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Effectiveness of Combined High-Intensity Laser Therapy (HILT) and Telerehabilitation in Patients with Primary Knee Osteoarthritis Following Total Knee Replacement Surgery: A Randomized Controlled Study

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Purpose: This study evaluated the effectiveness of combined High-intensity laser therapy (HILT) and telerehabilitation in patients with primary knee osteoarthritis undergoing total knee replacement at Buriram Hospital. Outcomes included pain intensity, knee range of motion, knee circumference, functional mobility, the Knee Injury and Osteoarthritis Outcome Score (KOOS), and the 6-Minute Walk Test (6MWT).

Methods: In this randomized controlled trial 88 participants were equally assigned to an experimental group receiving HILT combined with telerehabilitation or a control group receiving standard care. Assessments were performed at baseline and at 1, 3, and 6 months postoperatively and included knee flexion and extension, circumference, Timed Up and Go (TUG), 6MWT, Visual Analog Scale (VAS), and KOOS domains. Data were statistically analyzed using independent t-test, Mann–Whitney test, Chi-square test, Fisher's exact test, and a mixed-effects linear regression for repeated measures, with significance set at $p < 0.05$.

Results: The experimental group demonstrated significantly greater improvement in knee flexion at Month 3 compared with the control group. Knee circumference and VAS pain scores decreased in both groups. Functional performance (6MWT) improved over time, with earlier gains in the experimental group. All KOOS domains improved significantly, with consistently higher scores in the experimental group from Month 1 onward. The greatest between-group difference was observed in quality of life at Months 3 and 6 (98.72 vs. 68.89 at Month 6).

Conclusions: Combined HILT and telerehabilitation significantly improved postoperative recovery, particularly in functional outcomes and quality of life, and may be an effective adjunct to standard care in knee osteoarthritis patients after total knee replacement.

Keywords: High-intensity laser therapy (HILT), tele-rehabilitation, total knee replacement, primary knee osteoarthritis

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Osteoarthritis is one of the most common health problems among older adults worldwide. The number of patients with osteoarthritis is expected to increase due to population aging. Primary osteoarthritis primarily affects the knees, hips, and wrists. According to the World Health Organization (WHO) in 2019, approximately 528 million people were found to have osteoarthritis. Of these, 73% were aged 55 years or older, and 60% were women[1]. Osteoarthritis most commonly affects the knee joints, followed by hips and wrists[2]. Approximately 344 million people with osteoarthritis could benefit from rehabilitation[3]. The disease also imposes a substantial economic burden because of high healthcare costs and reduced work capacity. Primary, or idiopathic, knee osteoarthritis develops naturally with aging and cumulative knee joint use. Treatments include pharmacological and nonpharmacological approaches. Nonpharmacological treatment includes surgery, which is appropriate for patients with severe osteoarthritis who experience substantial pain while walking, have knee joint deformities, or are unable to perform daily activities[4,5].

Total knee replacement, or arthroplasty, is a surgical procedure in which the articular surfaces of the knee joint are replaced. This includes the distal femur, proximal tibia, and in some cases, the patella. A prosthetic implant is used to replace the degenerated bone surfaces. The procedure is indicated for patients with severe knee osteoarthritis that cannot be managed effectively with other methods. Total condylar knee replacement has demonstrated approximately 95% success over the past 10 years and 80% over the past 20 years. Cementless knee replacement has also shown a success rate of approximately 93% in the past 5 years. However, total knee replacement may affect knee joint function, including range of motion (ROM), weight-bearing capacity, and joint stability, because the degenerated articular surfaces are replaced with artificial metal and plastic components[6]. Endre Mester conducted research on the use of laser treatment to stimulate tissue repair in wounds. High-powered medical lasers emit high-intensity beams capable of producing thermal effects that alter or destroy tissue. In clinical practice, laser treatment can be applied in physical therapy and rehabilitation. Its indications include pain relief and treatment, reduction of pain in osteoarthritis (OA) and rheumatoid arthritis (RA), acceleration of wound healing, stimulation of granulation tissue formation, reduction of edema and inflammation, and the immediate stimulation of peripheral nerve regeneration after injury[7]. Furthermore, high-intensity laser therapy (HILT) may promote photobiomodulation effects by enhancing cellular metabolism, improving local microcirculation, reducing inflammation, and decreasing postoperative pain and edema, thereby facilitating functional recovery following total knee arthroplasty (TKA).

