Effect of combined hip and knee exercises on rehabilitation after total knee arthroplasty: A prospective randomized trial

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Abstract

Background: To explore the clinical effect of combined hip–knee joint exercise compared with traditional postoperative rehabilitation after total knee arthroplasty (TKA).

Methods: In a prospective, single-blind randomized controlled trial, 60 female patients with osteoarthritis who underwent unilateral TKA were randomly divided into three groups: a resistive intervention group, a nonresistive intervention group and a control group. Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) values, Forgotten Joint Score (FJS)-12 values, isokinetic muscle strength, and gait test results were measured and recorded preoperatively, two weeks postoperatively and three months postoperatively.

Results: With the preoperative evaluation as baseline, the resistive hip–knee joint exercise group had lower functional scores and stronger quadriceps femoris and hip abductor muscles than the nonresistive group ($p<0.05$ for both). Both hip–knee exercise groups had stronger quadriceps femoris, hip abductor and hip rotator muscles than the control group ($p<0.05$). Two weeks postoperatively, both hip–knee strength training groups had lower functional scores than the control group ($p<0.05$) but stronger quadriceps femoris and external hip rotator muscles ($p<0.05$). Preoperative and 2-week postoperative gait analysis revealed that combined hip–knee strengthening could increase step length ($p<0.05$) and the ability to stand on the affected limb ($p<0.05$).

Conclusion: A 12-week regimen of combined hip–knee exercises could improve the function of the affected limb after TKA, the movement patterns of the knee joint during gait, and the therapeutic effect of TKA and accelerate patients' rehabilitation. The effect of combined hip–knee exercises positively correlated with increases in exercise load.

1. Introduction

Osteoarthritis (OA) is a degenerative joint disease that seriously affects patient quality of life.[1–3]Total knee arthroplasty (TKA) is an effective method for reducing pain and restoring knee joint function in patients with end-stage knee OA with 75–89% patient satisfaction.[2, 3] The goal of this surgical treatment is to relieve local pain in the knee joint and restore lower limb function in patients with OA, but there is no significant improvement in primary or secondary decreases in function or in the loss of lower limb muscle strength.[4] Unlike improving range of motion (ROM) of the affected limb and pain management in most of the perioperative period of TKA, the goal of rehabilitation programs is to achieve the same lower limb muscle strength as that in healthy people through functional exercises.[5–7]

The quadriceps femoris can undergo varying degrees of disuse atrophy in the course of chronic osteoarthritis, and the weakening of motor signals from the central nervous system will also lead to a decline in muscle strength.[8–10] Because these factors are coupled with mechanical injury of the quadriceps femoris caused by the surgical incision from TKA, the focus of traditional rehabilitation treatment is on recovery of the quadriceps femoris.[11, 12]

In recent years, there has been increasing evidence that a decrease in muscle strength around the hip joint may increase the load of the knee joint and aggravate the progression of OA.[13–15] Some scholars proposed that weakness of hip muscles is a potential cause of the increased load on the medial intercompartment of the tibial-femoral joint.[16] Hence, two cross-sectional clinical studies have confirmed through hierarchical regression analysis that the improvements of knee extensor and hip abductor muscle strength have the same contributions to improving knee joint function.[4, 17] In addition, this conclusion has been supported by the results of high-quality longitudinal studies.[18]

Therefore, we draw two hypotheses: 1. compared with the traditional mode of postoperative rehabilitation, combined hip and knee exercises can further accelerate postoperative rehabilitation and improve the prognosis of patients undergoing TKA by promoting the functional recovery of the knee joint, reducing postoperative pain and improving postoperative gait; 2. the clinical effect of combined hip and knee exercises is positively correlated with an increase in muscle strength.

2. Materials And Methods

2.1. Experimental design

This experiment is a prospective, single-blind, randomized controlled clinical trial. The experiment was approved by the Ethics Committee of the First Affiliated Hospital of Jinan University (batch number: 01/02/2021KY-2021-002) and is registered in the China Clinical Trial Registration Center (Registration number: 19/07/2021ChiCTR2100049022). All patients signed informed consent forms for participation in the trial. The basic design and flow of the experiment are shown in Fig. 1.

2.2. Research object

The subjects of this study were patients who underwent unilateral TKA in the First Affiliated Hospital of Jinan University from January 2021 to January 2022. Sex is an independent predictor of postoperative complications after TKA.[18] To reduce the rotation errors and variations in surgical details that may lead to differences in experimental results and heterogeneity during the placement of femoral or tibial prostheses in different patients[19], the surgical procedures in this study were all performed by the same experienced senior doctor.

