Effects of Resistance Training on Muscle Recovery Post-Surgery: A Randomized Controlled Trial

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ABSTRACT:

Background/Objective: Postoperative muscle weakness significantly impairs functional recovery following orthopedic surgery. While progressive resistance training (RT) is increasingly incorporated into rehabilitation programs, robust empirical evidence regarding its clinical efficacy remains limited. This study aimed to evaluate the impact of early structured resistance training on quadriceps muscle strength, pain intensity, and functional mobility following Total Knee Arthroplasty (TKA).

Methods: A randomized controlled trial was conducted with 60 post-TKA patients allocated into two groups: an RT group (n = 30), which completed an 8-week progressive resistance exercise program (3 sessions/week), and a control group (n = 30), which received standard postoperative rehabilitation. Outcome measures included isometric quadriceps peak torque (dynamometry), pain intensity (Visual Analogue Scale [VAS]), self-reported functional status (WOMAC function subscale), and objective mobility performance (Timed Up and Go [TUG] and 30-second Sit-to-Stand tests), evaluated at baseline (week 1) and post-intervention (week 8). Group comparisons were analyzed using mixed-model repeated-measures ANOVA and Cohen's d effect sizes.

Results: The RT group demonstrated significantly superior gains in quadriceps muscle strength compared to controls (+38.6% vs. +12.4%, $p < 0.001$, Cohen's $d = 1.05$). Pain intensity decreased by 34.2% in the RT group versus 14.1% in the control group ($p = 0.002$, Cohen's $d = 0.82$). Self-reported function (WOMAC) improved by 26.8% in the RT group compared to 9.7% in controls ($p < 0.001$, Cohen's $d = 0.94$). Objective functional performance also showed marked enhancements in the RT group (TUG: −29.5%; Sit-to-Stand: +38.5%) over controls (TUG: −11.3%; Sit-to-Stand: +13.3%; $p < 0.001$, Cohen's $d = 0.88$). No intervention-related adverse events were observed.

Conclusion: Early supervised progressive resistance training is safe, well-tolerated, and substantially enhances muscular strength, pain reduction, and functional recovery compared to standard postoperative care alone.

Keywords: resistance training; postoperative rehabilitation; total knee arthroplasty; muscle recovery; quadriceps strength; functional performance; randomized controlled trial

1. Introduction

Osteoarthritis (OA) is the primary cause of joint impairment worldwide, leading to chronic pain and significant mobility restrictions, particularly in weight-bearing joints such as the knee [1]. In advanced stages, Total Knee Arthroplasty (TKA) serves as the definitive surgical intervention to relieve pain and restore joint function [1]. Annually, over 100,000 TKA procedures are performed in the United Kingdom and approximately 700,000 in the United States, with procedure volumes projected to rise steadily due to aging demographics and increasing obesity prevalence [2].

Although TKA is clinically effective and cost-effective, postoperative deficits remain common [3]. Patients frequently experience joint stiffness, impaired postural stability, disrupted motor control, and persistent extension deficits [3]. A primary contributor to these functional limitations is severe quadriceps femoris weakness, which can persist for months following surgery [4]. Quadriceps strength restoration is vital, as early strength recovery directly correlates with gait biomechanics, patient satisfaction, and overall functional outcomes [4].

Quadriceps atrophy impairs fundamental daily tasks such as walking, stair ambulation, sit-to-stand transitions, and independent living [5]. Standard postoperative rehabilitation primarily focuses on restoring range of motion, controlling pain, and light mobility training [5]. However, progressive resistance training provides the necessary mechanical stimulus to induce muscular hypertrophy and neuromuscular adaptations far superior to low-intensity mobility exercises [6]. Current clinical guidelines from the American Physical Therapy Association emphasize early strength training following TKA [6].

Despite these guidelines, clinical outcomes following post-TKA resistance training vary, and high-quality randomized evidence remains needed to elucidate its specific effects on strength, pain modulation, and objective physical performance. This randomized controlled trial was conducted to systematically assess the impact of an 8-week progressive resistance training protocol on quadriceps recovery, pain attenuation, and functional mobility in post-TKA patients compared to standard care.

2. Materials and Methods

2.1. Study Design and Ethics

This single-center, two-arm randomized controlled trial was conducted in accordance with the Declaration of Helsinki and the CONSORT guidelines. Ethical approval was secured from the institutional review board prior to enrollment, and written informed consent was obtained from all participants.

