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Twenty-four-week hospital-based progressive resistance training on functional recovery in female patients post total knee arthroplasty

Wei-Hsiu Hsu [a,b,1], Wei-Bin Hsu [a,1], Wun-Jer Shen [c], Zin-Rong Lin [d], Shr-Hsin Chang [a], Robert Wen-Wei Hsu [a,b,*]

[a] Sports Medicine Center, Chang Gung Memorial Hospital, Chiayi, Taiwan, Republic of China
[b] Department of Orthopaedic Surgery, Chang Gung Memorial Hospital, Chiayi, Taiwan, Republic of China
[c] PO CHENG Orthopedic Institute, Kaohsiung, Taiwan, Republic of China
[d] Department of Athletic Sports, National Chung Cheng University, Chiayi, Taiwan, Republic of China

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ABSTRACT

Background: After total knee arthroplasty (TKA) surgery, a decline in muscle strength is associated with a decrease in function. The aim of this study was to demonstrate the effect of a further 24 weeks of hospital-based resistance training under supervision, and precise dose on knee functional recovery and daily activities for female TKA patients.
Methods: Twenty-nine patients who underwent unilateral primary TKA were allocated into either resistance training (RT) ($n = 14$) or control (CON) ($n = 15$) groups. All patients were assessed, with an isokinetic dynamometer, for hip and knee flexor and extensor muscle strength, physical function test, and Knee Injury and Osteoarthritis Outcome Score (KOOS). Resistance training was initiated three months after index surgery. The assessments were performed before exercise (Baseline), in the middle of the resistance training at 12 weeks (Mid-exercise), completion of the resistance training (Post-exercise), and 12 weeks after resistance training completion (Follow-up). A statistical test was performed by using generalized estimating equations.
Results: Patients in RT had more of an increase in both knee extensor and flexor muscle strength than those in CON at the Post-exercise assessment. The six-minute walk test distance was more in RT compared with CON at the same Post-exercise assessment. Furthermore, the RT group had increases in Activities of daily living and Sports subscales compared to the CON group.
Conclusions: A further 24 weeks of hospital-based progressive resistance training facilitated improvement in knee muscle strength and functional outcome in TKA patients. Active hospital-based progressive resistance training is recommended for rehabilitation following TKA surgery.

1. Introduction

Total knee arthroplasty (TKA) is a well-established procedure for the treatment of advanced osteoarthritis (OA) of the knee joint to improve patients' function [1,2]. The number of patients receiving TKA has been rising every year [3–5]. Patients aged <65 years are predicted to comprise over 50% of all primary TKA patients in the United States [6]. Postoperative rehabilitation, which aims to

* Corresponding author at: Department of Orthopaedic Surgery, Chang Gung Memorial Hospital, No. 6, West Section, Chia-Pu Road, Pu-Tz City, Chia-Yi County 61363, Taiwan, Republic of China.
E-mail address: wwh@cgmh.org.tw (R.W.-W. Hsu).
[1] These authors contributed equally to this work.

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increase knee range of motion, muscle strength, and proprioceptive function, is important for improving function following TKA surgery. A decrease in lower extremity muscle strength, both in quadriceps and hamstrings, has been reported following TKA [7–9]. This decline in lower extremity muscle strength is associated with functional decline [8,10–12].

Effort has been devoted to enhancing postoperative rehabilitation, mainly between immediate postoperative to 12 weeks, with various interventions ranging from physiotherapy and walking, to lower extremity muscle strengthening exercise under different levels of supervision [13–22]. Little light has been shed on further exercise interventions in TKA patients after a regular 12-week rehabilitation program, especially with a precise dosage of exercise under supervision. Pozzi et al. systematically reviewed randomized controlled studies and recommended that strengthening exercises should be a major part of postoperative care, and exercise programs should be supervised and progressed in the rehabilitation of TKA [23].

Therefore, the purpose of this study was to demonstrate the effect of a further 24 weeks of hospital-based resistance training (RT) under supervision, and precise dose on knee functional recovery and daily activities for female TKA patients. Since sarcopenia and osteoporosis prevail in postmenopausal women, the present study focused on TKA in female patients and employed a 24-week hospital-based progressive RT course to strengthen lower extremity muscles in TKA patients and evaluated its effect on muscle strength, senior functional fitness test, and patient self-reported outcome.