2.2.1 Inclusion criteria

(1) Women between 45 and 80 years old met the diagnostic criteria for knee osteoarthritis.[17, 18]

(3) The strength of the hip abductor and knee extensor muscles was graded as 4–5 preoperatively.

2.2.2 Exclusion criteria

(1) Patients had a history of hip arthroplasty, knee collateral ligament reconstruction, or proximal tibial or distal femoral osteotomy.

(2) Body mass index (BMI) was greater than 30 kg/m².

(4) Lower limb muscle strength examination before TKA showed a lower limb muscle strength of grade 3 or lower, wheelchair use for more than three months, severe lower limb valgus deformity (more than 30°) or extraarticular deformity of the lower limb by more than 10°.

(5) Postoperative complications occurred.

(6) Patients completed less than 80% of the exercise regimen.

2.3. Randomization

Twenty pieces of paper, each with the words "resistive hip and knee exercises", "hip and knee exercises" and "routine rehabilitation" were placed into identical envelopes and sealed, and the envelopes were given to a nurse outside the research group for safekeeping. One envelope was taken the day before the patient was discharged from the hospital, and rehabilitation therapist A was informed of the patient grouping results.

2.4. Blinding method

Clinician C, who did not know the patients’ group assignments in the clinical trial, was responsible for scoring and measuring the clinical observation indexes of the patients throughout the trial.

2.5. Postoperative rehabilitation

The rehabilitation guidance instructions were provided to the patients after the operation. The exercise goal was to increase lower limb ROM, flexion and extension and the patients were instructed by rehabilitation therapist B every day.

2.6. Intervention

Rehabilitation doctor A conducted weekly follow-up telephone calls to summarize the exercise status of the patients in that week and give targeted advice to address any of the patients' doubts. Interventions in different groups are shown in Table 1.

2.6.1 Resistive hip and knee joint strengthening group

Patients in the resistive hip and knee joint strengthening exercise group received systematic, intensive hip and knee joint exercises 3 times a week for 12 weeks after discharge, with an interval of at least one day between each exercise. The specific modes of exercise and the ues of latex elastic belts are shown in Fig. 2.

2.6.2 Hip and knee joint strengthening group

The exercises for the patients in this group were basically the same as the resistive hip and knee joint exercises but without adding elastic bandages for resistive exercise.

2.6.3 Control group

In the control group, exercise was introduced by the rehabilitation guidance instructions which mainly includes the exercise of quadriceps femoris.

2.7. Clinical outcome observation indexes

Subjective tests include Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)Forgotten Joint Score (FJS-12)Visual analogue scale (VAS) on pain. Objective tests include ROM of the surgical lower limbStair Climbing Test (SCT) Timed Up and Go (TUG) testIsokinetic test of muscle strength and Gait test.

2.8 Sample size estimation

The significance level of repeated measurement variance was set as $\alpha = 0.05$, the effect size was 0.25, and the efficiency was 0.95. Therefore, a sample size of 51 patients was required to maintain the actual efficiency (0.96). Considering some of the reasons that lead to off-target, we estimated that a total of 60 patients were needed.

2.9 Statistical analysis

In this study, IBM SPSS Statistics Version 26.0 for Windows was used for statistical processing. One-way analysis of variance (ANOVA) and descriptive statistics were used to analyse the characteristics of the subjects. The Shapiro-Wilk test was used to test the normality of the general characteristics of the subjects. One-way ANOVA was used to test the homogeneity of dependent variables among the three groups before the operation and 2 weeks after the operation. Then, the Pearson correlation coefficient was used to construct a linear correlation matrix to analyse the correlation between the quadriceps femoris and hip abductor and knee joint function changes. In addition, multivariate ANOVA was used to compare the interactions between group assignment and measurement time. The data were analysed by ANOVA, and the baseline score was used as the covariable in the comparison of groups. The Bonferroni method was used for post hoc analyses. The statistical analysis and comparison of results before and after 12 weeks of intervention can reveal the effects of different rehabilitation treatments on the effect of TKA surgery; similarly, a comparison of the results after 12 weeks of intervention and 2 weeks postoperatively can reveal the effects of different rehabilitation treatments on the functional rehabilitation of the affected limbs after TKA. All tests were performed at a statistically significant level of $\alpha = 0.05$.

3. Results

The eligibility of 60 patients undergoing TKA was evaluated, and these participants agreed to participate and were randomly assigned to one of the three treatment groups (Fig. 1). There was no significant difference in age, height, weight or BMI among the three treatment groups($p > 0.05$)(Table 2). A total of 50 participants completed the study and returned to the hospital 3 months after the intervention to complete the final evaluation; 6 participants failed to complete 80% of the required exercises and withdrew from the study, and 3 participants dropped out due to personal reasons during follow-up. One participant withdrew due to serious incision complications.

