

sEMG-Neuromuscular Biofeedback-Led Telerehabilitation Post Robot-Assisted Total Knee Arthroplasty: A Randomised Trial.

Dheeraj Kumar, Jasmine Kaur Chawla

Original Article

Abstract

Background.

Arthrogenic muscle inhibition (AMI) of the quadriceps is a well-documented neuromuscular impairment after total knee arthroplasty (TKA) and is a key barrier to early functional recovery. Surface electromyographic (sEMG) biofeedback can target AMI by providing real-time, quantitative knowledge of voluntary motor output. We tested whether sEMG-led telerehabilitation, produces knee range of motion (ROM) and Knee Injury and Osteoarthritis Outcome Score (KOOS) outcomes comparable to conventional in-person physiotherapy following robot-assisted TKA (RA-TKA).

Methods.

Thirty patients were recruited at hospital discharge after RA-TKA and randomised 1:1 to sEMG-guided telerehabilitation (n = 15) or conventional in-person physiotherapy (n = 15). Both arms followed an identical two-week, daily structured exercise programme; the sEMG arm received real-time biofeedback via a wireless Trigno Discover sensor (Delsys) with synchronous video supervision. Outcomes were active knee flexion, extension deficit, and the five KOOS subscales, assessed at baseline (discharge) and at two weeks. Outcome assessors were blinded to allocation.

Results.

Both groups showed large within-group improvements across every outcome (all $p < 0.001$; Cohen's d_z 2.49–3.79). Active knee flexion improved from $88.27 \pm 2.96^\circ$ to $108.60 \pm 7.70^\circ$ in the sEMG arm ($\Delta +20.33^\circ$, 95% CI 17.23–23.44) and from $87.13 \pm 2.67^\circ$ to $107.40 \pm 6.58^\circ$ in the conventional arm ($\Delta +20.27^\circ$, 95% CI 16.85–23.68). KOOS-QoL improved by +57.93 points (sEMG) versus +54.17 points (conventional) ($p = 0.612$). Between-group analyses favoured sEMG on KOOS-Sport/Recreation ($\Delta +14.67$ points; $d = 1.12$) and KOOS-ADL (Mann-Whitney $p = 0.030$).

Conclusions.

sEMG-led telerehabilitation produced clinically equivalent ROM and KOOS outcomes to in-person physiotherapy in the early post-RA-TKA period, with a signal of advantage on higher-demand functional subscales. Findings support sEMG-led telerehabilitation as a viable neurorehabilitation modality where access to in-person specialist physiotherapy is constrained.

Trial registration.

Clinical Trial Registry, India: REF/2025/02/099521.

JK-Practitioner2026;31(3):88-94

Introduction

Knee osteoarthritis (OA) is the most prevalent degenerative joint disease worldwide, characterised by progressive articular cartilage degradation, subchondral bone remodelling, synovial inflammation and periarticular muscle weakness [1]. Its global burden is projected to increase by 74.9% by 2050 [2]. In India, the reported prevalence ranges from 22% to 39% of the adult population, with women and individuals aged over 65 years most affected [3]. Total knee arthroplasty (TKA) is the gold-standard surgical intervention for end-stage knee OA [4], and recent advances such as MAKO robotic-arm-assisted TKA (RA-TKA) offer pre-operative three-dimensional planning and intra-operative haptic guidance, improving implant alignment, soft-tissue balancing and short-term functional recovery [5-7].

Despite these surgical advances, recovery of quadriceps strength, joint ROM and patient-reported function depends critically on early post-operative rehabilitation [8]. A central neuromuscular impediment to this recovery is arthrogenic muscle inhibition (AMI) which is a reflex-mediated, ongoing failure of voluntary motor drive to the quadriceps that persists after the underlying joint pathology has been corrected [9,10]. AMI involves altered afferent input from the operated joint, attenuation

Author Affiliations

Dheeraj Kumar, PhD Scholar; **Jasmine Kaur Chawla**, Associate Professor: Department of Physiotherapy, School of Allied Health Sciences, Manav Rachna International Institute of Research and Studies, Faridabad, Haryana, India.

Correspondence

Jasmine Kaur Chawla

Department of Physiotherapy, School of Allied Health Sciences, Manav Rachna International Institute of Research and Studies, Faridabad-121003, Haryana, India.
Email : jasmine.k.chawla@gmail.com

Indexed

EMBASE, SCOPUS, IndMED, EMBSCO, Google Scholar besides other national and international databases.

