Hirosaki Med. J. **75**：11—21, 2024

ORIGINAL ARTICLE

Hip extensor strengthening exercises additional to physical therapy following knee replacement: A pilot randomized controlled trial

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Abstract The primary goals of knee replacement in osteoarthritis are pain relief and mobility improvement. Mobility depends on antigravity muscles, one of which is the hip extensor. However, only unverified evidence is available regarding the need for additional hip extensor strengthening exercises in physical therapy after knee replacement. This study aimed to compare the functional performance and patient-reported outcomes of a group that underwent conventional postoperative rehabilitation and a group that had hip extensor strengthening exercises incorporated into their rehabilitation. The subjects were hospitalized patients for total and unicompartmental knee arthroplasty, and 48 patients were randomly assigned to each group. Participants in both groups attended 8 weeks of physical therapy. Primary outcomes were the Knee Injury and Osteoarthritis Outcome Score, and three functional performance tests. No significant between-group differences or interactions were observed for any of the primary outcome measures at the 8-week follow-up. Our small randomized controlled trial did not support the addition of uniform hip extensor strengthening exercises to early postoperative physical therapy for total and unicompartmental knee arthroplasty. Early postoperative hip extensor strengthening exercises should be carefully considered in terms of their methods and target patients, and further research is needed to determine their effectiveness.

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Key words: Arthroplasty; Knee replacement; Muscle strength; Randomized controlled trial; Treatment outcome.

Introduction

Knee replacement (KR) is a major surgical procedure performed on older adult patients with knee osteoarthritis worldwide, mainly in developed countries[1-3]. The most common type of KR is total knee arthroplasty (TKA); in this procedure, all three knee joints or only the medial and lateral joints (i.e., excluding the patellofemoral joint) are replaced with artificial joints. Conversely, in unicompartmental knee arthroplasty (UKA), only one of the three knee joints (either the medial or lateral joint) that is causing pain is replaced with an artificial joint. Postoperative physical therapy is performed to promote the recovery of temporarily reduced knee joint range of motion, quadriceps muscle strength, and mobility[4]. However, postoperative mobility does not reach the level of healthy individuals of the same age[5-7], which is a challenge in physical therapy.

Several patients undergoing KR may experience mobility impairments associated with hip muscle weakness. The hip extensors are anti-gravity muscles essential for mobility. In particular, the gluteus maximus muscle contributes the most to the knee joint extension moment during stance phase in gait simulation analysis[8], suggesting that it compensates for the atrophy and impaired activation of the

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Received for publication, November 21, 2023
Accepted for publication, January 17, 2024

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quadriceps femoris[9, 10]. Because patients who undergo KA often have quadriceps muscle weakness after surgery[11-13], gluteus maximus function may be important to them. We previously revealed a significant correlation between hip extensor strength and the ability to walk, stand, and climb stairs at 3 months after TKA[14]. We also found that the knee flexion angle during the stance phase of walking at 1 year after TKA was correlated to the hip extensor strength[15].

Hinman et al. studied the hip extensors of community-dwelling patients with knee osteoarthritis and reported a 16% loss in comparison with the muscle strength in control participants without knee pain[16]. Kumagai et al. reported that the hip extensor strength of patients before TKA was 45% lower than that of healthy participants of the same age[17].

These findings indicate the need to incorporate hip extensor muscle strengthening exercises into physical therapy after KR. However, strengthening exercises targeting the gluteus maximus and adductor magnus muscles have not been verified for their effectiveness. The decision to incorporate strengthening training into a program is left to the therapist's discretion. Furthermore, the mobility impairments that hip extensor training is effective for remain unclear. Physical therapy programs should be based on scientific evidence and tailored to individual patient needs.

The purpose of this study was to compare the postoperative mobility and patient-oriented outcomes of a group that underwent conventional postoperative physical therapy (control group) and a group in which hip extensor muscle strengthening was added to their physical therapy (intervention group).

Methods

Study design and patients

The study was designed as a randomized controlled trial and was considered to be a pilot study based on the projected study sample size. The allocation ratio was targeted at 1 : 1. Study participants were recruited at the Kawamura Orthopedics Clinic in Furano, Hokkaido, Japan, between November 2019 and August 2020 and between January and December 2021. The participants were women aged 60–85 years who were diagnosed with medial knee osteoarthritis (Kellgren–Lawrence grade: ≥2) by the same physician and admitted to the hospital for initial unilateral total knee arthroplasty (TKA) or unicompartmental knee arthroplasty (UKA). The exclusion criteria were: 1) rheumatoid arthritis, 2) hip osteoarthritis, 3) previous neurological disease, 4) preoperative use of a walking aid other than a cane, and 5) difficulty in completing the questionnaire evaluation. We did not consider a history of bilateral knee OA as an exclusion criterion because the condition is prevalent in 49.4% of Japanese women[18]. Thus, we believed that including cases of unilateral knee OA alone would not be representative of the current status of knee OA in the country.