3.1 Function scale scores and pain

Based on the WOMAC scale, the functional score of the affected limb in the hip and knee joint strengthening group after TKA was lower than that in the control group ($p < 0.05$)(Table 3). Post hoc analysis showed that with the preoperative evaluation as the baseline, the functional score of the resistive hip-knee joint strengthening group was lower than that of the nonresistive hip-knee joint strengthening group, and the functional score of the nonresistive hip-knee joint strengthening group was lower than that of the control group ($p < 0.05$)(Table 3). If the results from 2 weeks after the operation were considered the baseline, the functional scores of the resistive and nonresistive hip and knee joint strengthening groups were lower than those of the control group ($p < 0.05$)(Table 3), but there was no

Table 1
Exercise schedule of loaded hip and quadriceps strengthening group, hip and quadriceps strengthening group and control group

	Load quantity	Time	Training quantity	Remarks
NRHKG	Self load	1-4weeks	Each exercise is divided into three groups 10 times for the first; 15 times for the second; 20 times for the third.	1.Exercise 3 times a week for 12 weeks. 2.The interval between two exercises is at least one day. 3.The rest interval between groups is 30 seconds.
	Self load + 5 lb elastic belt	5-8weeks		
	Self load + 10 lb elastic belt	9-12weeks		
NRHKG	Self load	1-12weeks		
Control group	Self load	1-12weeks		
RHKG:resistive hip and knee group; NRHKG: nonresistive hip and knee group and control group				

Table 2
General characteristics of participants

characteristics	All participants	RHKG	NRHKG	Control group	P
	Mean(SD)	Mean(SD)	Mean(SD)	Mean(SD)	
Age(years)	67.08 ± 6.29	65.65 ± 4.26	66.93 ± 7.79	68.56 ± 6.53	0.398
Height(cm)	155.59 ± 5.42	157.18 ± 4.86	154.16 ± 6.65	155.28 ± 4.66	0.284
weight(kg)	67.06 ± 9.34	64.65 ± 8.84	68.27 ± 10.49	68.32 ± 8.87	0.434
BMI	27.72 ± 3.82	26.10 ± 2.84	28.75 ± 4.33	28.38 ± 3.82	0.095
SD-Standard deviation;RHKG:resistive hip and knee group: NRHKG: nonresistive hip and knee group and control group					

Table 3
Statistical results of WOMAC、FJS、VAS、ROM、TUG、SCT

Measurement result	RHKG (A)	NRHKG(B)	Control group(C)	F	P	Post hoc
	Mean(SD)	Mean(SD)	Mean(SD)			
WOMAC						
BO	107.12 ± 12.83	107.40 ± 12.50	103.33 ± 13.82	0.517	0.600	
2 weeks PO	51.41 ± 14.44	53.80 ± 14.85	53.39 ± 14.74	0.125	0.883	
12 weeks PO	30.41 ± 8.43	33.07 ± 9.23	36.56 ± 9.52	49.232 [a]	0.000 [a]※	A>B>C
				116.406 [b]	0.000 [b]※	A>C, B>C
Times X Grouping				9.822	0.000※	
FJS						
2 weeks PO	47.00 ± 0.87	47.00 ± 0.85	47.22 ± 0.89	0.381	0.685	
12 weeks PO	40.76 ± 4.22	41.73 ± 4.51	42.50 ± 3.60	1.499 [b]	0.234 [b]	
VAS						
BO	5.82 ± 1.70	5.87 ± 1.60	5.22 ± 1.73	0.787	0.461	
2 weeks PO	4.11 ± 1.00	4.46 ± 1.19	4.39 ± 1.20	0.020	0.980	
12 weeks PO	2.76 ± 1.25	2.53 ± 1.25	2.33 ± 1.14	1.176 [a]	0.318 [a]	
				2.013 [b]	0.145 [b]	
Times X Grouping				2.079	0.090	
ROM(°)						
BO	100.88 ± 17.79	98.00 ± 15.33	99.18 ± 17.27	0.125	0.883	
2 weeks PO	95.88 ± 5.93	97.67 ± 5.30	96.94 ± 6.67	0.356	0.702	
12 weeks PO	121.18 ± 9.44	112.33 ± 12.08	111.11 ± 12.31	4.215 [a]	0.021 [a]※	A>C
				4.086 [b]	0.023 [b]※	A>C
Times X Grouping				2.306	0.064	
TUG(s)						
BO	19.24 ± 8.44	22.33 ± 8.23	22.89 ± 8.72	0.920	0.405	
2 weeks PO	26.29 ± 5.92	28.67 ± 6.09	26.33 ± 4.70	0.937	0.399	
12 weeks PO	14.88 ± 4.53	15.60 ± 5.72	19.28 ± 5.15	4.369 [a]	0.018 [a]※	A>C
				3.574 [b]	0.036 [b]※	A>C
Times X Grouping				1.445	0.225	