Cite this article as

Kumar D, Chawla JK. sEMG-Neuromuscular Biofeedback-Led Telerehabilitation Post Robot-Assisted Total Knee Arthroplasty: A Randomised Trial. JK Pract 2026;31(3):88-94.

Full length article available at jkpractitioner.com one month after publication

Keywords

surface electromyography; telerehabilitation; arthrogenic muscle inhibition; motor relearning; total knee arthroplasty

of cortical motor drive and impaired motor-unit recruitment, and can persist for weeks to months after TKA. Effective post-operative rehabilitation is therefore not only a problem of joint mobility but also a problem of motor relearning.

Surface electromyography (sEMG) biofeedback is well-suited to this motor-relearning problem. sEMG sensors placed over target muscles transduce motor-unit electrical activity into a real-time, quantitative signal of voluntary recruitment, allowing the patient to act as an augmented observer of their own motor output [11-13]. By converting an otherwise opaque neural process into immediate visual feedback, sEMG biofeedback can directly target AMI, drive cortical motor activation and reveal compensatory or asymmetric recruitment patterns that escape visual or palpatory observation.

Telerehabilitation is the remote delivery of rehabilitation services via digital platforms, video conferencing and wearable sensors that has emerged as a scalable alternative when access to in-person physiotherapy is constrained by cost, distance or caregiver availability [14,15]. Meta-analyses in the TKA population indicate that telerehabilitation produces ROM, pain and functional outcomes comparable to, and on some measures superior to, in-person care [16-18]. Preoperative telerehabilitation in TKA candidates has been shown to improve quadriceps strength and knee ROM [19], and wearable sensor-based platforms have demonstrated promise in knee OA more broadly [20]. However, the use of sEMG as the directing biofeedback modality within a post-operative RA-TKA telerehabilitation model has not, to our knowledge, been examined.

Anatomical recovery alone does not capture surgical success; Knee Injury and Osteoarthritis Outcome Score (KOOS) are now recognised as primary indicators of outcome [21]. The KOOS is a knee-specific instrument comprising five subscales Pain, Symptoms, Activities of Daily Living (ADL), Sport and Recreation, and Quality of Life with good reliability, validity and responsiveness to change after TKA [22-24].

The aim of this Research Note was to evaluate whether sEMG-led telerehabilitation, by targeting AMI through real-time neuromuscular biofeedback, produces ROM and KOOS outcomes comparable to those of conventional in-person physiotherapy in patients in the early post-RA-TKA period.

Materials & Methods

Study design

This was a two-arm parallel-group randomised controlled trial conducted in accordance with the Consolidated Standards of Reporting Trials (CONSORT) 2010 guidelines [25] and the principles of the Declaration of Helsinki [26]. The study was approved by the Institutional Ethics Committee of Manav Rachna International Institute of Research and Studies (EC/2024-25/060) and prospectively registered with the Clinical Trial Registry India (REF/2025/02/099521). Written informed consent was obtained from every participant. participant flow is

Participants

Thirty consecutive patients who had undergone RA-TKA were recruited from a single orthopaedic surgical unit at the time of hospital discharge. Inclusion criteria were: (i) age 50–80 years; (ii) no previous TKA; (iii) ability to read and write English; (iv) personal smartphone with the ability to use applications; and (v) willingness to participate and complete the intervention [27]. Exclusion criteria were rheumatoid arthritis or other systemic inflammatory diseases, current or past neurological or cognitive disorders, and unforeseen complications precluding adherence [27]. The trial was designed as a pilot study aimed at detecting a between-group effect size of $d \geq 0.8$ on the primary outcome (active knee flexion) at $\alpha = 0.05$ and 80% power; the resulting per-arm sample of $n = 15$ should be regarded as preliminary, with effect estimates intended to inform a larger confirmatory study.

Randomisation, allocation concealment and blinding

Participants were randomised 1:1 to sEMG telerehabilitation or conventional in-person physiotherapy using a computer-generated random number sequence prepared by an independent statistician [28]. Allocation was concealed in sequentially numbered, opaque, sealed envelopes opened by the recruiting physiotherapist at the point of enrolment [29]. Blinding of participants and treating therapists was not feasible given the nature of the interventions; however, outcome assessors performing goniometry and administering the KOOS were blinded to allocation throughout the two-week follow-up [30].

