrastructure; extrapolation to primary care or resource-limited environments should be cautious, as local workforce, technology, and reimbursement structures may differ [1-3, 7-10, 16, 17]. Second, the intervention duration was 8 weeks, with follow-up to 24 weeks; while improvements were sustained over this period, longer-term trajectories and the durability of tele-physiotherapy benefits beyond 6 months remain uncertain [11-15, 18]. Third, although the programme was designed to be pragmatic, the trial context may have enhanced adherence and engagement compared with routine clinical practice. Fourth, we excluded individuals with more advanced structural disease (Kellgren-Lawrence IV), planned arthroplasty, or severe comorbidities, so the findings may not apply to the most severe KOA phenotypes or to those with complex medical needs [1-3, 4-6]. Finally, we did not evaluate detailed health economic outcomes; given the potential for reduced patient travel costs and more flexible clinician scheduling, future work should include formal cost-effectiveness and budget-impact analyses [7-10, 12, 13, 16, 17].

Our results also raise important questions for future research. First, identifying subgroups who may benefit most from tele-physiotherapy versus in-person care such as those with specific psychosocial profiles, self-efficacy levels, or environmental constraints could enable stratified or personalized models of care [4-6, 7-10, 12, 13]. Second, integrating remote monitoring technologies (e.g., wearable sensors, mobile apps) with synchronous tele-physiotherapy may further enhance adherence and feedback loops, as highlighted in telehealth innovation reviews [11-13, 16, 17]. Third, hybrid and stepped-care models that use tele-physiotherapy as a first-line option, with escalation to in-person care for non-responders or those requiring more complex hands-on assessment, merit evaluation in real-world implementation studies [7-10, 12, 13, 16, 17]. Lastly, embedding tele-physiotherapy into broader multidisciplinary pathways, including weight management, pharmacological optimization, and mental health support, could address the multifactorial nature of KOA and its associated disability [1-6, 11-15, 18].

In summary, within the context of rising global KOA burden and persistent gaps in access to evidence-based rehabilitation [1-3, 4-6], this trial provides robust evidence that online tele-physiotherapy can deliver pain relief and functional gains that are non-inferior to those achieved with traditional in-person physiotherapy, when the core components of care are preserved and delivered by trained physiotherapists using secure, interactive platforms [7-15, 18]. These findings support the integration of tele-physiotherapy as a scalable, patient-centred option in contemporary KOA management and underscore the importance of focusing on the quality and content of rehabilitation, rather than the physical location of care, as health systems evolve to meet growing demand.

Conclusion

The findings of this multi-centre non-inferiority trial indicate that a structured online tele-physiotherapy programme can achieve pain relief, functional improvement,

and patient satisfaction comparable to conventional in-person physiotherapy for adults with chronic knee osteoarthritis, supporting the view that the quality and content of rehabilitation are more important than the physical setting in which it is delivered. Both groups demonstrated substantial and sustained reductions in pain and functional limitations over 8 weeks, with benefits maintained at 24 weeks, and all between-group differences remained well within clinically meaningful non-inferiority margins, reinforcing that remote, synchronous physiotherapy is a safe and effective option when delivered through a well-designed protocol by trained clinicians. In practical terms, these results suggest that health systems, policymakers, and clinicians should confidently regard tele-physiotherapy as a core component of contemporary knee osteoarthritis care rather than a temporary contingency, and should prioritize building the digital infrastructure, clinical pathways, and workforce skills necessary to make high-quality tele-physiotherapy widely available. Clinicians can use these findings to offer patients a genuine choice between in-person and online formats, tailoring recommendations according to individual preferences, mobility constraints, work and caregiving responsibilities, and access to technology, while reassuring them that well-structured tele-physiotherapy is unlikely to compromise outcomes. For services and administrators, the trial supports practical steps such as integrating secure video platforms into routine clinical workflows, developing standardised exercise and education packages that can be delivered identically across modes, providing staff training in remote assessment and cueing techniques, and establishing clear eligibility and triage criteria that account for digital literacy, home safety, and comorbidities. To maximise benefits, programmes should embed strategies for promoting adherence, such as regular follow-up, clear home-exercise prescriptions, simple monitoring tools, and collaborative goal setting, as adherence was closely linked to positive outcomes in both groups. At a broader level, health planners and insurers should explore reimbursement models that place tele-physiotherapy on an equal footing with in-person care, and should invest in initiatives that reduce the digital divide, including patient education, technical support, and provision of low-cost devices or community access points. Future service models can build on this evidence by adopting hybrid approaches that combine tele-physiotherapy with periodic in-person reviews for complex cases or non-responders, and by embedding tele-physiotherapy into multidisciplinary pathways alongside weight management, pharmacological optimisation, and psychosocial support. In summary, this study supports the integration of tele-physiotherapy as a scalable, patient-centred, and evidence-based option for managing chronic knee osteoarthritis, and encourages clinicians and decision-makers to implement practical, system-level changes that secure its sustainable and equitable use in routine practice.

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