2. Materials and methods

2.1. Participants

A consecutive cohort of female patients who underwent TKA by the senior author was included in the current study. Inclusion criteria were: female patients diagnosed with Albäck stage III–IV OA, without infectious joint disease or rheumatic disease; patients who received TKA without additional ligament reconstruction or corrective osteotomy. Exclusion criteria were patients with: diabetes, neuromusculoskeletal disorder, history of a lower limb fracture, presence of artificial limb, and otherwise unsuitable for exercise training.

Patients in both control (CON) and RT groups performed straight leg raises and range of motion exercises at home, with an interview at one, four and 12 weeks after discharge from hospital. Patients in the RT group were prescribed additional equipment-assisted RT for 24 weeks. The training started at three months after TKA operation. Assessments in both CON and RT groups were performed at the following time points: before TKA operation (Pre-operation), three months postoperatively and before exercise (Baseline), middle of RT at 12 weeks (Mid-exercise), completion of RT (Post-exercise), and 12 weeks after training (Follow-up). This study was approved by the Ethics Committee and Institutional Review Board (IRB:102-0979B) and registered in the ClinicalTrials.gov database (ID: NCT02928562). All patients provided informed consent.

2.2. Resistance training program

The lower limb RT was performed with stationary RT machines: leg press machine G3-S70; leg extension machine G3-S71; seat leg curl machine G3-S72; and hip adductor machine G3-S74. The 60-minute RT program was carried out three times a week for 24 weeks. At the beginning of training, the subjects underwent one repetition maximum (1RM) testing for each machine and the 1RM was reassessed before the nine to 24 weeks of training. The program was performed at progressive intensity with 60% load of 1RM in the first four weeks, 70% in the following four weeks, and 80% load in the last 16 weeks (Table 1). Thigh muscles were the primary target in this RT program. Strength training components were leg extension, seat leg curl, leg press, and hip adduction. Leg extension focused on quadriceps muscles training, while seat leg curls facilitated hamstring muscle training. Leg press enhanced the interplay of quadriceps, hamstring, and gluteus maximus. The hip adductor machine trained the inner hip muscles (adductor magnus and adductor brevis) and inner thigh muscles (adductor longus and the gracilis muscle).

Table 1
The progressive resistant exercise program.

Timeline	Training machine	Intensity	Frequency
1–4 weeks	Leg press machine Leg extension machine Seat leg curl machine Hip adductor machine	60% of 1RM 12 repetitions/set × 3 sets	3 days/week
5–8 weeks	Leg press machine Leg extension machine Seat leg curl machine Hip adductor machine	70% of 1RM 12 repetitions/set × 3 sets	3 days/week
9–24 weeks	Leg press machine Leg extension machine Seat leg curl machine Hip adductor machine	80% of 1RM 12 repetitions/set × 3 sets	3 days/week

One-minute rest between sets and 5-minute rest between machines.
1RM, 1 repetition maximum.

Table 2
Demography of the patients.

	CON (N = 15)	RT (N = 14)
Age (years)	69.5 (1.5)	72.0 (1.8)
Height (cm)	152.1 (1.5)	152.4 (1.1)
Weight (kg)	67.1 (2.9)	67.9 (3.0)
BMI (kg/m^2)	28.9 (1.0)	29.4 (1.5)

All equipment was obtained from the Johnson Health Tech Co. (Taichung, Taiwan). Each machine was then used for three sets of 12 repetitions with one-minute rest between sets, and five-minute rests between machines. The program was performed at the hospital Sports Medicine Center. At least one trained physical therapist supervised the motion and physical conditions of the subjects during training.

2.3. Muscle strength

Lower extremity muscle strength, including extension and flexion of the hip and knee, was tested using the HUMAC NORM system (CSMi, Stoughton, MA) [24,25]. Hip and knee muscle strength was evaluated with the subjects in a lying and seated position, respectively. The concentric/contraction mode was set at an angular velocity of 60°/s.

2.4. Functional fitness test

The six-minute walk test (6MWT) is used to assess exercise capacity in accordance with the American Thoracic Society standards guidelines (ATS) [26]. The eight-foot Up-and-Go test (8-ft Up-and-Go test) assessed motor agility in accordance with the American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD) Functional Fitness Test [27]. The 30-second chair stand test (30-s CST) assessed lower body muscle strength for TKA patients, with excellent reliability; its details have been previously described [28,29].