Informed consent was obtained from all of the participants. This study was approved by the Ethics Committee of Hirosaki University Graduate School of Health Sciences and the Ethics Committee of Kawamura Orthopedics Clinic. This report complied with the standard reporting guidelines[19], except for registration of the trial.

Randomization

The participants were randomly assigned to the control or intervention group after eligibility assessment. Adaptive randomization was used as the randomization method. The participants were assigned using a random number table, and then assigned to the control or intervention group, whichever was fewer, using TKA or UKA factors as a minimization method. The entire process from eligibility assessment to randomization was performed by the principal investigator in the order of admission. Blinding was not available.

Procedures

All patients were evaluated the day before surgery and 8 weeks postoperatively. The same expert surgeon made all surgical decisions. Standard KR was performed under spinal anesthesia using a mid-vastus approach with an air tourniquet. Triathlon implants were used (Stryker, Kalamazoo, MI, USA) and components were cemented in place after alignment was verified using a navigation system. TKA was either of the posterior-stabilized (PS) or cruciate-substituting (CS) type. The anterior cruciate ligament was resected, and in the CS type, either resection or preservation of the posterior cruciate ligament (PCL) was performed. The patella was replaced in all patients who underwent TKA. Triathlon Partial Knee Resurfacing was used in all patients who underwent UKA. UKA was performed using a narrower mid-vastus approach, and all ligaments were preserved; components were cemented using the same method as that used in TKA.

Interventions

All patients received physical therapy for 8 weeks, starting from postoperative day 1. The planned hospital stay durations were of approximately 4 and 3 weeks for TKA and UKA, respectively. After discharge, the patients were transferred to outpatient rehabilitation. Each physical therapy session lasted approximately 40 min. Inpatient physical therapy consisted of 1–2 sessions per day, 6 days a week, and outpatient physical therapy consisted of 1–2 visits per week and home exercises. In each group, therapists were instructed to set the exercise load using the Ten-Repetition Maximum method and to perform one to three sets of 10 repetitions. The loading volume for isometric contraction exercises was 6 seconds of maximal voluntary contraction. The programs for TKA and UKA were identical.

Conventional physical therapy programs consisted mainly of knee joint range-of-motion exercises, quadriceps muscle strengthening, and movement exercises (Table 1). The intervention group underwent additional hip extensor strengthening exercises (Table 2).

The hip extensor strengthening exercises included the gluteus maximus muscle setting exercise, supine hip extension exercise, supine hip extension adduction resistance exercise, and standing hip extension exercise. During the gluteus maximus setting exercise, the patients performed 10 maximal voluntary contractions of approximately 5 seconds in the prone position. During the supine hip extension exercise, a towel was placed against the patients' abdomen to prevent lumbar spine compensation; if the manual muscle testing grade was <3, active-assisted exercises were adopted, and the load was gradually increased to make way for active and resistance exercises. For both the gluteus maximus setting and supine hip extension exercises, knee flexion was recommended to the extent possible. During the back supine hip extension adduction exercise, the therapist applied manual resistance to the patients' distal lower leg or the distal thigh and directed them to perform a hip extension adduction resistance exercise from hip flexion abduction to hip flexion external rotation. During the standing hip extension exercise, the patients were placed in a one-leg standing position and made to perform hip extension on the raised side.

Physical therapy was performed by physical therapists with 1–4 years of experience, who had previously been instructed using a postoperative physical therapy manual. They were also responsible for the pre- and postoperative outcome assessments. No adverse events were observed in either group during the study

Table 1. Conventional Physical Therapy Exercises (Common Program)