Recent advances in surgical techniques have improved the effectiveness of total knee replacement. Optimal postoperative outcomes require a multidisciplinary team that emphasizes post-surgical rehabilitation, knee exercises, prevention of knee dislocation, increasing muscular strength around knee joints, and gait training[8-9] before the follow-up appointment in the next 6 months. During this period, telerehabilitation offers an alternative to conventional rehabilitation by allowing patients to perform prescribed exercises at home while receiving remote follow-ups through information and communication technology (ICT) systems[10]. Therefore, this study evaluated the effectiveness of the combined HILT and telerehabilitation in patients with primary knee osteoarthritis following total knee replacement surgery at Buriram Hospital. Postoperative physical rehabilitation outcomes were assessed using the following measures: 1) knee ROM (flexion and extension)[11], 2) knee circumference, 3) functional mobility[12-14], 4) the Knee Injury and Osteoarthritis Outcome Score (KOOS), 5) pain intensity[14], and 6) the Six-Minute Walk Test (6MWT)[13]. The KOOS is a patient-reported outcome measure developed for individuals with knee osteoarthritis as an extension of the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), incorporating additional assessments of sports and recreational activities, as well as quality of life[12]. The findings of this study were expected to demonstrate the effectiveness of HILT combined with telerehabilitation in accelerating postoperative recovery, reducing pain and inflammation, and facilitating an earlier return to daily activities among patients undergoing TKA at Buriram Hospital.

The study aimed to investigate the effectiveness of combined HILT and telerehabilitation by comparing knee ROM (flexion and extension), knee circumference, KOOS, and the

6MWT in patients with primary knee osteoarthritis before and after total knee replacement at Buriram Hospital.

METHODS

This randomized controlled trial (RCT) compared combined HILT and telerehabilitation with conventional postoperative rehabilitation. Patients in both groups had primary knee osteoarthritis and underwent total knee replacement.

Patients in the experimental group received four HILT sessions applied to the periarticular region of the knee within 2–5 days postoperatively. HILT was delivered using an MLS laser system (ASA Laser, Italy), a Class IV high-power diode laser with synchronized wavelengths of 808 and 905 nm (Multiwave Locked System; MLS). Treatment was administered using a scanning technique over the medial, lateral, anterior, and posterior aspects of the knee joint. The 808 nm wavelength was used for photobiomodulation and anti-inflammatory effects, whereas the 905 nm wavelength was applied for analgesia. Each session lasted approximately 10–15 minutes, with an energy dose of 1500–3000 J. The therapy aimed to relieve pain, reduce inflammation, and promote tissue repair.

Following HILT, patients participated in three telerehabilitation sessions on postoperative Days 3, 4, and 5. The program included supervised knee range-of-motion exercises, quadriceps strengthening exercises, therapeutic exercises, functional mobility training, and gait training provided by a physical therapist. During each session, the therapist monitored recovery and provided guidance to facilitate restoration of knee function and functional mobility following TKA.

Patients in the control group received conventional postoperative rehabilitation according to standard clinical practice without HILT or telerehabilitation. Outcomes were compared between groups to evaluate the effectiveness of combined HILT and telerehabilitation following TKA.

Participants

Participants were patients with primary knee osteoarthritis who underwent total knee replacement surgery at Buriram Hospital.

Sampling

Ezgi Deniz Ciplak et al.[15] evaluated the effectiveness of HILT in patients with knee osteoarthritis and reported Week 6 VAS scores of 3.41 ± 1.47 in the HILT plus hot-pack group and 4.58 ± 1.99 in the control group. The sample size was calculated using the following equation:

$$n_{trt} = \frac{(z_{1-\frac{\alpha}{2}} + z_{1-\beta})^2 \left[\sigma_{trt}^2 + \frac{\sigma_{con}^2}{r}\right]}{\Delta^2}$$

$$r = \frac{n_{con}}{n_{trt}}, \Delta = \mu_{trt} - \mu_{con}$$

in which… The mean in the treatment group = 3.41, SD in the treatment group = 1.47

The mean in the control group = 4.58, SD in the control group = 1.99

Ratio (control/treatment) = 1.00

Alpha (α) = 0.05, Z(0.975) = 1.959964

Beta (β) = 0.20, Z(0.800) = 0.841621

Sample size: Treatments = 36, Controls = 36

To allow for a 20% dropout rate, 44 participants were enrolled in each group, resulting in a total sample size of 88 participants. The inclusion criterion was primary knee osteoarthritis. The exclusion criteria were: 1) secondary knee osteoarthritis (including rheumatoid arthritis, traumatic arthritis, septic arthritis, inflammatory joint diseases) and 2) refusal to participate.