2.2. Participants and Eligibility Criteria

Sixty patients admitted to the orthopedic rehabilitation unit of a tertiary medical center following primary unilateral TKA were recruited. Inclusion criteria were: (1) age 50–75 years; (2) primary TKA for severe knee osteoarthritis; (3) medical clearance for postoperative exercise; and (4) ability to ambulate independently with or without assistive devices. Exclusion criteria included: (1) revision TKA or simultaneous bilateral TKA; (2) neurological, cardiovascular, or musculoskeletal comorbidities severely affecting lower-limb function; (3) major surgical complications requiring reintervention; and (4) medical contraindications to progressive exercise.

2.3. Randomization and Allocation Concealment

Participants were randomly assigned (1:1 ratio) to either the Resistance Training (RT) group (n = 30) or the Control group (n = 30). Randomization was generated via a computer software program with concealed sequence allocation. Group assignments were placed in opaque, sealed envelopes opened by an independent researcher not involved in outcome assessment.

2.4. Intervention Protocol

2.4.1. Resistance Training Group

In addition to standard care, the RT group engaged in a supervised progressive resistance exercise program beginning 1 week post-surgery, continuing for 8 weeks (3 sessions/week, 45–60 minutes/session). The exercise selection specifically targeted the operative lower limb, focusing on the quadriceps femoris, hamstrings, and gluteal musculature. Exercises included leg presses, seated knee extensions, prone leg curls, hip abductions, and standing calf raises.

Training intensity initiated at 50–60% of 1-Repetition Maximum (1RM) during weeks 1–4 and progressed to 70–80% 1RM during weeks 5–8. Exercises were executed in 2–3 sets of 8–12 repetitions with 1.0–1.5 minute rest intervals. Licensed physical therapists supervised all sessions to enforce proper biomechanics and monitor safety.

2.4.2. Control Group

The control group received standard postoperative physical therapy, consisting of range-of-motion exercises, gait retraining, and low-intensity functional activities. Resistance or external strength-loading exercises were strictly excluded from the control intervention.

2.5. Outcome Measures

Evaluations occurred at baseline (week 1 post-surgery) and post-intervention (week 8) by outcome assessors blinded to group allocation.

- **Muscle Strength:** Quadriceps femoris isometric peak torque (Nm) was assessed using a standardized handheld dynamometer.
- **Pain Intensity:** Evaluated via the Visual Analogue Scale (VAS), ranging from 0 (no pain) to 10 (worst imaginable pain).
- **Self-Reported Function:** Assessed using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) function subscale.
- **Performance-Based Function:** Measured using the Timed Up and Go (TUG) test (seconds) and the 30-second Sit-to-Stand test (repetitions).

2.6. Statistical Analysis

Data analysis was performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Data normality was confirmed via the Shapiro-Wilk test. Continuous variables are expressed as mean ± standard deviation (SD). Group-by-time interaction effects were evaluated using mixed-model repeated-measures ANOVA (2 groups × 2 timepoints). Effect sizes were quantified using Cohen's d (small = 0.2, medium = 0.5, large = 0.8). Statistical significance was defined as $p < 0.05$.

3. Results

All 60 participants completed the 8-week intervention and post-intervention assessments (100% retention rate). No intervention-related adverse events, muscular injuries, or surgical complications occurred, supporting the safety of early progressive resistance training.

At baseline, no statistically significant differences were observed between the RT and Control groups regarding age, sex distribution, body mass index (BMI), time post-surgery, or baseline clinical outcomes ($p > 0.05$), confirming successful randomization (Table 1).

Table 1. Baseline Characteristics of Participants

Variable	RT Group (n = 30)	Control Group (n = 30)	p-value
Age (years)	64.3 ± 6.1	65.1 ± 5.8	0.61
Sex (Male / Female)	14 / 16	13 / 17	0.79
BMI (kg/m²)	28.7 ± 3.9	29.1 ± 4.2	0.68
Time post-surgery (days)	7.2 ± 1.1	7.4 ± 1.0	0.54
Baseline Quadriceps Strength (Nm)	82.6 ± 14.3	81.9 ± 15.1	0.87

Quadriceps muscle strength increased significantly in both groups over time, but gains were substantially greater in the RT group (+38.6% vs. +12.4%, $p < 0.001$, Cohen's $d = 1.05$; Table 2).