Goal	Exercises	Start date / criteria
Prevent vascular and pulmonary complications	Ankle pumping	Postoperative Day 1
Control pain and swelling	Cold, compression, and elevation	Postoperative Day 1
Increase knee extension ROM	Hamstring/Calf stretch	Postoperative Day 1
Recovery of knee flexion ROM	Quads stretch and massage Active assistive flexion ROM Hamstring curls in prone position	Postoperative Day 1 Postoperative Day 1 Possible to prone position
Improve quadriceps strength	Quads set. Inner range quads Sitting knee extention Squats	Postoperative Day 1 Possible to Quads set. Possible to Inner range quads Possible to knee extension in end sitting position
Improve hip abduction strength	Sidelying hip abduction	Postoperative Day 3
Improve trunk and ankle strength	Trunk curl Heel raises	Postoperative Day 1 Postoperative Day 3
Reestablish functional mobility	Gait training Sit-to-stand Step-ups / downs	Possible to standing posiiton Possible to squats Possible to sit-to-stand

Table 2. Additional Hip Extension Exercises (Intervention group)

Goal	Exercises	Start date / criteria
Improve hip extension strength	Gmax sets Supine hip ext Prone hip ext Bridging / Standing hip ext	Possible to prone position Postoperative Day 3 Possible to prone position Postoperative Week 2

period.

Outcome measures

The main outcomes were the results of the Five-Meter Walk Test (5MWT), Five-Times Sit-to-Stand Test (FTSS)[20, 21], Stair Climb Test (SCT)[22], and Knee Injury and Osteoarthritis Outcome Score (KOOS)[23].

The 5MWT measured the time that passed during a 5 m walking section by setting acceleration sections of 1.0 m at the start of a total walking length of 6 m. The start point, 1.0 m, and finish points were marked with lines. The FTSS measured the time required to stand up and down from a chair (43 cm height) five times. The SCT measured the time to complete a round-trip of nine stairsteps (17.5 cm step height). The data collector judged and measured time using a stopwatch. All measurements were performed twice and the shortest speed was recorded.

The KOOS is a patient-oriented outcome measure for patients with knee osteoarthritis and is widely used to monitor postoperative progress and outcomes. It comprises subscales of pain, symptoms, activities of daily living (ADL), sport and recreation function, and knee-related quality of life (QOL). A meta-analysis reported that it is reliable and valid[23].

The sub-outcome was hip extensor strength. Hip extensor muscle strength was measured in the sitting position using a handheld dynamometer, according to the method described by Seko et al.[24] (Figure 1). The measured values were multiplied by the lever arm length (m) and standardized by the body weight (kg) to calculate the torque-to-weight ratio (Nm/kg). The intra- and inter-rater reliabilities were both >0.8.

Figure 1 Hip extensor muscle strength measurement
Sitting position of isometric muscle strength for the hip extensor using a handheld dynamometer. The pelvis tilted posteriorly, placing the HHD on the distal third of the thigh. The tester held both hands at the pelvic iliac crest site from his position in front of the participant and instructed the participant to push his or her thigh down. HHD indicates handheld dynamometer.

Statistical analysis

Split-plot analysis of variance (mixed-effects model for repeated measures, MMRM) with a linear mixed model was applied to the analyses. After confirming normality using the Shapiro–Wilk test, the corresponding t-test was applied to normal data, and the Wilcoxon test to non-normal data. Correlation tests were performed to investigate the factors influencing the rate of change in hip extensor strength. R Ver 2.8.0 was used for the above analyses, with a significance level of 0.05.

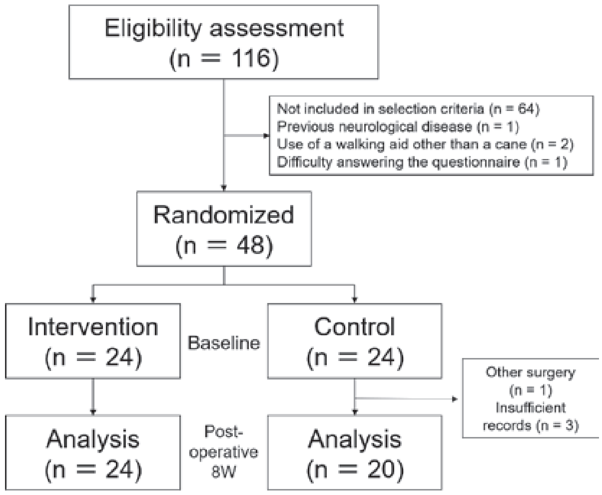

Figure 2 Flowchart of the participant recruitment

RESULTS

Participant flow and characteristics

A total of 52 patients met the inclusion criteria and participated in this study (Figure 2). Of these, 4 were excluded, and 48 patients were randomly assigned to either the intervention or control group. Four in the control group dropped out, therefore 24 patients in the interventions and 20 in the controls groups were finally analyzed.