Interventions

Both groups commenced rehabilitation under inpatient physiotherapy supervision from postoperative day one and continued for two weeks after hospital discharge in their allocated mode (telerehabilitation or in-person). The exercise programme was fully standardised in content, progression criteria and session duration; the only differential was the mode of delivery and the presence of sEMG biofeedback.

sEMG telerehabilitation group. Participants performed home-based rehabilitation exercises guided by a wireless Trigno Discover sEMG system (Delsys, USA), which transmitted muscle-activation data in real time to a dedicated tablet application and provided continuous visual biofeedback on muscle recruitment during therapeutic exercises [31]. Physiotherapists supervised sessions synchronously via Zoom, delivering verbal coaching, and reviewed sEMG recordings asynchronously between sessions to adjust exercise parameters. Sessions were conducted daily for two weeks (45–60 minutes per session) and comprised warm-up, progressive therapeutic exercise (quadriceps strengthening, active ROM, closed-kinetic-chain loading, balance and proprioceptive training, gait re-education) and cool-down.

Conventional rehabilitation group. Participants received individual, in-person physiotherapy at home from the same qualified physiotherapists who supervised the sEMG arm, at the same frequency (daily, 45–60

minutes per session, for two weeks). The same structured exercise programme was followed without sEMG monitoring or biofeedback; therapists used conventional clinical observation, tactile facilitation and verbal instruction.

Outcome measures

Primary outcomes were active knee flexion ROM and active extension deficit (residual flexion contracture), measured in degrees with a digital goniometer by the same blinded assessor. Flexion was measured in supine with the knee actively flexed through its maximum comfortable range; extension deficit was measured in prone with gravity-assisted extension. Three measurements were obtained at each time point and averaged. Assessments were performed at baseline (discharge, before commencement of the rehabilitation programme) and two weeks post-discharge.

Secondary outcomes were the five KOOS subscales [22]: Pain (9 items), Symptoms (7 items), ADL (17 items), Sport and Recreation (5 items) and Quality of Life (4 items). Each subscale is transformed to a 0–100 scale, with higher scores indicating better outcomes. The KOOS was self-completed at baseline and at two weeks, and subscale scores were calculated using the published scoring algorithm. All 30 participants completed every item at both time points.

Statistical analysis

Normally distributed continuous variables are presented as mean $\pm$ standard deviation; non-normally distributed variables as median (interquartile range). Between-group comparisons at baseline used independent-samples t-tests (Welch's correction where variances were unequal) and the Mann–Whitney U test for non-normal data. Within-group changes used paired-samples t-tests (Wilcoxon signed-rank tests where appropriate). Between-group post-intervention scores and change scores were compared with independent-samples t-tests or Mann–Whitney U tests as indicated. Effect sizes are reported as Cohen's d_z (paired), Cohen's d (independent) and the rank-biserial correlation r (non-parametric), with thresholds of small (≥ 0.2), medium (≥ 0.5) and large (≥ 0.8). Within-group comparisons were Bonferroni-adjusted; between-group comparisons were further corrected using the Benjamini–Hochberg false discovery rate. The threshold for statistical significance was $p < 0.05$. There were no missing data ($n = 30$).

Results

Participant flow and baseline characteristics

All 30 randomised participants completed the two-week intervention and both assessment points. No intervention-related adverse events were reported. Baseline demographic and clinical characteristics were comparable between groups (Table 1). Mean age was 65.1 ± 4.4 years in the sEMG arm and 66.6 ± 6.8 years in the conventional arm, with an identical 5:10 male-to-female ratio in each group. Baseline ROM and KOOS subscale scores were statistically comparable between the two groups.

Primary outcomes: Knee range of motion Active knee flexion improved by approximately 20° in both the

groups (Table 2): from $88.27 \pm 2.96^\circ$ to $108.60 \pm 7.70^\circ$ in the sEMG arm ($\Delta +20.33^\circ$; 95% CI 17.23–23.44; $p < 0.001$; $d_z = 3.31$) and from $87.13 \pm 2.67^\circ$ to $107.40 \pm 6.58^\circ$ in the conventional arm ($\Delta +20.27^\circ$; 95% CI 16.85–23.68; $p < 0.001$; $d_z = 3.00$). The between-group difference in flexion change was negligible (mean difference 0.07° ; $p = 0.978$; $d = 0.01$). Extension deficit decreased substantially in both groups, with near-complete resolution: sEMG $7.20 \pm 5.67^\circ$ to $3.07 \pm 2.74^\circ$ ($\Delta -4.13^\circ$; $p < 0.001$) and conventional median 10.0° (IQR 5.0–10.0) to 0.0° (IQR 0.0–5.0) ($\Delta -5.87^\circ$; $p < 0.001$). The between-group difference in extension change was not statistically significant ($p = 0.138$).