2.5. Knee Injury and Osteoarthritis Outcome Score assessment

Clinical knee scoring by the Chinese version Knee Injury and Osteoarthritis Outcome Score (KOOS) scales was performed in the outpatient self-explanatory assessment [30].

2.6. Sample size

Generalized estimating equations (GEEs) was performed for statistical analysis. The primary outcome of the study was knee extensor strength. To calculate actual effect size, the Effect Size for Cross-sectional GEE Models software was used (https://bookdown.org/rdpeng/geepower/) and set with: 3.74 (standard deviation-outcome), 4.23 (standard deviation-exposure), 29 (total of subjects), 4 (visits per subject), 0.5 (within-subject correlation), 0.8 (power), and 0.05 (type I error). The output of effect size was 0.51.

2.7. Statistical analysis

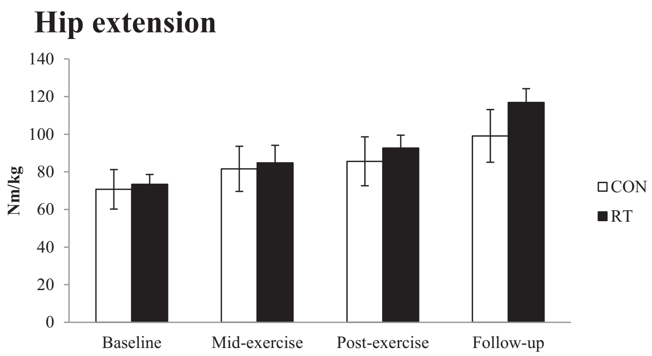
Statistical Package for the Social Sciences, Windows version 17.0 (SPSS, Chicago, IL, USA) was used to analyze all data. All continuous data were presented as the mean (standard deviation). GEEs were used for determining the differences between RT and CON groups and within the groups [31]. A *P*-value of <0.05 was considered statistically significant. To reduce bias, the study tried to find controls with matching age and body mass index (BMI).

Table 3
Comparison of muscle strength between two groups of total knee arthroplasty patients.

(Nm/kg)	Baseline			Mid-exercise			Post-exercise			Follow-up		
	CON	RT	*P*	CON	RT	*P*	CON	RT	*P*	CON	RT	*P*
HE	70.7 (10.5)	73.4 (5.2)	0.820	81.6 (12.0)	84.8 (9.3)	0.834	85.6 (13.0)	92.6 (6.9)§	0.635	99.1 (14.0)§	116.9 (7.3)§	0.259
HF	30.9 (3.9)	27.2 (2.9)	0.452	29.4 (4.9)	32.1 (3.9)	0.663	29.7 (5.0)	32.6 (3.6)	0.640	27.6 (4.8)	37.8 (3.3)§	0.081
KE	38.7 (5.8)	43.6 (5.6)	0.541	43.5 (5.1)	57.6 (6.7)§	0.095	42.1 (4.3)	61.4 (6.6)§	0.014*	62.3 (11.5)§	68.1 (5.3)§	0.647
KF	42.0 (5.1)	50.1 (3.4)	0.183	52.2 (4.6)	57.6 (4.9)§	0.418	44.9 (3.0)	61.1 (4.5)§	0.003*	53.4 (5.3)	58.8 (3.4)§	0.390

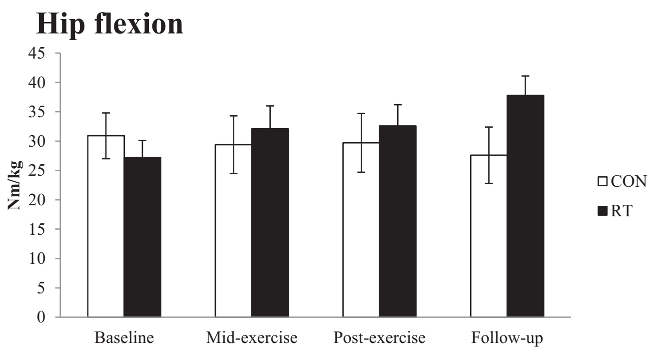
Abbreviations: HE, hip extension; HF, hip flexion; KE, knee extension; KF, knee flexion; CON, control; RT, resistance training.
* Significant between-group difference.
§ Significant difference compared to Pre-exercise within the individual group ($P < 0.05$).

