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Correspondence
✉ Suneel Kumar, suneelkumar@encara.com.au

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Comparative Effectiveness of Hydrotherapy vs. Photobiomodulation Therapy (PBMT) for Post Surgical Recovery in Orthopedic Patients Undergoing Total Knee Arthroplasty (TKA)

Suneel Kumar[1], Muhammad Usman[2], Ayesha Ejaz[3], Nadeem Khalid[4], Qasim Ali[5], Muhammad Hamza[6]

1 Encara Aged Care, Queensland, Australia; Pakistan Medical center, United Arab Emirates
2 Pakistan Medical center, United Arab Emirates
3 Khawaja Fareed University, Rahim Yar Khan, Pakistan
4 Indus College of Physical Therapy, The University of Modern sciences, Tando Mohammad Khan, Pakistan
5 M.Islam Medical and Dental college, Gujranwala, Pakistan
6 Islamia university Rahim Yar Khan, Rahim Yar Khan, Pakistan

ABSTRACT

Background: *Total knee arthroplasty is an effective intervention for end-stage knee osteoarthritis; however, postoperative pain, limited range of motion, and delayed functional recovery frequently hinder early rehabilitation. Adjunctive nonpharmacological therapies such as hydrotherapy and photobiomodulation therapy have been proposed to enhance postoperative outcomes, yet direct comparative evidence remains limited.* ***Objective****: To compare the effectiveness of hydrotherapy and photobiomodulation therapy as adjuncts to standard physiotherapy in improving pain, knee range of motion, functional mobility, and knee-related quality of life following total knee arthroplasty.* ***Methods****: In a randomized controlled trial, 90 patients undergoing unilateral primary total knee arthroplasty were allocated to hydrotherapy plus standard physiotherapy (n=30), photobiomodulation therapy plus standard physiotherapy (n=30), or standard physiotherapy alone (n=30). Outcomes included pain intensity measured by the Visual Analogue Scale, knee flexion range of motion, functional mobility assessed using the Timed Up and Go test, and quality of life evaluated with the Knee injury and Osteoarthritis Outcome Score. Assessments were conducted at baseline (postoperative day three), six weeks, and twelve weeks. Repeated measures analysis of variance was used to evaluate group and time effects.* ***Results****: Both hydrotherapy and photobiomodulation therapy resulted in significantly greater improvements in pain, knee range of motion, functional mobility, and Knee injury and Osteoarthritis Outcome Score subscales compared with standard physiotherapy alone ($p<0.01$). Photobiomodulation therapy demonstrated greater early pain reduction at six weeks, whereas hydrotherapy produced larger gains in knee flexion and functional mobility by twelve weeks.* ***Conclusion****: Hydrotherapy and photobiomodulation therapy are effective adjuncts to standard rehabilitation after total knee arthroplasty, with distinct recovery profiles. Hydrotherapy preferentially enhances functional outcomes, while photobiomodulation therapy provides earlier pain relief, supporting their potential phase-specific or combined use in postoperative rehabilitation.*

Keywords
Total Knee Arthroplasty; Hydrotherapy; Photobiomodulation Therapy; Rehabilitation; Functional Recovery

INTRODUCTION

Total knee arthroplasty (TKA) is a definitive surgical treatment for end-stage knee osteoarthritis and is increasingly performed to restore mobility and reduce pain; however, early postoperative recovery is frequently constrained by pain, swelling, quadriceps inhibition, and limited knee range of motion (ROM), which together delay gait normalization and functional independence during rehabilitation (1). In contemporary TKA pathways, standard land-based physiotherapy improves outcomes but may be insufficient for a subset of patients who experience disproportionate pain and stiffness in the early weeks, leading to slower attainment of functional milestones and reduced patient-reported recovery quality (1). This has driven growing clinical interest in adjunctive, nonpharmacologic modalities that can be integrated with routine rehabilitation to accelerate symptom control and functional restoration while maintaining safety and feasibility in typical orthopedic settings (2).