SD-Standard deviation;※-p<0.05;[a]-Comparison between 12 weeks after intervention and BO; [b]-Comparison between 12 weeks after intervention and 2 weeks after operation; WOMAC-Western Ontario and McMaster Universities Osteoarthritis Index; FJS-Forgotten Joint Score; VAS-Visual analogue scale; ROM-Range of motion; TUG-Times up and Go; SCT-Stair Climbing Test; RHKG:resistive hip and knee group; NRHKG: nonresistive hip and knee group and control group

Measurement result	RHKG (A)	NRHKG(B)	Control group(C)	F	P	Post hoc
	Mean(SD)	Mean(SD)	Mean(SD)			
SCT(s)						
BO	48.00 ± 11.39	45.87 ± 10.91	50.94 ± 11.98	0.819	0.447	
2 weeks PO	59.65 ± 18.36	55.60 ± 13.60	65.39 ± 10.04	1.945	0.154	
12 weeks PO	29.88 ± 7.69	30.20 ± 5.36	37.50 ± 12.02	4.463 [a]	0.017 [a※]	A>C, B>C
				4.174 [b]	0.022 [b※]	A>C
Times X Grouping				0.306	0.873	

SD-Standard deviation;※-p<0.05;[a]-Comparison between 12 weeks after intervention and BO; [b]-Comparison between 12 weeks after intervention and 2 weeks after operation; WOMAC-Western Ontario and McMaster Universities Osteoarthritis Index; FJS-Forgotten Joint Score; VAS-Visual analogue scale; ROM-Range of motion; TUG-Times up and Go; SCT-Stair Climbing Test; RHKG:resistive hip and knee group; NRHKG: nonresistive hip and knee group and control group

Table 4
Statistical results of isokinetic test and gait test

Measurement result	RHKG (A)	NRHKG(B)	Control group(C)	F	P	Post hoc
	Mean(SD)	Mean(SD)	Mean(SD)			
Quadriceps(100Nm/KG)						
BO	44.83 ± 14.81	41.94 ± 15.46	39.81 ± 13.06	0.533	0.590	
2 weeks PO	19.09 ± 9.76	14.18 ± 7.86	17.12 ± 8.28	1.277	0.288	
12 weeks PO	58.18 ± 16.20	50.44 ± 15.76	43.48 ± 15.35	23.011 [a]	0.000 [a※]	A>B>C
				18.033 [b]	0.000 [b※]	A,B>C
Times X Grouping				10.846	0.000※	
Hip abductors(100Nm/KG)						
BO	41.34 ± 15.00	38.64 ± 17.50	38.96 ± 13.41	0.156	0.856	
2 weeks PO	25.02 ± 7.39	21.58 ± 7.61	21.11 ± 8.16	1.296	0.283	
12 weeks PO	53.30 ± 20.00	41.50 ± 20.49	36.81 ± 16.17	44.328 [a]	0.000 [a※]	A>B>C
				6.090 [b]	0.005 [b※]	A>C
Times X Grouping				15.859	0.000※	
Hip extortor(100Nm/KG)						
BO	18.37 ± 6.91	18.10 ± 5.27	15.36 ± 4.20	1.554	0.222	
2 weeks PO	10.05 ± 3.98	10.46 ± 3.59	11.00 ± 3.32	0.301	0.742	
12 weeks PO	23.20 ± 10.32	21.65 ± 7.40	16.43 ± 5.71	13.328 [a]	0.000 [a※]	A>C,B>C
				82.747 [b]	0.000 [b※]	A>B>C
Times X Grouping				6.995	0.000※	
Step size(cm)						
BO	45.90 ± 5.97	48.85 ± 7.60	44.59 ± 8.64	1.358	0.267	
2 weeks PO	38.91 ± 5.35	41.53 ± 7.36	41.14 ± 5.51	0.901	0.413	
12 weeks PO	63.23 ± 5.89	58.42 ± 6.46	52.46 ± 7.19	12.139 [a]	0.000 a※	A>C,B>C
				11.295 [b]	0.000 b※	A>C,B>C
Times X Grouping				4.896	0.001※	
Walking speed(m/s)						
BO	0.44 ± 0.15	0.43 ± 0.15	0.38 ± 0.17	0.707	0.498	
2 weeks PO	0.46 ± 0.23	0.47 ± 0.16	0.50 ± 0.14	0.267	0.767	
12 weeks PO	0.75 ± 0.24	0.65 ± 0.27	0.57 ± 0.21	2.032 [a]	0.081 [a※]	