Secondary outcomes: KOOS subscales

All five KOOS subscales improved significantly within both groups (all $p < 0.001$; d_z 2.49–3.79; Table 3), with mean changes of +35 to +58 points, substantially above the minimal clinically important difference of 8–10 points reported for TKA populations. Post-intervention scores in the sEMG arm reached 89.43 (Pain), 83.57 (Symptoms), 93.72 (ADL), 67.67 (Sport/Rec) and 82.11 (QoL); corresponding scores in the conventional arm were 85.93, 81.42, 87.75, 53.00 and 79.20.

Between-group analysis favoured sEMG telerehabilitation on the higher-demand functional subscales. The largest difference was on KOOS-Sport/Recreation (sEMG 67.67 ± 11.32 vs conventional 53.00 ± 14.74 ; mean difference +14.67 points; $p = 0.005$; Cohen's $d = 1.12$, a large effect; Bonferroni-adjusted $p = 0.102$). KOOS-ADL also favoured sEMG (Mann–Whitney $p = 0.030$; $r = -0.47$; change-score advantage +9.97 points; $d = 0.67$). No between-group difference reached significance on KOOS-Pain, KOOS-Symptoms or KOOS-QoL ($p > 0.20$).

Discussion

This study shows that sEMG-led telerehabilitation produces ROM and KOOS outcomes broadly equivalent to in-person physiotherapy in the early post-RA-TKA period, with a clear signal of advantage on the higher-demand functional KOOS subscales (Sport/Recreation and ADL). Both interventions delivered statistically significant and clinically meaningful improvements across every primary and secondary outcome over two weeks (within-group $p < 0.001$; d_z 2.49–3.79).

The convergence of ROM outcomes between arms ($\Delta +20.33^\circ$ vs $+20.27^\circ$; $p = 0.978$) is consistent with previous meta-analyses showing that telerehabilitation matches or exceeds in-person care for ROM, pain and function after TKA [16–18]. Our two-week post-intervention flexion values (108.6° sEMG; 107.4° conventional) fall just short of the $\sim 110^\circ$ required for stair-climbing and low-level kneeling but exceed the $\sim 90^\circ$ required for sitting and chair transfers, indicating functionally meaningful gains by both delivery modes.

The between-group advantage favouring sEMG on KOOS-Sport/Recreation ($d = 1.12$) and KOOS-ADL is plausibly mediated by the neuromuscular mechanism we hypothesised. AMI of the quadriceps is well documented after knee surgery and reflects altered afferent discharge from the operated joint, attenuating

Table 1. Baseline demographic and clinical characteristics of the two groups.

Characteristic	sEMG Telerehab (n = 15)	Conventional Rehab (n = 15)
Age (years), Mean $\pm$ SD	65.13 $\pm$ 4.37	66.60 $\pm$ 6.82
Gender (Male / Female)	5 / 10	5 / 10
Surgical technique	RA-TKA	RA-TKA
Baseline flexion ROM (°)	88.27 $\pm$ 2.96	87.13 $\pm$ 2.67
Baseline extension deficit (°)	7.20 $\pm$ 5.67	8.13 $\pm$ 3.58
Baseline KOOS-Pain	42.24 $\pm$ 11.89	39.81 $\pm$ 15.91
Baseline KOOS-Symptoms	48.11 $\pm$ 9.24	40.71 $\pm$ 10.95
Baseline KOOS-ADL	37.36 $\pm$ 10.78	41.37 $\pm$ 13.31
Baseline KOOS-Sport/Rec	17.00 $\pm$ 13.99	13.67 $\pm$ 10.93
Baseline KOOS-QoL	24.19 $\pm$ 13.95	25.03 $\pm$ 13.15

Note. RA-TKA = robot-assisted total knee arthroplasty; KOOS = Knee Injury and Osteoarthritis Outcome Score; ADL = Activities of Daily Living; QoL = Quality of Life. Values are mean $\pm$ SD unless otherwise stated.