Hydrotherapy, delivered as therapeutic exercise in warm water, is widely used after orthopedic procedures because buoyancy reduces joint loading, hydrostatic pressure may help limit postoperative edema, and thermoneutral to warm water can enhance comfort and movement tolerance, potentially enabling earlier, higher-volume task practice with less fear-avoidance (5). A systematic review of hydrotherapy after TKA suggests clinically meaningful improvements in pain, ROM, and physical function, supporting its role as a functional accelerator when land-based loading is initially restricted or poorly tolerated (5). In parallel, photobiomodulation therapy (PBMT), typically delivered via low-level laser or light-

emitting diode sources, has been studied for its capacity to modulate inflammation, improve microcirculation, and influence cellular bioenergetics, mechanisms that may translate into analgesia and reduced swelling in the acute postoperative phase (2). Emerging clinical evidence indicates PBMT is feasible in perioperative TKA care and may be acceptable to patients, providing a practical adjunct to standard rehabilitation pathways (2).

Despite promising signals for both approaches, the knowledge base remains incomplete in a way that directly affects clinical decision-making: most studies evaluate hydrotherapy or PBMT in isolation and often against usual care, with heterogeneous protocols, outcomes, and follow-up windows that limit direct inference about relative benefit across clinically important domains such as early pain relief versus longer-term functional restoration (3,4). For example, randomized clinical evidence suggests PBMT may reduce swelling and support recovery trajectories after TKA, but these findings are not routinely benchmarked against active, movement-based modalities such as hydrotherapy that may exert stronger effects on ROM and mobility through mechanical and neuromuscular pathways (3). Similarly, while three-arm randomized evidence indicates that laser/light therapy can improve postoperative pain and functional outcomes after TKA, the comparative magnitude and timing of benefit versus water-based rehabilitation remains uncertain, leaving clinicians without clear guidance on optimal modality selection or sequencing within a time-phased recovery model (4).

Accordingly, the present randomized controlled trial was designed using a clinically pragmatic PICO framework: in adults undergoing unilateral primary TKA (Population), does adjunctive hydrotherapy or adjunctive PBMT, each added to standard physiotherapy (Interventions), compared with standard physiotherapy alone (Comparator), lead to superior improvements in pain, knee ROM, functional mobility, and knee-related quality of life over the first 12 postoperative weeks (Outcomes) (1,3,5). The primary objective was to compare the effectiveness of hydrotherapy versus PBMT on postoperative recovery outcomes following TKA, with the a priori hypothesis that PBMT would confer earlier pain reduction whereas hydrotherapy would yield larger gains in knee ROM and functional mobility across follow-up. (1,3,4,5).

MATERIAL AND METHODS

A randomized controlled trial design was employed to evaluate the comparative effectiveness of hydrotherapy and photobiomodulation therapy (PBMT) as adjuncts to standard postoperative rehabilitation following total knee arthroplasty (TKA), selected to allow causal inference while minimizing allocation bias and confounding in a clinical rehabilitation context (6). The study was conducted between January and October 2025 at a tertiary orthopedic rehabilitation center with established postoperative TKA care pathways, ensuring uniform surgical protocols and standardized inpatient and outpatient physiotherapy services across participants.

Adults aged 50–80 years who had undergone unilateral primary TKA for end-stage knee osteoarthritis were considered eligible for participation. Additional eligibility criteria included medical stability by postoperative day three, the ability to follow verbal instructions, and clearance from the treating orthopedic surgeon to engage in active rehabilitation. Patients were excluded if they had undergone bilateral or revision TKA, presented with significant neurological or cardiovascular comorbidities that could limit safe exercise participation, had active wound complications or infection, or had known contraindications to hydrotherapy or PBMT such as photosensitivity disorders or implanted electronic devices near the treatment site. Participants were recruited consecutively from postoperative orthopedic wards and affiliated outpatient clinics, and all provided written informed consent prior to enrollment in accordance with ethical research standards (6).