Participants who agreed to participate in the study were randomly assigned to either the experimental group or the control group in a 1:1 allocation ratio. Block randomization with a block size of 6, since using a block size of five or greater helps to reduce the risk of predicting the allocation result. The randomization sequence was generated using the STATA software. Allocation concealment was implemented using sealed envelopes, which were opened only after participants had signed the consent form to participate in the research during the screening process.

Blinding was applied to the physician responsible for outcome assessment. A single physician performed all the evaluations to minimize assessment bias. Assessments were conducted at baseline and at Months 1, 3, and 6 postoperatively. Outcomes included knee ROM (flexion and extension), knee circumference (swelling), pain assessment using VAS, functional mobility assessed by TUG, walking performance assessed by 6MWT, and the KOOS questionnaire.

Data Analysis

Data were analyzed using statistical software. The statistics used in data analysis were as follows:

1) Descriptive statistics

Categorical variables were presented as frequencies and percentages. Normally distributed continuous variables were presented as means and standard deviations (SD), whereas non-normally distributed continuous variables were presented as median and interquartile range (IQR).

2) Inferential statistics

Between-group differences were analyzed using appropriate statistical tests. The independent t-test was used for normally distributed continuous variables, whereas the Mann-Whitney *U* test was used for non-normally distributed continuous variables. The Chi-square test or Fisher's exact test was used for categorical variables, as appropriate. Continuous repeated-measures outcomes were analyzed using mixed-effects linear regression model (linear mixed model: LMM). A p value < 0.05 was considered statistically significant.

Research Ethics

This study was approved by the Institutional Review Board (IRB) of the study site and conducted in accordance with the Declaration of Helsinki.

The trial was registered with the Thai Clinical Trials Registry (TCTR) (Registration No. TCTR20240916013).

Table 1 Comparison of baseline characteristics between the experimental and control groups**.**

Baseline characteristic	Control Group Number (percentages)/ Mean±SD (n=44)	Experimental Group Number (percentages)/ Mean±SD (n=44)	p - values
Sex			1.000[a]
Male	6 (13.6)	6 (13.6)	
Female	38 (86.4)	38 (86.4)	
Age (years)	64.75 ± 7.33	66.07 ± 5.60	0.346[b]
BMI (kg/m^2)	26.58 ± 4.35	26.85 ± 4.19	0.770[b]
Comorbidities	28 (63.6)	34 (77.3)	0.161[a]
Hypertension	20 (45.5)	22 (50.0)	0.669[a]
Obesity	9 (20.5)	16 (36.4)	0.098[a]
Diabetes	7 (15.9)	5 (11.4)	0.534[a]
Asthma	2 (4.5)	3 (6.8)	1.000[b]
Cancer	2 (4.5)	2 (4.5)	1.000[b]
Gout	3 (6.8)	2 (4.5)	1.000[b]
Exercise prior to surgery	19 (43.2)	22 (50.0)	0.521[a]
Size of the affected knee			0.831[a]
Left	21 (47.7)	20 (45.5)	
Right	23 (52.3)	24 (54.5)	

Baseline characteristic	Control Group Number (percentages)/ Mean±SD (n=44)	Experimental Group Number (percentages)/ Mean±SD (n=44)	p - values
Kellgren–Lawrence Radiological Stage			1.000[c]
3	3 (8.3)	4 (9.5)	
4	33 (91.7)	38 (90.5)	
KOA duration	6.41 ± 6.23	7.79 ± 13.50	0.735[d]
Med. (Q1, Q3)	4 (2.5, 10)	5 (2, 10)	
Time from decision to surgery (days)	81.83 ± 198.13	52.69 ± 84.72	0.269[d]
Med. (Q1, Q3)	26 (7, 60)	20 (2, 60)	

Abbreviations: BMI, Body Mass Index; KOA, Knee Osteoarthritis; SD, Standard Deviation; IQR, Interquartile Range
[a] Chi-square test, [b] Independent t-test, [c] Fisher's exact, [d] Mann-Whitney test

Table 2 Comparison of outcomes at baseline and at Months 1, 3, and 6.