SD-Standard deviation;※-p<0.05; [a]-Comparison between 12 weeks after intervention and BO;[b]-Comparison between 12 weeks after intervention and 2 weeks after operation; RHKG:resistive hip and knee group; NRHKG: nonresistive hip and knee group and control group

Measurement result	RHKG (A)	NRHKG(B)	Control group(C)	F	P	Post hoc
	Mean(SD)	Mean(SD)	Mean(SD)			
				2.490 [b]	0.094 [b※]	
Times X Grouping				1.265	0.289	
Percentage of one-legged support phase(%)						
BO	36.33 ± 7.82	37.32 ± 6.18	35.91 ± 7.04	0.166	0.847	
2 weeks PO	35.90 ± 8.83	33.31 ± 7.82	35.41 ± 13.45	0.271	0.764	
12 weeks PO	49.69 ± 7.66	50.38 ± 8.21	42.21 ± 9.20	4.751 [a]	0.013 [a※]	A>C,B>C
				5.390 [b]	0.008 [b※]	A>C,B>C
Times X Grouping				2.112	0.086	

SD-Standard deviation;※-p<0.05; [a]-Comparison between 12 weeks after intervention and BO;[b]-Comparison between 12 weeks after intervention and 2 weeks after operation; RHKG:resistive hip and knee group; NRHKG: nonresistive hip and knee group and control group

Table 5
Correlation matrix diagram of covariates

Variable	1	2	3	4	5	6	7	8	9	10
1.Age										
2.Height	-0.241									
3.weight	-0.010	0.308※								
4.WOMAC	-0.194	-0.300※	0.004							
5.Quadriceps	0.149	0.077	-0.468※※	-0.181※						
6.Hip abductors	0.198	0.111	-0.417※※	-0.196※	0.938※※					
7.Hip extortor	0.098	0.058	-0.473※※	-0.241※※	0.937※※	0.949※※				
8.Step size	-0.170	-0.157	-0.018	-0.302※※	0.539※※	0.433※※	0.481※※			
9.Stand on one side	0.039	-0.098	-0.013	-0.308※※	0.398※※	0.302※※	0.324※※	0.458※※		
10.Walking speed	0.112	0.077	-0.095	-0.365※※	0.207※	0.167※	0.206※	0.346※※	0.301※※	

WOMAC-Western Ontario and McMaster Universities Osteoarthritis Index

※-p<0.05;※※-p<0.01

significant difference between the resistive and nonresistive hip and knee joint strengthening groups (p > 0.05)(Table 3). No significant difference in the FJS score, VAS score or activity range have been seen among the three treatment groups (p > 0.05) (Table 3).

3.2 Objective tests and measurements

In the Timed Up and Go and stair climbing tests, the times of the resistive hip-knee joint strengthening group were significantly shorter than those of the control group (p < 0.05)(Table 4).

The isokinetic test of the extensor mechanism, hip abduction and muscle strength was performed at three time points, and it was found that joint strengthening of the hip and knee can improve the muscle strength of the quadriceps femoris, abductor muscle and abductor muscles of the hip joint to different degrees over that achieved with routine rehabilitation exercises. Taking the preoperative evaluation as the baseline, the quadriceps femoris and hip abductor muscles of the resistive hip and knee joint strengthening group were stronger than those of the nonresistive hip joint strengthening group ($p < 0.05$)(Table 4). The quadriceps femoris, hip abductor and hip external circumflex muscles of the hip joint in both the resistive and nonresistive strengthening groups were significantly stronger than those of the control group ($p < 0.05$)(Table 4). Taking the evaluation 2 weeks after operation as the baseline, the hip external circumflex muscles in the resistive hip and knee joint strengthening group were stronger than those in the nonresistive hip and knee joint strengthening group ($p < 0.05$)(Table 4). The quadriceps femoris and hip external circumflex muscles in both the resistive and nonresistive hip-knee joint strengthening groups were significantly stronger than those in the control group ($p < 0.05$)(Table 4).