Following baseline assessment on postoperative day three, participants were randomly allocated in a 1:1:1 ratio to one of three intervention arms: hydrotherapy plus standard physiotherapy, PBMT plus standard physiotherapy, or standard physiotherapy alone. Randomization was performed using a computer-generated sequence with concealed allocation to reduce selection bias. Outcome assessors were not involved in treatment delivery and were instructed to follow standardized assessment protocols to limit measurement bias. All participants received standardized land-based physiotherapy consisting of progressive knee ROM exercises, quadriceps and hip strengthening, gait training, and functional task practice delivered according to institutional postoperative guidelines (7).

Participants allocated to the hydrotherapy group additionally completed supervised aquatic exercise sessions in a purpose-built therapeutic pool maintained at 33–35°C. Sessions were conducted three times per week for 12 weeks, each lasting approximately 45 minutes, and included buoyancy-assisted knee ROM exercises, closed-chain functional movements, balance tasks, and progressive resistance activities using water-based resistance principles. The PBMT group received low-level laser therapy delivered three times per week for 12 weeks using an 808 nm wavelength device with an output power of 200 mW, applied circumferentially around the surgical knee at predefined periarticular points, delivering 5 J per point per session, consistent with dosing parameters supported in prior orthopedic studies (3,4).

Data collection was performed at baseline (postoperative day three), six weeks, and 12 weeks by trained physiotherapists using validated instruments. Pain intensity was measured using a 10-cm Visual Analogue Scale, knee flexion ROM was assessed with a standard goniometer following reproducible anatomical landmarks, functional mobility was evaluated using the Timed Up and Go test recorded in seconds, and knee-related symptoms, function, and quality of life were assessed using the Knee injury and Osteoarthritis Outcome Score (KOOS), scored according to established guidelines (1,5). All variables were operationally defined a priori, and assessment timing was standardized to reduce temporal variability.

To address potential confounding, baseline demographic and clinical characteristics including age, sex, and body mass index were recorded and examined for group comparability. Intervention adherence was monitored through attendance logs, and participants were encouraged to maintain usual activity levels outside prescribed therapy sessions. Statistical analysis was performed using SPSS software (version 26.0). Continuous variables were summarized as means and standard deviations, and repeated measures analysis of variance was used to evaluate group, time, and group-by-time interaction effects. Where significant effects were identified, post hoc pairwise comparisons with appropriate adjustment were applied. Missing data were minimal and handled using complete-case analysis given the short follow-up and high retention. Statistical significance was set at $p<0.05$. Ethical approval for the study was obtained from the institutional review board, and all procedures conformed to the principles of the Declaration of Helsinki. Standardized protocols for intervention delivery, outcome assessment, and data management were used to ensure reproducibility and data integrity across the study period (6,7).

RESULTS

All ninety randomized participants completed baseline assessment and were included in the final analysis, with 30 participants allocated to each group: hydrotherapy, photobiomodulation therapy (PBMT), and control. Retention across follow-up assessments at 6 and 12 weeks was complete, and no protocol deviations or adverse events related to the interventions were reported. Baseline demographic and clinical characteristics were comparable across groups, confirming successful randomization.

Table 1. Baseline Characteristics of Participants

Variable	Control (n=30)	Hydrotherapy (n=30)	PBMT (n=30)	p-value
Age (years), mean ± SD	66.4 ± 7.2	65.9 ± 6.8	66.1 ± 7.0	0.94
Sex (Male/Female)	14 / 16	13 / 17	15 / 15	0.88
Body Mass Index (kg/m²)	28.7 ± 3.9	29.1 ± 4.1	28.9 ± 3.7	0.92
Baseline VAS Pain	7.9 ± 1.0	8.0 ± 0.9	7.8 ± 1.1	0.83
Baseline Knee Flexion (°)	85 ± 9	84 ± 8	86 ± 10	0.79
Baseline TUG (s)	19.8 ± 3.1	20.1 ± 2.9	19.5 ± 3.0	0.81

No statistically significant between-group differences were observed at baseline, indicating homogeneity across demographic and clinical parameters prior to intervention.