Table 2. Knee range of motion (degrees): pre- and post-intervention by group.

ROM measure	sEMG Pre	sEMG Post	sEMG Δ (95% CI)	Conv Pre	Conv Post	Conv Δ (95% CI)
Knee flexion (°)	88.27 $\pm$ 2.96	108.60 $\pm$ 7.70	+20.33 [17.23, 23.44]; p < 0.001*	87.13 $\pm$ 2.67	107.40 $\pm$ 6.58	+20.27 [16.85, 23.68]; p < 0.001*
Extension deficit (°)	7.20 $\pm$ 5.67	3.07 $\pm$ 2.74	-4.13 [-5.96, -2.31]; p < 0.001*	10.0 (5.0–10.0)†	0.0 (0.0–5.0)†	-5.87 [-7.04, -4.69]; p < 0.001*

Note. Conv = Conventional Physiotherapy; sEMG = sEMG-guided Telerehabilitation; Δ = mean change score (Post – Pre) with 95% CI. *Within-group p < 0.001 (paired t-test; Wilcoxon signed-rank for Conv extension deficit). Extension-deficit values represent residual flexion contracture; a negative Δ indicates improvement. †Median (IQR) reported for non-normally distributed data.

Table 3. KOOS subscale scores (0–100): pre- and post-intervention by group.

KOOS subscale	sEMG Pre	sEMG Post	sEMG Δ (95% CI)	Conv Pre	Conv Post	Conv Δ (95% CI)
Pain	42.24 ± 11.89	89.43 ± 10.70	+47.19 [39.07, 55.32]; p < 0.001*	39.81 ± 15.91	85.93 ± 9.59	+46.11 [39.77, 52.46]; p < 0.001*
Symptoms	48.11 ± 9.24	83.57 ± 5.71	+35.46 [30.01, 40.91]; p < 0.001*	40.71 ± 10.95	81.42 ± 7.29	+40.71 [33.65, 47.76]; p < 0.001*
ADL	37.36 ± 10.78	93.72 ± 6.65	+56.36 [48.84, 63.88]; p < 0.001*	41.37 ± 13.31	87.75 ± 6.93	+46.39 [38.87, 53.90]; p < 0.001*
Sport/Rec	17.00 ± 13.99	67.67 ± 11.32	+50.67 [42.01, 59.32]; p < 0.001*	13.67 ± 10.93	53.00 ± 14.74	+39.33 [31.34, 47.33]; p < 0.001*
Quality of Life	24.19 ± 13.95	82.11 ± 11.77	+57.93 [47.96, 67.89]; p < 0.001*	25.03 ± 13.15	79.20 ± 13.28	+54.17 [43.84, 64.49]; p < 0.001*

Note. Higher scores indicate better outcome. ADL = Activities of Daily Living; Sport/Rec = Sport and Recreation; Conv = Conventional Physiotherapy; Δ = mean change score (Post – Pre) with 95% CI.

cortical motor drive and impairing voluntary discharge outpatient attendance is constrained by recruitment for weeks to months [9,10]. sEMG transport, cost and caregiver availability. The biofeedback directly targets AMI by providing the combination of widely available smartphones, 4G/5G patient with continuous, quantitative knowledge of connectivity and inexpensive wearable sensors makes voluntary motor output through increasing cortical sensor-enabled telerehabilitation a scalable model, motor drive, accelerating motor relearning and exposing consistent with prior evidence on videoconference-compensatory or asymmetric recruitment patterns that delivered biofeedback in musculoskeletal care [32].

escape visual observation [12,13]. Selective **Limitations** include the short two-week follow-up; biofeedback of vastus medialis and vastus lateralis may longer-term outcomes at 3–12 months were not be particularly important during eccentric weight-bearing tasks, which load the very subscales (Sport/Rec, arm, so the biofeedback signal cannot be isolated from ADL) on which we observed the largest between-group other effects of remote monitoring and digital advantage. The sample (n = 30) was sized for a pilot,