In the gait analysis, shown in Table 4, we found that compared with the results before and 2 weeks after the operation, combined strengthening of the hip and knee could increase the step length ($p < 0.05$) and improve the percentage of individuals who could bear weight on the affected limb ($p < 0.05$). However, the difference between resistive and nonresistive exercises was not statistically significant ($p > 0.05$). The difference in walking speed among the three groups was not statistically significant ($p > 0.05$).

3.3 Correlation matrix diagram of covariates

The Pearson linear correlation analysis results revealed that the WOMAC score for knee joint function was negatively correlated with the strength of the quadriceps femoris ($r = 0.181$, $p < 0.05$), hip abductor ($r = 0.196$, $p < 0.05$) and external hip rotator muscles ($r = 0.241$, $p < 0.01$)(Table 5).

In gait analysis, the step length, ability to stand on only the affected limb and walking speed were also negatively correlated with the WOMAC score representing the function of the knee joint ($r=-0.302$, $p < 0.01$; $r=-0.308$, $p < 0.01$; $r=-0.365$, $p < 0.01$, respectively) (Table 5).

There was also a strong correlation between the muscle strength of the affected limb and the gait analysis index, in which the step length had the highest correlation with the muscle strength of the affected limb. In particular, the quadriceps femoris, hip abductor and hip circumflex muscle were positively correlated with stride length ($r = 0.539$, $p < 0.01$, $r = 0.433$, $p < 0.01$, and $r = 0.481$, $p < 0.01$, respectively)(Table 5). Second, there was also a positive linear correlation between the strength of the quadriceps femoris, hip abductor and hip circumflex muscles of the affected limb and the ability to stand on only the affected limb ($r = 0.398$, $p < 0.01$, $r = 0.302$, $p < 0.01$, and $r = 0.324$, $p < 0.01$, respectively)(Table 5). The positive linear correlation between muscle strength and walking speed was the weakest, but the quadriceps femoris, abductor hip muscle, and hip circumflex muscle strength was still positively correlated with walking speed ($r = 0.207$, $p < 0.05$; $r = 0.167$, $p < 0.05$; $r = 0.206$, $p < 0.05$, respectively) (Table 5).

4. Discussion

In this trial involving 60 participants, it was found that compared with traditional rehabilitation treatment focusing on the quadriceps femoris, a 12-week rehabilitation intervention of combined hip and knee exercises after surgery can improve the therapeutic effect of TKA and accelerate postoperative rehabilitation by improving the function of the affected limbs, accelerating the recovery of walking and climbing and improving the gait of the knee joint after TKA. The effect of combined hip and knee exercises was positively correlated with the increase in exercise load.

As one of the most commonly used scales to evaluate the function of the lower extremities, the WOMAC is confirmed to be effective, reliable and sensitive when applied to Chinese OA patients.[19, 20] Through the WOMAC scale we found that combined strengthening of the hip and knee joints as a means of postoperative rehabilitation was helpful for improving the curative effect of TKA (p 0.05) and accelerate the recovery of postoperative function (p 0.05). Meanwhile, the FJS-12 has been proven to have a strong correlation with the traditional WOMAC and other osteoarthritis score[21–23], but most of the subjects were evaluated

with the FJS-12 score after more than one year postoperatively.[22, 24] This is because this scale cannot reach the plateau period to evaluate the curative effect until more than one year after the operation. In this study, different rehabilitation treatments led to different surgical effects ($F = 49.232$, $p < 0.05$) and rehabilitation effects ($F = 116.604$, $p < 0.05$) in WOMAC, but there were no significant differences among different treatment groups ($F = 1.499$, $p > 0.05$) in FJS-12. This result is consistent with the conclusion of the "floor effect" of FJS-12 in previous research.[25–27]

Contrary to what we initially hypothesized, the application of early combined hip and knee strengthening exercises did not effectively improve knee pain. A review of the study found that we did not control for or detail the frequency and dose of oral or topical painkillers in different groups, so we speculate that the VAS scores recorded during the last follow-up do not fully reflect the true knee joint pain levels. Additionally, the exercise intensity and resistance of the rehabilitation exercises in the three treatment groups were different, and the resulting differences in muscle fatigue and pain adaptability also affected the effectiveness of the VAS scores.