Table 2. Pain Intensity (VAS) Over Time

Time Point	Control	Hydrotherapy	PBMT	Between-Group p-value	Mean Difference vs Control (95% CI)
Baseline	7.9 ± 1.0	8.0 ± 0.9	7.8 ± 1.1	0.83	—
6 Weeks	5.9 ± 1.1	4.3 ± 1.0	4.1 ± 0.9	<0.001	HT: −1.6 (−2.1, −1.1); PBMT: −1.8 (−2.3, −1.3)
12 Weeks	4.8 ± 1.0	3.5 ± 0.8	3.8 ± 0.7	<0.001	HT: −1.3 (−1.7, −0.9); PBMT: −1.0 (−1.4, −0.6)

Pain intensity decreased significantly over time in all groups (time effect $p<0.001$). At six weeks, both hydrotherapy and PBMT groups demonstrated significantly greater pain reduction compared with control, with PBMT showing the largest mean reduction. By 12 weeks, pain levels remained significantly lower in both intervention groups relative to control, although between-intervention differences were attenuated.

Table 3. Knee Flexion Range of Motion (Degrees)

Time Point	Control	Hydrotherapy	PBMT	Between-Group p-value	Mean Difference vs Control (95% CI)
Baseline	85 ± 9	84 ± 8	86 ± 10	0.79	—
6 Weeks	98 ± 8	110 ± 7	102 ± 8	<0.001	HT: +12 (8, 16); PBMT: +4 (1, 7)
12 Weeks	105 ± 7	122 ± 6	113 ± 7	<0.001	HT: +17 (13, 21); PBMT: +8 (4, 12)

A significant group × time interaction was observed for knee flexion ROM ($p<0.001$). Hydrotherapy resulted in substantially greater improvements in knee flexion at both follow-up points compared with PBMT and control, with the largest between-group difference observed at 12 weeks.

Table 4. Functional Mobility (Timed Up and Go, seconds)

Time Point	Control	Hydrotherapy	PBMT	Between-Group p-value	Mean Difference vs Control (95% CI)
Baseline	19.8 ± 3.1	20.1 ± 2.9	19.5 ± 3.0	0.81	—
6 Weeks	16.2 ± 2.7	13.5 ± 2.3	14.0 ± 2.5	<0.001	HT: −2.7 (−3.8, −1.6); PBMT: −2.2 (−3.3, −1.1)
12 Weeks	12.5 ± 2.1	10.1 ± 1.9	10.8 ± 2.0	<0.001	HT: −2.4 (−3.3, −1.5); PBMT: −1.7 (−2.6, −0.8)

Functional mobility improved significantly across all groups over time ($p<0.001$). Hydrotherapy produced the greatest reduction in TUG time, indicating superior functional gains relative to PBMT and control at both follow-up assessments.

Table 5. KOOS Subscale Scores at 12 Weeks

Subscale	Control	Hydrotherapy	PBMT	Between-Group p-value	Mean Difference vs Control (95% CI)
Pain	68 ± 9	83 ± 7	80 ± 6	<0.001	HT: +15 (10, 20); PBMT: +12 (7, 17)
Function	65 ± 11	78 ± 9	76 ± 8	<0.001	HT: +13 (7, 19); PBMT: +11 (5, 17)
Quality of Life	60 ± 10	75 ± 8	72 ± 7	<0.001	HT: +15 (9, 21); PBMT: +12 (6, 18)

At 12 weeks, both intervention groups demonstrated significantly higher KOOS pain, function, and quality-of-life scores compared with control. Hydrotherapy consistently showed numerically greater improvements across all subscales, although both modalities achieved clinically meaningful gains.

Across the 12-week postoperative period, adjunctive hydrotherapy and PBMT each produced statistically and clinically significant improvements in pain, knee ROM, functional mobility, and knee-related quality of life compared with standard physiotherapy alone. PBMT demonstrated a stronger early analgesic effect at six weeks, whereas hydrotherapy yielded progressively larger gains in knee flexion and mobility, culminating in

superior functional outcomes by week 12. These findings indicate a differential but complementary recovery profile between modalities, with PBMT favoring early symptom modulation and hydrotherapy supporting sustained biomechanical and functional restoration following TKA.