The baseline characteristics of the two groups were similar for both TKA and UKA (Table 3): in patients who underwent TKA, two PS types were assigned to the control group only, and PCL preservation patients of the CS type were 8:3 times more common in the intervention group than in the control group.

Table 3. Patient demographic data

Variable		TKA		UKA	
		Int-G n = 12	Con-G n = 10	Int-G n = 12	Con-G n = 10
Age, mean (SD)	(yrs)	73.8 (5.8)	74.0 (6.5)	74.8 (6.4)	76.5 (5.2)
Height, mean (SD)	(cm)	151.0 (6.7)	151.8 (5.5)	149.7 (6.7)	146.9 (4.7)
Mass, mean (SD)	(kg)	61.0 (13.7)	61.4 (9.1)	55.6 (8.9)	52.1 (6.8)
Body mass index, mean (SD)	(kg/m^2)	26.9 (6.5)	26.7 (4.2)	24.8 (2.7)	21.3 (3.7)
Side of surgery (N)	L : R	9 : 3	4 : 6	7 : 5	6 : 4
A History of Bilateral Knee OA (N)		5	7	5	6
CS type TKA, PCL preservation (N)		8	3	–	–
CS type TKA, PCL cut (N)		4	5	–	–
PS type TKA, PCL cut (N)		0	2	–	–

Int-G = Intervention group, Con-G = control group
TKA = total knee arthroplasty, UKA = Unicompartmental knee arthroplasty
CS = cruciate substituting type, PS = posterior stabilized type
PCL = posterior cruciate ligament
SD = standard deviation

Table 4. MMRM of TKA patients

Outcomes		Pre		PO8 w		*p* value		
		Int-G	Con-G	Int-G	Con-G	Pre vs PO8w	Int-G vs Con-G	Interaction
KOOS	Pain	59.5 (12.0)	57.6 (11.7)	74.6 (12.4)	78.5 (12.4)	*<0.01*	*0.750*	*0.349*
	Symptom	65.8 (18.1)	67.1 (18.0)	73.6 (11.9)	77.8 (11.8)	*0.080*	*0.488*	*0.528*
	ADL	66.5 (12.3)	64.5 (11.1)	81.7 (8.3)	84.7 (11.6)	*<0.01*	*0.898*	*0.456*
	QOL	39.5 (16.5)	40.7 (12.4)	57.1 (9.1)	56.1 (16.2)	*<0.01*	*0.830*	*0.504*
Functional performance	5MWT	3.69 (1.17)	4.22 (0.95)	3.74 (0.85)	3.92 (0.87)	*0.060*	*0.836*	*0.660*
	FTSS	12.23 (2.17)	11.56 (2.15)	11.29 (1.73)	10.98 (2.30)	*0.137*	*0.509*	*0.739*
	SCT	18.83 (9.50)	19.11 (6.55)	16.65 (7.09)	15.70 (4.34)	*<0.01*	*0.912*	*0.516*
Strength	Hip ext.	0.35 (0.19)	0.41 (0.33)	0.40 (0.13)	0.44 (0.29)	*0.613*	*0.492*	*0.467*

Values shown are mean (standard deviation), *p* value significant at 0.05
Pre = preoperative, PO = postoperative
Int-G = Intervention group, Con-G = control group
TKA = total knee arthroplasty, MMRM = mixed effect model for repeated measures
KOOS = Knee injury and Osteoarthritis Outcome Score
5MWT = 5-m walking test, FTSS = sit-to-stand test, SCT = stair climbing test

Outcome measures

In patients who underwent TKA, no significant between-group differences and interactions were noted for all KOOS subscales, mobility ability, and hip extensor strength (Table 4).

In patients who underwent UKA, significant between-group differences were noted in the hip extensor strength, but no significant between-group differences and interactions were noted for all KOOS subscales and mobility ability (Table 5).

In a before-and-after comparison, only the UKA intervention group improved significantly more postoperatively than preoperatively (Table 6). However, the difference was small (95% CI: 0.2–0.0).

The rate of change in hip extensor strength in the TKA intervention group was significantly negatively correlated with preoperative hip extensor strength, and a higher preoperative strength did not improve postoperative strength. No such correlation was observed in the UKA intervention group (Figure 3).