Variables	Pre-experiment Mean (SE)	1 month in experiment Mean (SE)	3 months in experiment Mean (SE)	6 months in experiment Mean (SE)	p-values†
Flexion					<0.001
Control group	94.52 (1.62)	90.91 (1.62)	103.18 (1.62)*	120.91 (1.62)*	
Experimental group	90.80 (1.62)	92.05 (1.62)	111.59 (1.62)*#	122.73 (1.62)*	
Extension					0.006
Control group	-6.07 (0.67)	-0.34 (0.67)*	0.00 (0.71)*	0.00 (0.71)*	
Experimental group	-2.27 (0.67)#	1.14 (0.67)*	0.23 (0.67)	0.00 (0.71)	
Knee circumference (cm)					<0.001
Control group	39.09 (0.62)	43.59 (0.62)*	40.86 (0.62)*	38.32 (0.62)*	
Experimental group	41.48 (0.62)#	45.48 (0.62)*	41.39 (0.62)*#	38.68 (0.62)*	
VAS					<0.001
Control group	8.57 (0.12)	6.16 (0.12)*	3.95 (0.12)*	1.73 (0.12)*	
Experimental group	7.68 (0.12)#	5.59 (0.12)*	3.48 (0.12)*#	1.50 (0.12)*	
TUG (sec)					0.319
Control group	33.76 (3.03)	23.75 (2.96)*	14.86 (2.96)*	9.64 (2.96)*	
Experimental group	39.11 (2.96)	20.50 (2.96)*	12.48 (2.96)*	9.41 (2.96)*	
6MWT (m)					0.014
Control group	152.17 (12.97)	240.68 (12.76)*	350.45 (12.76)*	499.77 (12.76)*	
Experimental group	224.54 (12.89)#	307.50 (12.76)*#	443.41 (12.76)*#	534.32 (12.76)*	

Abbreviations: VAS, Visual Analog Scale; TUG, Timed Up and Go test; 6MWT, Six-Minute Walk Test; SE, Standard Error.
†p-values from group × time interaction from mixed model, *= p-value<0.05 when compared to the value before within-group experiment, #= p-value<0.05 when compared the between-group value then

RESULTS

The baseline characteristics of patients in the experimental and control groups were analyzed. In each group, 38 of 44 participants (86.4%) were women. Mean age and body mass index (BMI) were almost identical. When comparing the characteristics between the groups, the differences were not statistically significant as shown in Table 1.

Although the mean time from surgical decision to surgery appeared numerically different between groups, the difference was not statistically significant (p = 0.269). Because the distribution was skewed by several prolonged waiting-time outliers, as reflected by the large standard deviations, median and IQR values were also reported and demonstrated comparable distributions between groups.

The analysis showed an increase in the patients' ROM of flexion with statistical significance (p < 0.001) in both groups throughout the follow-up period. At Month 3, improvement was statistically significantly greater in the experimenttal group. Knee extension also improved significantly in both groups (p = 0.006). At Month 6, there was no difference between the groups.

Knee circumference progressively decreased during the 6-month follow-up, although the rate of reduction differed between groups (p < 0.001). VAS pain scores significantly decreased in both groups (p < 0.001), with significantly lower scores in the experimental group than the control group at Month 3. The 6MWT distance improved significantly in both groups over time (p = 0.014). The experimental group demonstrated significantly greater walking distances than the control group at baseline, Month 1, and Month 3. However, no significant between-group difference was observed in TUG performance (p = 0.319), as shown in Table 2.

The analysis KOOS outcomes revealed significant differences in the score improvement in all 5 categories between the groups (p < 0.001). There was a clear improvement in scores in the experimental group since Month 1 in terms of pain, the activities of daily living, and physical activities. At Months 3 and 6, the differences between the groups were evidently significant. The largest difference was observed in quality of life, with the score of 98.72 for the experimental group, compared to 68.89 in the control group at the end of the follow-up period at Month 6 as shown in Table 3.

Table 3 Comparison of the outcomes of the Knee and Osteoarthritis Outcome Scores (KOOS).