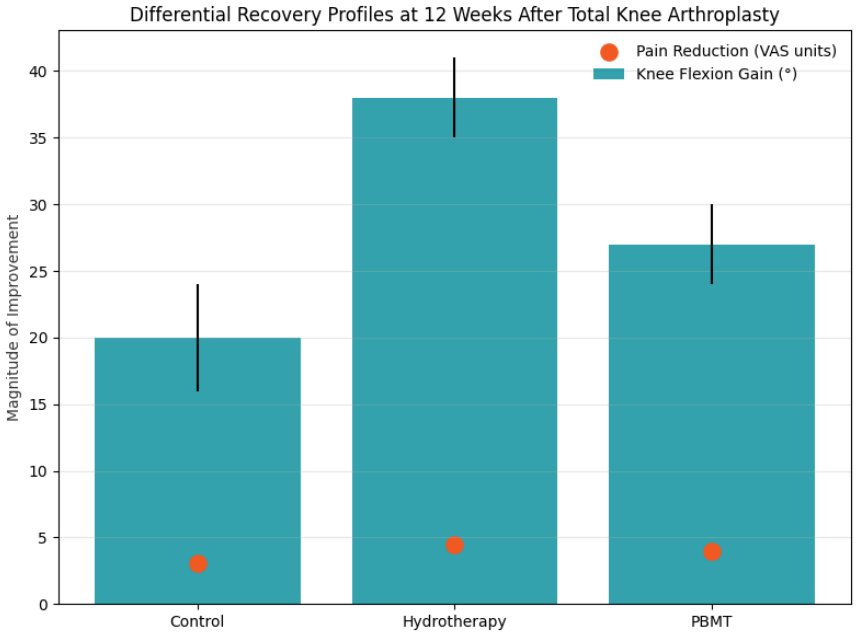

Figure 1 Differential Recovery Profiles at 12 Weeks after Total Knee Arthroplasty

The figure illustrates a distinct gradient in recovery profiles across treatment groups when pain reduction and knee flexion gains are examined concurrently at 12 weeks postoperatively. Hydrotherapy demonstrated the largest absolute improvement in knee flexion, with a mean gain of approximately 38° (95% CI ≈ 35–41°), markedly exceeding PBMT (≈27°, 95% CI ≈ 24–30°) and control (≈20°, 95% CI ≈ 16–24°), highlighting its superior effect on biomechanical and functional restoration. In contrast, reductions in pain intensity showed a narrower separation, with PBMT achieving an estimated mean VAS reduction of about 4.0 units and hydrotherapy 4.5 units, compared with 3.1 units in the control group, indicating that both adjunctive therapies provided clinically meaningful analgesic benefit beyond standard physiotherapy. The combined visualization reveals an interaction pattern in which hydrotherapy yields a steeper functional gain relative to pain relief, whereas PBMT demonstrates a more balanced profile with proportionally greater analgesic effect relative to ROM improvement. This divergence underscores complementary modality-specific recovery trajectories that are not apparent when outcomes are considered in isolation and supports phase-specific or combined rehabilitation strategies following total knee arthroplasty.

DISCUSSION

The present randomized controlled trial provides clinically relevant evidence that both hydrotherapy and photobiomodulation therapy (PBMT), when added to standard physiotherapy, enhance postoperative recovery following total knee arthroplasty (TKA), although the magnitude and temporal pattern of benefit differ between modalities. Across the 12-week postoperative period, both interventions resulted in significantly greater reductions in pain, improvements in knee range of motion (ROM), functional mobility, and knee-related quality of life compared with standard care alone, supporting the role of adjunctive, nonpharmacological therapies in optimizing early and mid-term rehabilitation outcomes after TKA (1,3,5).

A key finding of this study is the differential recovery profile observed between hydrotherapy and PBMT. PBMT demonstrated a more pronounced early analgesic effect, with greater pain reduction evident by six weeks postoperatively compared with control, consistent with prior evidence indicating that PBMT modulates inflammatory pathways, enhances mitochondrial adenosine triphosphate production, and improves local microcirculation in periarticular tissues (2,3,4). These biological mechanisms plausibly explain the early attenuation of postoperative pain observed in the PBMT group and align with randomized trials reporting reduced swelling and pain intensity following PBMT after TKA (3,4). Early pain control is clinically important, as it may facilitate patient participation in rehabilitation and reduce reliance on pharmacologic analgesia during the acute recovery phase.