Table 5. MMRM of UKA patients

Outcomes		Pre		PO8w		*p* value		
		Int-G	Con-G	Int-G	Con-G	Pre vs PO8w	Int-G vs Con-G	Interaction
KOOS	Pain	56.8 (20.6)	51.7 (23.4)	77.4 (11.7)	75.1 (14.1)	*<0.01*	*0.558*	*0.824*
	Symptom	66.9 (15.7)	53.6 (26.4)	74.3 (10.6)	76.3 (16.5)	*<0.01*	*0.391*	*0.128*
	ADL	71.9 (13.1)	67.4 (17.7)	86.2 (9.7)	83.4 (12.5)	*<0.01*	*0.417*	*0.937*
	QOL	41.3 (22.6)	34.6 (23.6)	69.4 (23.1)	62.6 (19.6)	*<0.01*	*0.379*	*0.965*
Functional performance	5MWT	4.11 (1.46)	4.70 (2.02)	4.27 (2.18)	3.67 (0.60)	*0.371*	*0.990*	*0.228*
	CS-5	10.90 (2.71)	11.69 (5.42)	9.93 (3.47)	10.49 (3.08)	*0.256*	*0.991*	*0.725*
	SCT	14.91 (6.17)	17.51 (14.20)	15.34 (4.97)	13.87 (4.78)	*0.346*	*0.906*	*0.333*
Strength	Hip ext.	0.40 (0.25)	0.51 (0.28)	0.50 (0.25)	0.46 (0.20)	*0.800*	*0.824*	*<0.05*

Values shown are mean (standard deviation), *p* value significant at 0.05
Pre = preoperative, PO = postoperative
Int-G = Intervention group, Con-G = control group
UKA = Unicompartmental knee arthroplasty, MMRM = mixed effect model for repeated measures
KOOS = Knee injury and Osteoarthritis Outcome Score
5MWT = 5-m walking test, FTSS = sit-to-stand test, SCT = stair climbing test

Table 6. Comparison of hip extensor muscle strength Pre and Post operative in each group

Group		Pre	PO8w	95%CI	*p*-value
TKA	Intervention group, means (SD)	0.35 (0.19)	0.40 (0.13)	−0.15~0.06	*0.329*
	Control group, median (IQR)	0.41 (0.33)	0.44 (0.29)	−	*0.945*
UKA	Intervention group, means (SD)	0.40 (0.25)	0.50 (0.25)	−0.20~−0.00	*<0.05*
	Control group, means (SD)	0.51 (0.28)	0.46 (0.20)	−0.09~0.26	*0.286*

p value significant at 0.05
TKA = total knee arthroplasty, UKA = Unicompartmental knee arthroplasty
Pre = preoperative, PO = postoperative
SD = standard deviation, IQR = interquartile range, CI = confidence interval

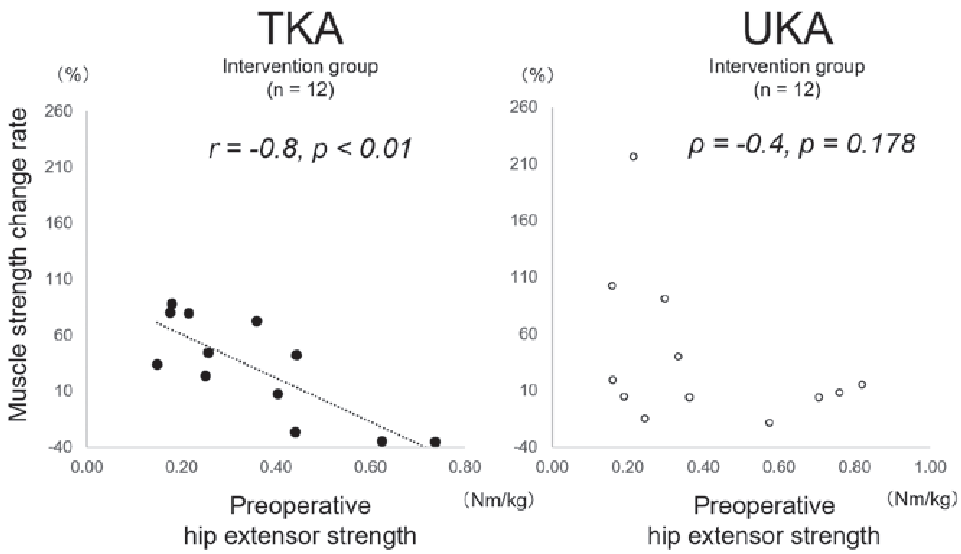

Figure 3 Scatter plot of preoperative hip extensor muscle strength and muscle strength change rate in each intervention group

Discussion

This is the first study to evaluate the effects of additional hip extensor strengthening in an early physical therapy program after KA. Our small randomized controlled trial showed no significant between-group differences or interactions between the intervention and control groups in the KOOS or mobility at the 8-week follow-up. Schache et al.[25] investigated the effects of additional hip abduction muscle strengthening exercises 6 weeks after TKA and reported no significant improvement in KOOS or mobility at 6 or 26 weeks. Our study was similar to that of Schache et al., and it did not support the uniform addition of hip extensor strengthening exercises to early postoperative physical therapy for TKA and UKA.