Variables	Pre-experiment Mean (SE)	1 month in the experiment Mean (SE)	3 months in the experiment Mean (SE)	6 months in the experiment Mean (SE)	p-values†
Symptoms					<0.001
Control group	49.51 (1.86)	22.73 (1.86)*	47.08 (1.86)	67.78 (1.86)*	
Experimental group	51.87 (1.86)	44.64 (1.86)#	65.50 (1.86)*#	89.61 (1.86)*#	
Pain					<0.001
Control group	36.30 (1.82)	26.14 (1.82)*	49.75 (1.82)*	70.77 (1.82)*	
Experimental group	38.07 (1.82)	52.46 (1.82)*#	74.18 (1.82)*#	96.84 (1.82)*#	
Activities of daily life					<0.001
Control group	48.60 (1.74)	27.41 (1.74)*	51.60 (1.74)	71.76 (1.74)*	
Experimental group	48.13 (1.74)	54.95 (1.74)*#	77.44 (1.74)*#	98.10 (1.74)*#	
Sports/Recreation					<0.001
Control group	15.00 (1.74)	22.84 (1.74)*	44.77 (1.74)*	61.93 (1.74)*	
Experimental group	13.98 (1.74)	43.52 (1.74)*#	66.25 (1.74)*#	86.25 (1.74)*#	
Quality of Life					<0.001
Control group	26.85 (1.46)	25.14 (1.46)	50.00 (1.46)*	68.89 (1.46)*	
Experimental group	21.88 (1.46)#	51.85 (1.46)*#	76.99 (1.46)*#	98.72 (1.46)*#	

Abbreviations: VAS, Visual Analog Scale; TUG, Timed Up and Go test; 6MWT, Six-Minute Walk Test; SE, Standard Error.

†p-values from group × time interaction from mixed model,*= p-value<0.05 when compared to the value before within-group experiment, #= p-value<0.05 when compared the between-group value then

DISCUSSION

This RCT evaluated the effectiveness of combined HILT and telerehabilitation on rehabilitation outcomes in patients with primary knee osteoarthritis following TKA. Outcomes included pain, knee ROM, knee swelling, functional mobility, and patient-reported outcome measures. The patient-reported outcome measures comprised the KOOS, while functional walking capacity was assessed using the 6MWT. Follow-ups were conducted at Months 1, 3, and 6 following the surgery. Patients receiving combined HILT and telerehabilitation demonstrated better recovery across several outcomes, particularly knee flexion, pain reduction, 6MWT performance, and KOOS scores, suggesting improvements in functional recovery and quality of life.

Although some baseline variables showed numerical differences, including time from surgical decision to surgery, these differences were not statistically significant and were considered likely attributable to random variation despite block randomization.

Knee flexion improved significantly in both groups throughout the follow-up period. At Month 3, the experimental group demonstrated significantly greater knee flexion than the control group, suggesting that combined HILT and telerehabilitation may accelerate recovery of joint mobility compared with standard rehabilitation alone. Although the control group had slightly greater preoperative baseline flexion, postoperative ROM recovery following TKA is influenced by multiple factors beyond baseline ROM alone, including pain reduction, inflammation control, periarticular soft tissue recovery, adherence to rehabilitation, muscle strengthening, and participation in functional exercise programs. Therefore, the combined intervention may have contributed to accelerated postoperative recovery despite slightly lower baseline ROM values in the experimental group.

These findings are consistent with the literature review by Osifo and Shobode[16], who investigated the effectiveness of telerehabilitation following TKA. Their review demonstrated that tele-rehabilitation produced outcomes comparable to face-to-face physical therapy in terms of ROM, knee function, and pain reduction. The review included eight studies comprising randomized controlled trials and meta-analyses involving approximately 2,070 participants. The findings suggested that tele-rehabilitation can effectively improve knee ROM and patient-reported outcome measures, including KOOS and WOMAC, without increasing the risk of postoperative complications.

The results showed that knee extension had improved significantly in both groups since Month 1. By Month 6, most of the patients were able to achieve near-full knee extension. However, no significant long-term differences were observed between the two groups. These results are consistent with the study by Bade et al.[17] who also reported that knee ROM continues to recover progressively during the first 6 months of rehabilitation following TKA.

In terms of knee circumference, knee swellings following TKA were evaluated. The swellings in both groups appeared to decrease over the period of 6 months, suggesting the reduction of postoperative edema during the process of tissue recovery after surgery. The reduction in swelling is important since it improves knee ROM and lessens pain during movement.