A



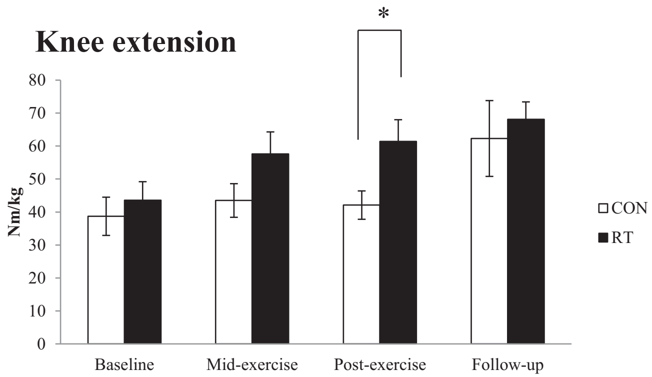
CON	70.7 (10.7)	81.6 (12.0)	85.6 (13.0)	99.1 (14.0) §
RT	73.4 (5.2)	84.8 (9.3)	92.6 (6.9) §	116.9 (7.3) §

B



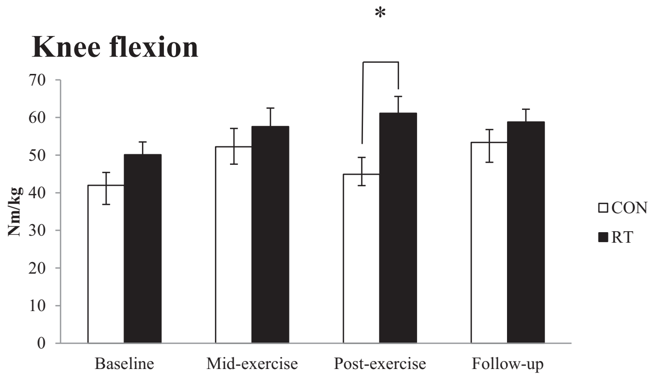
CON	30.9 (3.9)	29.4 (4.9)	29.7 (5.0)	27.6 (4.8)
RT	27.2 (2.9)	32.1 (3.9)	32.6 (3.6)	37.8 (3.3) §

C



CON	38.7 (5.8)	43.5 (5.1)	42.1 (4.3)	62.3 (11.5) §
RT	43.6 (5.6)	57.6 (6.7) §	61.4 (6.6) §	68.1 (5.3) §

D



CON	42.0 (5.1)	52.2 (4.6)	44.9 (3.0)	53.4 (5.3)
RT	50.1 (3.4)	57.6 (4.9) §	61.1 (4.5) §	58.8 (3.4) §

Figure 1. Mean hip extension (A), hip flexion (B), knee extension (C), and knee flexion (D) strength in CON and RT groups at Baseline, Mid-exercise, Post-exercise, and Follow-up time points. CON, control; RT, resistance training. *Significant between-group difference. §Significant difference compared to Baseline within the individual group ($P < 0.05$).

Table 4
Comparison of physical function between the two groups of total knee arthroplasty patients.

	Baseline			Mid-exercise			Post-exercise			Follow-up		
	CON	RT	*P*	CON	RT	*P*	CON	RT	*P*	CON	RT	*P*
6MWT (m)	325.2 (25.4)	336.7 (24.3)	0.743	349.6 (15.1)	382.3 (14.4)	0.117	342.7 (16.5)	395.0 (20.1)§	0.044*	337.9 (17.8)	386.2 (20.8)§	0.078
8-ft Up-and-Go (s)	9.6 (0.6)	9.6 (1.2)	0.973	9.4 (0.7)	8.6 (0.6)	0.383	8.5 (0.4)	8.3 (0.5)	0.787	9.0 (0.4)	8.6 (0.6)	0.626
30-s CST (times)	12.7 (0.9)	11.7 (0.8)	0.410	12.7 (0.7)	13.6 (0.7)	0.376	14.3 (0.9)	14.7 (0.6)§	0.713	14.0 (1.1)	13.9 (1.0)	0.907

Abbreviations: 6MWT, 6-minute walk test; 8-Ft Up-and-Go, 8 feet up and go; 30-s CST, 30-second chair stand test.
* Significant between-group difference.
§ Significant difference compared to Pre-exercise within the individual group ($P < 0.05$).