Through linear correlation matrix mapping of the statistical data, we found that the correlations of WOMAC with quadriceps femoris and hip abductor muscle strength were $r=-0.181$ and $r=-0.196$, respectively, indicating that the WOMAC decreased with increasing quadriceps femoris and hip abductor muscle strength, and the lower the WOMAC score was, the better the knee joint function. Therefore, the prognosis and functional rehabilitation of patients after TKA are closely related to the strengths of the quadriceps femoris and abductor muscles of the hip; this is in agreement with the results of Piva's observational study, which revealed correlations of the strengths of the quadriceps femoris ($r=-0.194$) and abductor muscles of the hip ($r=-0.247$) and WOMAC.[4] Improving muscle strength and lower limb function through exercise interventions also helps demonstrate that combined hip and knee exercises can improve the prognosis and accelerate the functional rehabilitation of patients after TKA.[18]

The conclusion of this study is similar to that of a small preparatory experiment conducted by Harikesavan et al., in which specialized training of the hip abductor could help improve the strength of the hip abductor muscles; in the experimental group, the specialized training of the hip abductor significantly improved the results of the one-leg standing test and 6-min walking test.[28] However, the research by Schache et al. reached the opposite conclusion.[28] During the exercise intervention, Schache did not effectively establish separate experimental and control groups and did not unify the training regimen across different rehabilitation trainers, which may have had some impact on the effectiveness of the rehabilitation guidance.[29] In addition, the opposite conclusions of Schache and Harikesavan may also be related to the large differences in the intensity of the hip abductor exercises.[29] Kwangsun also believes that hip exercises performed through a 12-week exercise intervention can improve the function and gait of patients after TKA[30], but the participants in his study were all discharged from the hospital within one year after TKA, which goes beyond the scope of rapid recovery. During the intervention, it is difficult to exercise the hip joint alone, and the related instruments are not used to quantitatively measure the changes in muscle strength.

There are still some shortcomings in this study. Firstly, this study failed to record the oral or external application of painkillers during exercise and rehabilitation, which became a potential factor to reduce the authenticity and effectiveness of VAS. Secondly, we underestimated the floor effect of FJS-12, which made the scale unreliable in this study.

5. Conclusions

A 12-week regimen of combined hip and knee exercises after TKA improved the function of the affected limb, the movement patterns of the knee joint during gait, and the therapeutic effect of the surgery in addition to accelerating patients rehabilitation. The effect of combined hip and knee exercises was positively correlated with increases in exercise load.

Declarations

Supplementary Materials: None.

Author Contributions: Conceptualization, Wenyi Gan and Guorong She; methodology, Wenyi Gan and Guorong She; software, Hua Li; validation, Wenyi Gan, Zhengang Zha and Xiaofei Zheng.; formal analysis,Junyuan Chen; investigation, Wenyi Gan and

Guorong She; resources, Wenyi Gan and Guorong She; data curation, Wenyi Gan; writing—original draft preparation, Wenyi Gan; writing—review and editing, Huajun Wang; visualization, Qiu Dong; supervision, Xiaofei Zheng; project administration, Wenyi Gan; funding acquisition, Zhengang Zha. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the First Affiliated Hospital of Jinan University (protocol code KY-2021-002 , Feb 1st, 2021) and is registered in the China Clinical Trial Registration Center (Registration number: 19/07/2021ChiCTR2100049022,full trial protocol can be accessed at http://www.chictr.org.cn/edit.aspx?pid=130387&htm=4).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patients to publish this paper.

Data Availability Statement: The data may be available at a reasonable request.

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Conflicts of Interest: The authors declare no conflict of interest.