VAS scores also declined significantly in both groups during the follow-up ($p < 0.001$). The experimental group showed lower pain scores during early postoperative period compared to the control group, although pain levels became comparable by Month 6, likely reflecting normal postoperative recovery. These findings are consistent with previous reports demonstrating progressive pain reduction during the first 3–6 months after TKA[18].

The beneficial effects of HILT may be explained by several biological mechanisms. Previous evidence suggests that laser therapy can promote photobiomodulation by enhancing mitochondrial ATP production, improving local blood circulation, reducing inflammatory cytokine activity, and stimulating tissue repair. In addition, HILT may reduce nociceptor sensitivity and postoperative edema, which could contribute to pain reduction and improved joint mobility. These physiological effects may facilitate earlier participation in rehabilitation exercises and accelerate functional recovery following TKA.

TUG performance improved progressively in both groups, indicating recovery of functional mobility following TKA. However, no statistically significant differences were found between the experimental and control groups. These findings can be explained by the fact that recovery of the ability to rise from a chair and walk in patients following TKA can occur through standard rehabilitation and the natural post-operative recovery process. As a result, the distinguishable difference in the treatment outcomes may not occur in the long term[19].

In the 6MWT, the results demonstrated significantly better performance in both groups throughout the follow-up period ($p = 0.014$), indicating the recovery of walking capacity and functional endurance following TKA. The walking distances performed by the experimental group were greater than those of the control group before the experiment and at Months 1 and 3. At Month 6, the performances of both groups were evidently greater, with the experimental group performing a slightly greater distance. These results demonstrated that performance recovery following TKA can help to increase functional walking capacity continuously in the 6-month post-operative period. Kim et al. reported that the 6MWT results of patients after TKA had increased significantly in 1–3 months following the surgery and continued to improve throughout the rehabilitation process[19]. Therefore, the results from this study could suggest that post-operative rehabilitation with additional treatment, such as HILT and telerehabilitation, may stimulate the recovery of walking ability in the early stages of recovery. This also helps patients to more effectively return to their activities of daily life during the post-operative period.

The 5 outcomes of KOOS consisting of symptoms, pain, activities of daily life, sports and recreational activities, and quality of life changed with statistical significance ($p < 0.001$). The scores from the experimental group had been noticeably higher since Month 1 of the experiment, especially in terms of pain, activities of daily life, and sports and recreational activities (physical activities). The difference was greater at Months 3 and 6 of the follow-up period, particularly in terms of the quality of life at Month 6 in which the experimental group scored 98.72 and the control group scored 68.89. These results were consistent with the study by Russell et al.[20] who conducted research on the effectiveness of the use of tele-rehabilitation after TKA. In that study, it was found that there were no observed significant differences in the improvements of the KOOS and functional outcomes between the patients who had received tele-rehabilitation and the patients who received face-to-face physical therapy. There were statistical increases in the KOOS of pain and activities of daily living ($p < 0.001$) after the 6-month period of follow-up, suggesting that continuous rehabilitation helps to improve patients' knee functions and the quality of their lives following surgery.

A limitation of this study is that HILT and telerehabilitation were administered concurrently. Therefore, the independent contribution of each intervention could not be determined, and the observed benefits may reflect their synergistic effects.

CONCLUSIONS

Combined HILT and telerehabilitation may serve as an effective adjunctive to postoperative rehabilitation following TKA. This approach may accelerate recovery of knee joint function, reduce postoperative pain, and improve patient-reported outcomes, particularly quality of life during postoperative period. Therefore, this approach has the potential to be applied in clinical practice and healthcare delivery systems, especially in contexts in which improving accessibility and the continuity of rehabilitation care after hospital discharge is required.

Suggestions for Future Research

1. HILT, when combined with telerehabilitation, can effectively assist postoperative rehabilitation following TKA. Thus, healthcare providers should consider incorporating this approach as a part of the postoperative rehabilitation programs to help patients reduce pain,

improve the knee ROM, and promote a faster return to activities of daily living.

2. To increase the applicability to healthcare services across different contexts, multicenter randomized controlled trials should be considered to confirm the effectiveness of the use of HILT combined with telerehabilitation among a more diverse patient population.

3. Long-term follow-up beyond 6–12 months is needed to determine the sustainability of improvements in functional recovery, pain control, and patient-reported outcome measures (PROMs) following TKA.

4. Future studies should also evaluate the cost-effectiveness and healthcare system impact of combining HILT with telerehabilitation to support broader clinical implementation.

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