KOOS-Quality of Life improved substantially in both and the loss of statistical significance on KOOS-arms (from ~24 points to ~80 points), with a modest Sport/Recreation after Bonferroni correction (adjusted p non-significant numerical advantage for sEMG (+3.76 = 0.102) reflects this. Future multi-centre trials with points; p = 0.612). This pattern is consistent with prior longer follow-up, isokinetic dynamometry, gait analysis evidence that biofeedback-assisted telerehabilitation and quantitative sEMG outcomes (e.g., motor-unit improves patient-reported outcomes by increasing recruitment indices) are warranted.

engagement and self-monitoring [32,33]. The slightly **Conclusions**

greater within-group change in the Symptoms domain in the Symptoms domain in the sEMG-led telerehabilitation produced ROM and KOOS the conventional arm (+40.71 vs +35.46; p = 0.258) outcomes comparable to in-person physiotherapy at two reflects a baseline imbalance, not a treatment effect: weeks post-RA-TKA, with a signal of advantage on post-intervention scores were nearly identical between demanding functional subscales. By providing real-time arms (81.42 vs 83.57; p = 0.377), suggesting that early neuromuscular feedback that targets arthrogenic muscle joint healing in this domain proceeds on its own time inhibition and supports motor relearning, sEMG-led course irrespective of biofeedback [34]. telerehabilitation is a viable neurorehabilitation

From an implementation perspective, sEMG-led modality for the early post-arthroplasty period, telerehabilitation has direct relevance to the Indian particularly where access to in-person specialist healthcare context, where specialist orthopaedic physiotherapy is limited.

physiotherapy is concentrated in urban areas and post- **Acknowledgements**

The authors thank the patients who participated in this trial and the orthopaedic and physiotherapy staff who supported recruitment and intervention delivery. We are grateful to the independent statistician who generated the allocation sequence, and to Delsys for technical training on the Trigno Discover platform. We also thank the School of Allied Health Sciences, Manav Rachna International Institute of Research and Studies, for institutional support.

Ethical approval

This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was granted by the Institutional Ethics Committee of Manav Rachna International Institute of Research and Studies (EC/2024-25/060). The trial was prospectively registered with the Clinical Trial Registry India (REF/2025/02/099521).

Funding

This study received partial equipment support from the De Luca Foundation (USA) and Delsys (India Exclusive Trigno Starter Kit Program; agreement PPL/delsys/2025/10-02). The funders had no role in study design, data collection, analysis, interpretation of data, manuscript preparation, or the decision to submit the manuscript for publication.

Conflicts of interest

Delsys manufactures the Trigno Discover sEMG hardware used in this trial and provided partial equipment support, as described in the Funding statement. Beyond this equipment support, the authors declare no other conflicts of interest. Each author has completed the ICMJE conflict-of-interest disclosure form.

References

1. Mohd Yunus MH, Nordin A, Kamal H. Pathophysiological perspective of osteoarthritis. *Medicina (Kaunas)*. 2020;56(11):614. <https://doi.org/10.3390/medicina56110614>
2. GBD 2021 Osteoarthritis Collaborators. Global, regional, and national burden of osteoarthritis, 1990-2020 and projections to 2050: a systematic analysis for the Global Burden of Disease Study 2021. *Lancet Rheumatol*. 2023;5(9):e508-e522. [https://doi.org/10.1016/S2665-9913\(23\)00163-7](https://doi.org/10.1016/S2665-9913(23)00163-7)
3. Yadav R, Verma AK, Uppal A, Chahar HS, Patel J, Pal CP. Prevalence of primary knee osteoarthritis in the urban and rural population in India. *Indian J Rheumatol*. 2022;17(3):239-43. https://doi.org/10.4103/injr.injr_337_20
4. Kamlay P, Bagewadi R, Khodnapur G, Bulagond A, Biradar BS, Nandi S. Clinical and functional outcomes following primary total knee arthroplasty in patients with knee osteoarthritis: a prospective study. *Cureus*. 2025;17(6):e86944. <https://doi.org/10.7759/cureus.86944>
5. Kayani B, Konan S, Tahmassebi J, Pietrzak JRT, Haddad FS. Robotic-arm assisted total knee arthroplasty is associated with improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based total knee arthroplasty: a prospective cohort study. *Bone Joint J*. 2018;100-B(7):930-7. <https://doi.org/10.1302/0301-620X.100B7.BJJ-2017-1449.R1>
6. Roche M. The MAKO robotic-arm knee arthroplasty