3. Results

Between August 2014 and August 2015, 45 female patients suffering from end-stage OA were identified from the senior author's clinics. Five patients were excluded due to not meeting inclusion criteria. After initial allocation (20 in CON and 20 in RT), 11 subjects (five in CON and six in RT) were excluded from analysis due to discontinued participation. A total of 29 patients (15 in CON and 14 in RT) completed the treatment algorithm and proceeded to final analysis. The average program adherence rate was 67% in RT.

Patients' demography is shown in Table 2. Mean age was 69.5 (1.5) and 72.0 (1.8) years for CON and RT, respectively. Height and weight were similar between the CON and RT groups. Lower extremity muscle strength, active functional test, and KOOS were similar between CON and RT ($P > 0.05$) (Supplemental Table 1).

The isokinetic dynamometer assessment showed that patients in RT had more of an increase in both knee extensor and knee flexor muscle strength than those in the CON group at the Post-exercise measurement (RT vs. CON, 61.4 ± 6.6 vs. 42.1 ± 4.3 Nm/kg for knee extensor, $P < 0.05$; 61.1 ± 4.5 vs. 44.9 ± 3.0 Nm/kg for knee flexor, $P < 0.05$) (Table 3) (Figure 1). However, these differences became insignificant because knee extensor and flexor muscle strength increased in the CON group at the Follow-up measurement. When comparison was performed within the individual group, the CON group had an increase only in hip extensor and knee extensor muscle strength at final Follow-up as compared to the Baseline measurement ($P < 0.05$). In contrast, the RT group had an increase in all measured lower extremity muscle strength, including hip extensor, hip flexor, knee extensor, and knee flexor ($P < 0.05$). More interestingly, those increases occurred earlier in the measured time point. For example, knee extensor and flexor muscle strength had an immediate increase at the Mid-exercise time point, and the hip extensor had an increase at the Post-exercise time point ($P < 0.05$). It was found that a further 24 weeks of lower extremity strengthening improved muscle strength, with immediate response on knee flexor and extensor and then the hip extensor strength.

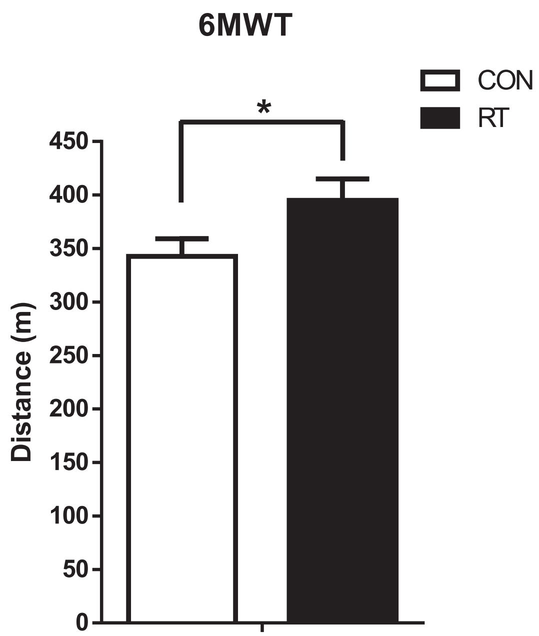


Figure 2. Comparison of 6MWT outcome between CON and RT groups at Post-exercise time point. 6MWT, six-minute walk test, CON, control; RT, resistance training. *Significant between-group difference ($P < 0.05$).

Table 5
Comparison of Knee Injury and Osteoarthritis Outcome Score subscales between two groups of total knee arthroplasty patients.