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Figures

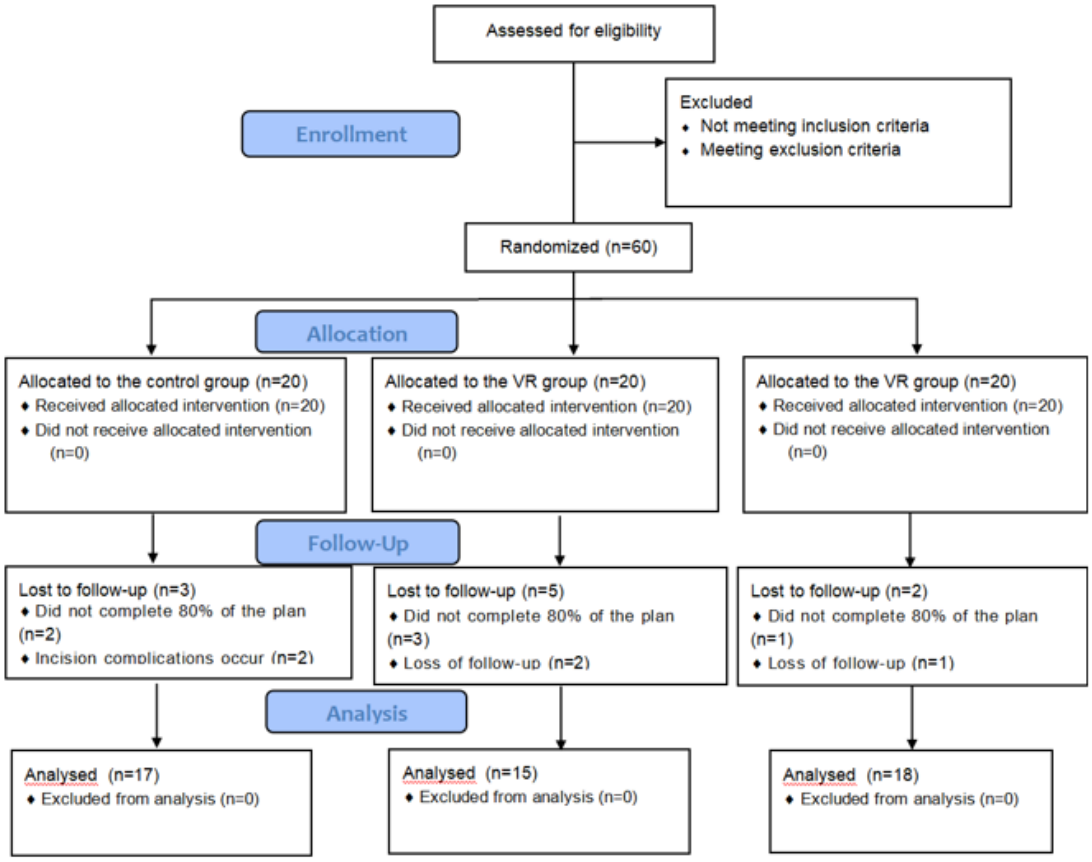

Figure 1

CONSORT 2010 flow diagram showing the study process.

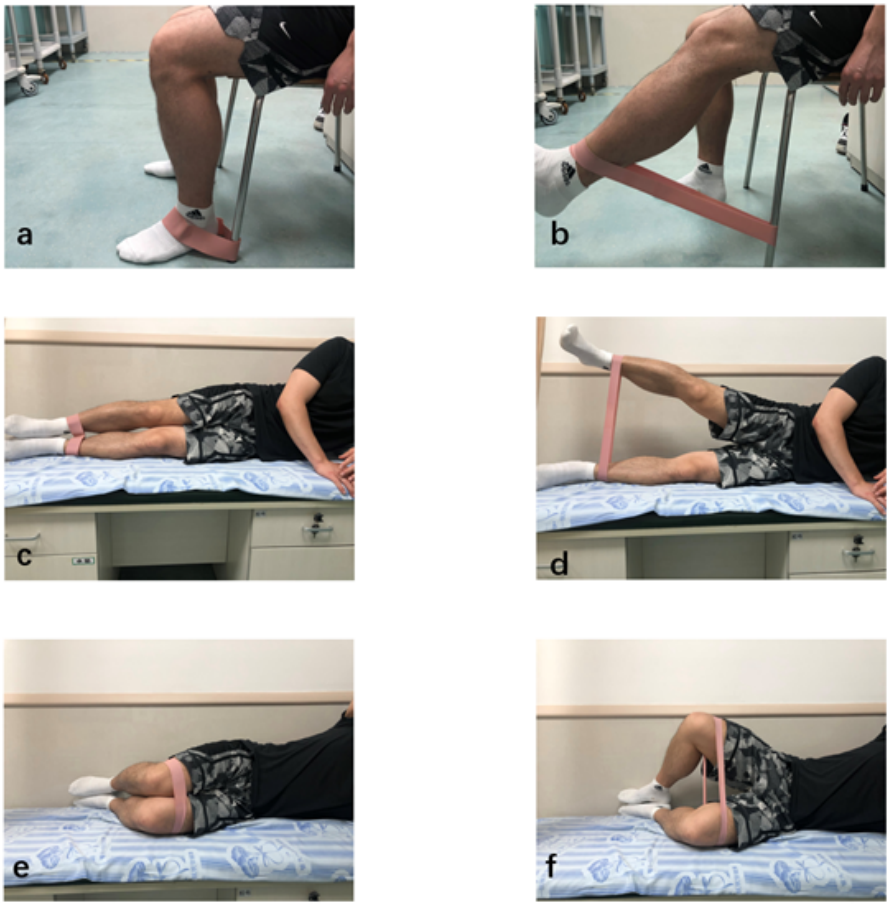

Figure 2

Exercises diagram

a□b□Quadriceps exercise ;c□d□Abductor muscle exercise of hip joint ;e□f□External circumflex muscles exercise of the hip joint