- system. *Arch Orthop Trauma Surg*. 2021;141(12):2043-7. <https://doi.org/10.1007/s00402-021-04208-0>
7. Alrajeb R, Zarti M, Shuaib Z, Alzobi O, Ahmed G, Elmhiregh A. Robotic-assisted versus conventional total knee arthroplasty: a systematic review and meta-analysis of randomized controlled trials. *Eur J Orthop Surg Traumatol*. 2024;34(3):1333-43. <https://doi.org/10.1007/s00590-023-03798-2>
8. Mizner RL, Petterson SC, Stevens JE, Vandenborne K, Snyder-Mackler L. Early quadriceps strength loss after total knee arthroplasty: the contributions of muscle atrophy and failure of voluntary muscle activation. *J Bone Joint Surg Am*. 2005;87(5):1047-53. <https://doi.org/10.2106/JBJS.D.01992>
9. Sonnery-Cottet B, Hopper GP, Gousopoulos L, Vieira TD, Thaumat M, Fayard JM, Freychet B, Ouanezar H, Cavaignac E, Saithna A. Arthrogenic muscle inhibition following knee injury or surgery: pathophysiology, classification, and treatment. *Video J Sports Med*. 2022;2(3):26350254221086295. <https://doi.org/10.1177/26350254221086295>
10. Hart JM, Pietrosimone B, Hertel J, Ingersoll CD. Quadriceps activation following knee injuries: a systematic review. *J Athl Train*. 2010;45(1):87-97. <https://doi.org/10.4085/1062-6050-45.1.87>
11. Farina D, Enoka RM. Evolution of surface electromyography: from muscle electrophysiology towards neural recording and interfacing. *J Electromyogr Kinesiol*. 2023;71:102796. <https://doi.org/10.1016/j.jelekin.2023.102796>
12. Achens JT, Raj Victor VS, Joseph JK. Early activation of quadriceps with pressure biofeedback for the prevention of arthrogenic muscle inhibition following lower limb orthopedic surgeries: a proof of concept clinical trial. *J Chiropr Med*. 2022;21(4):296-304. <https://doi.org/10.1016/j.jcm.2022.05.005>
13. Sturma A, Hruby LA, Prahm C, Mayer JA, Aszmann OC. Rehabilitation of upper extremity nerve injuries using surface EMG biofeedback: protocols for clinical application. *Front Neurosci*. 2018;12:906. <https://doi.org/10.3389/fnins.2018.00906>
14. Agnihotri S, Gupta N, Sindwani P, Srivastava A, Ahmad A, Karki M. Telerehabilitation: exploring the untapped potential. *Cureus*. 2024;16(4):e57405. <https://doi.org/10.7759/cureus.57405>
15. Crawford T, Parsons J, Webber S, Fricke M, Thille P. Strategies to increase access to outpatient physiotherapy services: a scoping review. *Physiother Can*. 2022;74(2):197-207. <https://doi.org/10.3138/ptc-2020-0119>
16. Liu X, Yang G, Xie W, Lu W, Liu G, Xiao W, Li Y. Efficacy of telerehabilitation for total knee arthroplasty: a meta-analysis based on randomized controlled trials combined with a bibliometric study. *J Orthop Surg Res*. 2024;19(1):874. <https://doi.org/10.1186/s13018-024-05381-9>
17. Tsang MP, Man GCW, Xin H, Chong YC, Ong MT, Yung PS. The effectiveness of telerehabilitation in patients after total knee replacement: a systematic review and meta-analysis of randomized controlled trials. *J Telemed Telecare*. 2024;30(5):795-808. <https://doi.org/10.1177/1357633X221097469>
18. Wang Y, Liu X, Wu Q, Zhu Q, Zhang M. Impact of telerehabilitation on rehabilitation efficacy and patient satisfaction after knee surgery: systematic review and meta-analysis of randomized controlled trials. *J Med Internet Res*. 2025;27:e76844. <https://doi.org/10.2196/76844>