	Baseline			Mid-exercise			Post-exercise			Follow-up		
	CON	RT	P	CON	RT	P	CON	RT	P	CON	RT	P
Sym	74.6 (3.1)	70.9 (4.2)	0.478	73.8 (4.8)	78.8 (3.0)§	0.376	77.6 (5.1)	85.3 (3.5)§	0.207	86.4 (3.6)§	82.9 (4.7)§	0.559
Pain	77.8 (3.4)	73.8 (4.5)	0.475	88.4 (2.6)§	86.5 (3.0)§	0.619	91.4 (2.2)§	93.8 (1.7)§	0.408	95.2 (2.2)§	94.7 (1.6)§	0.856
ADL	77.2 (3.9)	73.4 (4.7)	0.535	86.3 (2.4)§	86.8 (2.8)§	0.883	86.7 (2.1)§	94.2 (1.3)§	0.002*	90.8 (1.7)§	97.0 (0.9)§	0.001*
Sports	63.3 (5.3)	61.6 (5.5)	0.829	56.6 (3.8)	61.5 (5.0)	0.208	53.2 (4.2)§	67.9 (5.8)	0.039*	56.5 (5.7)§	65.7 (4.5)	0.209
QOL	63.0 (4.6)	63.3 (6.1)	0.968	65.6 (6.7)	76.2 (3.5)§	0.161	71.1 (5.4)	80.7 (4.7)§	0.177	80.1 (5.8)§	82.0 (3.2)§	0.768

Abbreviations: Sym, symptom; ADL, activity of daily living; QOL, quality of life.
* Significant between-group difference.
§ Significant difference compared to Pre-exercise within the individual group ($P < 0.05$).

Functional outcome of the functional fitness tests demonstrated that the 6MWT distance had an increase in the RT group compared with CON at the Post-exercise measurement (RT vs. CON, 395.0 ± 20.1 vs. 342.7 ± 16.5 m, $P < 0.05$) (Table 4) (Figure 2). This difference corresponded to the increase in knee muscle strength at this same time point. In the temporal comparison, 6MWT ($P < 0.01$) and 30-s CST ($P < 0.01$) were shown to be increased at the Post-exercise measurement as compared to Baseline measurement in the RT group.

Paralleling the biomechanical results, KOOS showed similar trends to RT group, and had an increase in Activities of daily living (ADL) and Sports subscales as compared to the CON group at the Post-exercise measurement (RT vs. CON, 94.2 ± 1.3 vs. 86.7 ± 2.1 for ADL, $P < 0.05$; 67.9 ± 5.8 vs. 53.2 ± 4.2 Nm/kg for Sports, $P < 0.05$) (Table 5) (Figure 3). When the comparison was performed within the individual groups in a temporal manner, it was shown that both RT and CON groups had an increase in all subcategories at Follow-up measurement as compared to Baseline measurement. This phenomenon could reflect recovery following TKA surgery. However, the improvement in the symptoms and quality of life (QOL) subcategories for the RT group occurred six months earlier than the CON group. Contrasted to the improvements noted above, the Sports subscale in the CON group showed a more significant decrease ($P < 0.05$) at Mid-exercise and Post-exercise than Pre-exercise measurement.

4. Discussion

The major findings of this study were that a further 24 weeks of hospital-based RT increased lower extremity muscle strength (i.e. knee extensors and flexors) at Post-exercise measurement. Meanwhile, the functional fitness tests of 30-s CST testing and ambulatory capacity (6MWT testing) in the RT group increased, as progressive RT enhanced the recovery of functional mobility after TKA [29,32–34]. These phenomena paralleled the earlier improvement in KOOS [35–37]. This program used leg extensions, seat leg curls, leg presses, and hip adduction for thigh and hip muscle strengthening. It was observed that this program increased the strength of both flexors and extensors around the hips and knees. It was shown that the exercise program improved knee