In contrast, studies on hip abductor muscle strengthening exercises in patients performed after more than 3 months following TKA have reported their effectiveness in some outcomes. Harikesavan et al.[26] continued hip abductor strengthening until 16 weeks after discharge following TKA and reported that the 6-min walk and single-leg standing test results at 3 and 12 months postoperatively were significantly better than those in the control group. In addition, a randomized controlled trial comparing the effects of quadriceps and hip abductor exercises in patients at 3 months and 1 year after TKA reported a significant interaction in items indicating the ability to support oneself on a single leg during walking[27]. Compared with their study, this study was conducted relatively early in the postoperative period; this was due to the following reason. Hip extensors primarily act on joint moments in the sagittal plane; thus, we expected the effect of hip extensor training to be different from that of abductor training, and hypothesized that this effect would be demonstrated in the early postoperative period (i.e., when quadriceps muscle weakness was evident). However, because previous studies on postoperative hip training have shown superior results in the long-term postoperative period, it is necessary to further clarify the relationship between the postoperative results (especially in the sagittal plane) and the hip extensor muscle groups and to investigate the effects of intervention at ≥3 months postoperatively.

In this study, hip extensor strength showed no significant between-group differences in patients who underwent TKA, and only a small improvement in patients who underwent UKA. This may be because the movement exercises and closed quadriceps programs were common to both groups. Wall squats and step exercises have been reported to increase gluteus maximus muscle activity[28].

Another finding of this study was that the effects of the hip extensor-strengthening exercises differed between TKA and UKA, suggesting that they were influenced by the preoperative muscle strength of patients undergoing TKA. Although the same hip joint training was performed postoperatively in patients who underwent TKA and UKA, only the UKA intervention group showed significant muscle strength gains. Because the postoperative impact of UKA are generally milder than those of TKA, we hypothesized that functional impairment (such as pain around the knee joint, muscle weakness, and limited joint range of motion) affected the intensity of hip training. In the TKA intervention group, the training effect was poorer in patients with a better preoperative muscle strength, suggesting that high-load training according to the principle of overload was more difficult with TKA. In this study, the hip extensor strength measurement in the sitting position mainly reflects the activity of the gluteus maximus muscle[29]. However, hip extension training in each position does not necessarily imply that only the gluteus maximus muscle is active. After TKA, the hamstring strength declines, as does the quadriceps strength[30]. In this study, hip extension training in knee flexion was prescribed as much as possible to reduce the effect on the hamstrings, but this may have been insufficient depending on the limitation on the degree of knee flexion range of motion postoperatively.

The problem with this study is that it did not assess contralateral lower extremity function. The functional mobility test applied by this study is affected by contralateral lower extremity function. Therefore, in order to correctly determine the effects of hip training, contralateral lower extremity function must be constant before and after surgery, or the increase or decrease must be similar between groups. This study did not confirm this, and it is an issue for the future. The application of unilateral lower extremity function testing as an outcome should also be considered.

The limitations of this study were that it was a uniform intervention that did not consider the patient's original muscle strength and that it was limited to the early 8-week postoperative period. Future studies should examine the effects of hip extensor muscle strengthening in patients with low preoperative muscle strength and in patients more than 3 months postoperatively. Effective hip extensor strength training should also be considered for patients with a high preoperative muscle strength. In addition, this preliminary unblinded study was conducted at a single institution and had a small sample size.

Conclusion

Our small randomized controlled trial did not support the addition of uniform hip extensor strengthening exercises to early postoperative physical therapy for TKA and UKA. Future studies should examine the effects of hip extensor muscle strengthening in patients with low preoperative muscle strength and over a longer follow-up period.

Conflicts of Interest

The authors declare no conflicts of interest directly relevant to the content of this article.

Acknowledgments

We would like to thank the Kawamura Orthopedic Clinic Rehabilitation Staff and patient participants for their contributions to this clinical trial.

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