19. **An J, Ryu HK, Lyu SJ, Yi HJ, Lee BH.** Effects of preoperative telerehabilitation on muscle strength, range of motion, and functional outcomes in candidates for total knee arthroplasty: a single-blind randomized controlled trial. *Int J Environ Res Public Health*. 2021;18(11):6071. <https://doi.org/10.3390/ijerph18116071>
20. **Plavoukou T, Kasnesis P, Contiero Syropoulou A, Papagiannis G, Stasinopoulos D, Georgoudis G.** Wearable sensor-based telerehabilitation versus conventional physiotherapy in knee OA: insights from the KneE-PAD pilot study. *Appl Sci*. 2025;15(24):12988. <https://doi.org/10.3390/app152412988>
21. **Billig JJ, Sears ED, Travis BN, Waljee JF.** Patient-reported outcomes: understanding surgical efficacy and quality from the patient's perspective. *Ann Surg Oncol*. 2020;27(1):56-64. <https://doi.org/10.1245/s10434-019-07748-3>
22. **Roos EM, Lohmander LS.** The Knee injury and Osteoarthritis Outcome Score (KOOS): from joint injury to osteoarthritis. *Health Qual Life Outcomes*. 2003;1:64. <https://doi.org/10.1186/1477-7525-1-64>
23. **Peer MA, Lane J.** The Knee Injury and Osteoarthritis Outcome Score (KOOS): a review of its psychometric properties in people undergoing total knee arthroplasty. *J Orthop Sports Phys Ther*. 2013;43(1):20-8. <https://doi.org/10.2519/jospt.2013.4057>
24. **Kim GW.** Patient-reported outcome measure of knee function: Knee Injury and Osteoarthritis Outcome Score (KOOS). *Ann Rehabil Med*. 2023;47(6):441-3. <https://doi.org/10.5535/arm.230009>
25. **Moher D, Hopewell S, Schulz KF, Montori V, Gøtzsche PC, Devereaux PJ, Elbourne D, Egger M, Altman DG.** CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. *BMJ*. 2010;340:c869. <https://doi.org/10.1136/bmj.c869>
26. **World Medical Association.** Declaration of Helsinki: ethical principles for medical research involving human subjects. *Jahrb Wiss Ethik*. 2009;14(1):233-8. <https://doi.org/10.1515/9783110208856.233>
27. **Farrokhi N, Sarzaeem MM, Feizi D.** Feasibility and acceptability of a telerehabilitation intervention on patients undergoing total knee arthroplasty in Iran: randomised controlled trial protocol. *BMJ Open*. 2024;14(6):e083784. <https://doi.org/10.1136/bmjopen-2023-083784>
28. **Schulz KF, Grimes DA.** Generation of allocation sequences in randomised trials: chance, not choice. *Lancet*. 2002;359(9305):515-9. [https://doi.org/10.1016/S0140-6736\(02\)07683-3](https://doi.org/10.1016/S0140-6736(02)07683-3)
29. **Doig GS, Simpson F.** Randomization and allocation concealment: a practical guide for researchers. *J Crit Care*. 2005;20(2):187-91. <https://doi.org/10.1016/j.jcrc.2005.04.005>
30. **Karanicolas PJ, Farrokhyar F, Bhandari M.** Practical tips for surgical research: blinding: who, what, when, why, how? *Can J Surg*. 2010;53(5):345-8.
31. **Bawa A, Banitsas K.** Design validation of a low-cost EMG sensor compared to a commercial-based system for measuring muscle activity and fatigue. *Sensors (Basel)*. 2022;22(15):5799. <https://doi.org/10.3390/s22155799>
32. **Janela D, Costa F, Weiss B, Areias AC, Molinos M, Scheer JK, Lains J, Bento V, Cohen SP, Correia FD, Yanamadala V.** Effectiveness of biofeedback-assisted asynchronous telerehabilitation in musculoskeletal care: a systematic review. *Digit Health*. 2023;9:20552076231176696. <https://doi.org/10.1177/20552076231176696>
33. **Seron P, Oliveros MJ, Gutierrez-Arias R, Fuentes-Aspe R, Torres-Castro RC, Merino-Osorio C, Nahuelhual P, Inostroza J, Jalil Y, Solano R, Marzuca-Nassr GN, Aguilera-Eguía R, Lavados-Romo P, Soto-Rodríguez FJ, Sabelle C, Villarroel-Silva G, Gomolán P, Huaiquilaf S, Sanchez P.** Effectiveness of telerehabilitation in physical therapy: a rapid overview. *Phys Ther*. 2021;101(6):pzab053. <https://doi.org/10.1093/ptj/pzab053>
34. **Sheen JR, Mabrouk A, Garla VV.** Fracture healing overview. In: *StatPearls*. Treasure Island (FL): StatPearls Publishing; 2025. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK551678/>