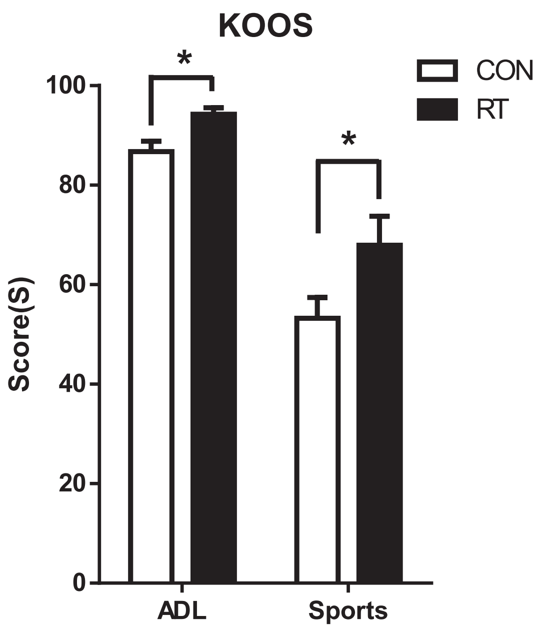


Figure 3. Comparison of Activities of daily living and Sports subscales of KOOS between CON and RT groups at Post-exercise time point. ADL, activities of daily living; CON, control; RT, resistance training; KOOS, Knee Injury and Osteoarthritis Outcome Score. *Significant between-group difference ($P < 0.05$).

flexor and extensor muscle strength at an earlier time point (i.e. Mid-exercise assessment) and lasted to the final assessment in the RT group. Hip muscle strength increased later than knee muscle strength (i.e. hip extensor increased at Post-exercise assessment and hip flexor increased at Follow-up assessment, respectively). While in the CON group, increase in knee flexor and extensor strength was only observed on the final Follow-up assessment. It is clear that the exercise program improved muscle strength at an earlier time point. More importantly, the ADL subcategory in the functional assessment increased more in the RT than CON group.

Previous studies have shown that increased quadriceps strength correlates with better outcomes and performance in TKA patients [8,10–12]. A previous study showed that quadriceps strength and senior functional fitness tests (Timed Up and Go, Stair Climbing test, and 6MWT) were significantly improved at 12 months after TKA surgery under a progressive strengthening protocol compared to regular rehabilitation [20]. It paralleled the literature that muscle strengthening could improve quadriceps strength and functional outcome (Timed Up and Go) [22]. Furthermore, extensor muscle strength was significantly improved in the RT group, which was associated with improvements in 6MWT functional testing (Table 4) and the ADL subscale in KOOS (Table 5). These results were consistent with Pua et al., who suggested that ipsilateral quadriceps strength was the most determinant physical factor in gait speed recovery in their large-scale study [38]. It was possible that lower leg muscle strength plays a pivotal role in the functional outcomes of TKA patients [38,39]. Additionally, the 30-s CST had no difference between the CON and RT group (Table 3). This might have resulted from the less precise timed-based metric test [40].

During lower limb muscle strengthening with weight-bearing requirements, all patients in the RT were supervised by one trained physical therapist. No patient in the RT exercise group reported discomfort or injury or needed further medical management. This indicates that hospital-based progressive RT is safe for TKA patients and feasible following TKA surgery.

Several limitations of this study must be acknowledged. First, the small sample size in this biomechanical study did not demonstrate the whole effect of RT in TKA. Nevertheless, improvements in multiple metrics over time indicated that RT was beneficial in muscle strength and function. Second, the results are limited to the short-term effect of RT (12 months after surgery). It was shown that the control group gradually improved their strength, and longer follow-up could have shown comparable results with the muscle strengthening group. Third, the 30-second sit-to-stand test may have impacted the findings, as a time-limited test has limitations on precision that are not evident in a repetition-based test [40]. Finally, this study was limited to 29 patients out of a potential pool of 40 patients. A larger randomized controlled trial is warranted to further confirm the findings from the present study.

5. Conclusions

A hospital-based postoperative progressive RT protocol is safe and feasible for TKA patients. After supervised exercise training, knee muscle strength (flexion and extension) and functional outcomes of TKA patients were significantly improved. The authors believe that a hospital-based progressive muscle strengthening protocol could be incorporated into a standard TKA rehabilitation program.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.knee.2019.02.008.

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Conflict of interest

The authors have no conflicts of interest to declare.

Authors' contributions

WHH, writing original drafts, investigation, review and editing; WBH, original drafts, investigation, writing, review and editing; WJS, methodology, writing, review and editing; ZRL, methodology; SHC, software, data curation, validation; RWWH, conceptualization, methodology, project administration, resources, supervision, writing, review and editing.

Ethics approval and consent to participate

Based on the Helsinki declaration, this study was approved by the Ethics Committee and Institutional Review Board (IRB:102-0979B) and registered in the ClinicalTrials.gov database (ID: NCT02928562). All patients provided informed consent.

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