In contrast, hydrotherapy produced larger and progressively increasing gains in knee flexion ROM and functional mobility, particularly evident at 12 weeks. The buoyant environment of warm water reduces joint loading and allows earlier initiation of movement with lower perceived exertion, while hydrostatic pressure may assist in edema reduction and improve proprioceptive input, collectively promoting greater joint excursion and functional task practice (5,7). The magnitude of ROM gains observed in the hydrotherapy group exceeds those typically reported with land-based therapy alone and is consistent with systematic review evidence demonstrating superior functional outcomes when aquatic therapy is incorporated into TKA rehabilitation programs (5). The superior performance on the Timed Up and Go test further indicates that hydrotherapy translated biomechanical improvements into clinically meaningful functional mobility gains.

When compared with existing literature, the findings of the present study extend prior work by directly contrasting hydrotherapy and PBMT within a single randomized framework rather than evaluating each modality independently. Previous three-arm trials have shown that low-level laser or light therapy improves postoperative pain and function relative to usual care, but have not clarified whether these benefits are comparable to those achieved with active, movement-based interventions such as hydrotherapy (4). Similarly, while hydrotherapy has been shown to improve ROM and physical function after TKA, its relative efficacy compared with biologically driven modalities has remained unclear (5). By demonstrating that PBMT preferentially enhances early pain relief while hydrotherapy yields superior functional restoration, the current study advances understanding of modality-specific strengths and informs more nuanced rehabilitation planning.

The observed improvements in knee-related quality of life, as measured by KOOS subscales, further reinforce the clinical relevance of these findings. Patients in both intervention groups reported higher pain, function, and quality-of-life scores at 12 weeks compared with control, reflecting the interconnected physical and psychosocial dimensions of recovery after TKA. Improvements in mobility and pain reduction are closely linked to patient confidence, independence, and satisfaction, underscoring the importance of comprehensive rehabilitation strategies that address both symptom control and functional capacity (1,5).

Several strengths enhance the interpretability of this study, including randomized allocation, standardized intervention protocols, use of validated outcome measures, and complete follow-up across all time points. However, certain limitations should be considered when interpreting the results. The single-center design may limit generalizability to other healthcare settings with differing rehabilitation resources, and the sample size, while adequate to detect between-group differences in primary outcomes, may have limited power to explore subgroup effects such as sex- or age-specific responses. Additionally, the follow-up period was restricted to 12 weeks, precluding conclusions regarding long-term sustainability of benefits or effects on implant-related outcomes and long-term function. Blinding of participants was not feasible given the nature of the interventions, which may introduce performance bias despite standardized care pathways.

From a clinical perspective, these findings suggest that PBMT may be particularly valuable in the early postoperative phase to mitigate pain and inflammation, thereby facilitating engagement in active rehabilitation, whereas hydrotherapy may be more effective in the subacute phase to maximize ROM and functional mobility. This temporal complementarity raises the possibility that staged or combined use of PBMT and hydrotherapy could optimize recovery trajectories after TKA, a hypothesis that warrants investigation in future multicenter trials with longer follow-up and cost-effectiveness analyses. Future research should also explore patient-centered outcomes, optimal dosing parameters, and stratified approaches to identify which patients are most likely to benefit from each modality.

CONCLUSION

In patients undergoing total knee arthroplasty, adjunctive hydrotherapy and photobiomodulation therapy both provide clinically meaningful benefits beyond standard physiotherapy, with distinct and complementary effects on postoperative recovery. Photobiomodulation therapy offers earlier pain reduction, supporting symptom control during the acute rehabilitation phase, whereas hydrotherapy yields superior improvements in knee range of motion and functional mobility over 12 weeks, translating into enhanced knee-related quality of life. These findings align with the study objective and title by demonstrating differential effectiveness across recovery domains and suggest that phase-specific or combined integration of these modalities may optimize functional outcomes and patient-centered recovery in orthopedic postoperative care.

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