Table 2. Changes in Quadriceps Muscle Strength

Group	Baseline (Nm)	Post-intervention (Nm)	% Change	p-value*
RT Group	82.6 ± 14.3	114.5 ± 16.8	+38.6%	< 0.001
Control Group	81.9 ± 15.1	92.1 ± 15.6	+12.4%	0.041

** Within-group p-values. Between-group difference (group × time interaction): $p < 0.001$; Cohen's $d = 1.05$ (large).*

Pain intensity scores (VAS) decreased significantly in both groups, with the RT group exhibiting a markedly greater reduction (−34.2% vs. −14.1%, $p = 0.002$, Cohen's $d = 0.82$; Table 3).

Table 3. Pain Intensity (VAS Scores)

Group	Baseline	Post-intervention	% Reduction	p-value*
RT Group	6.8 ± 1.1	4.5 ± 1.0	−34.2%	0.002
Control Group	6.7 ± 1.2	5.8 ± 1.1	−14.1%	0.048

** Within-group p-values. Between-group difference: $p = 0.002$; Cohen's $d = 0.82$ (large).*

Self-reported functional capability (WOMAC function subscale) showed superior improvement in the RT group compared to controls (+26.8% vs. +9.7%, $p < 0.001$, Cohen's $d = 0.94$; Table 4).

Table 4. Self-Reported Functional Outcomes (WOMAC Function)

Group	Baseline	Post-intervention	% Improvement	p-value*
RT Group	58.4 ± 9.7	74.1 ± 8.9	+26.8%	< 0.001
Control Group	59.1 ± 10.2	64.8 ± 9.6	+9.7%	0.032

** Within-group p-values. Between-group difference: $p < 0.001$; Cohen's $d = 0.94$ (large).*

Objective performance-based mobility tests demonstrated significantly superior outcomes in the RT group for both TUG (−29.5% vs. −11.3%, $p < 0.001$) and Sit-to-Stand (+38.5% vs. +13.3%, $p < 0.001$; Table 5).

Table 5. Performance-Based Functional Tests

Outcome	Group	Baseline	Post-intervention	% Change	p-value*
TUG (s)	RT Group	14.2 ± 2.1	10.0 ± 1.8	−29.5%	< 0.001
	Control	14.0 ± 2.0	12.4 ± 1.9	−11.3%	0.045
Sit-to-Stand (reps)	RT Group	9.1 ± 1.8	12.6 ± 2.0	+38.5%	< 0.001
	Control	9.0 ± 1.7	10.2 ± 1.9	+13.3%	0.039

** Within-group p-values. Between-group differences: $p < 0.001$ for both outcomes; Cohen's $d = 0.88$ (large).*

4. Discussion

This randomized controlled trial evaluated the efficacy of early progressive resistance training following Total Knee Arthroplasty. The principal findings indicate that structured RT significantly enhances quadriceps muscle strength, reduces pain intensity, and improves both subjective functional ability and objective mobility performance compared to standard postoperative rehabilitation alone. The absence of adverse events confirms that supervised resistance training is clinically feasible and safe during early recovery.

4.1. Effects of Resistance Training on Muscle Strength

Quadriceps femoris weakness post-TKA stems from surgical trauma, arthrogenic muscle inhibition, and disuse atrophy [7]. Standard post-acute therapy often lacks the load intensity required to stimulate optimal hypertrophic and neural adaptations [8]. In contrast, progressive resistance loading provides mechanical strain that promotes motor unit recruitment and muscle tissue hypertrophy [8,9]. The +38.6% strength gain in the RT group exceeds standard rehabilitation benchmarks [10,11], highlighting the necessity of progressive mechanical loading to overcome persistent weakness [12,13].

4.2. Pain Reduction and Exercise Tolerance

A major concern regarding early progressive exercise is the potential escalation of postoperative pain. However, participants in the RT group experienced significantly greater pain reduction (−34.2%) than controls (−14.1%). Improved periarticular muscle strength stabilizes the joint complex, reduces abnormal mechanical stress during weight-bearing activities, and enhances neuromuscular control [14,15]. Furthermore, resistance exercise induces endogenously mediated analgesia, enhancing pain modulation without aggravating joint tissues [16].

4.3. Improvements in Self-Reported and Objective Function

Functional gains reflected both subjective perception (WOMAC) and objective mobility metrics (TUG and Sit-to-Stand). Enhanced quadriceps strength directly improves dynamic balance, gait speed, and sit-to-stand mechanics [17,18]. These mobility gains reduce fall risk, enhance patient confidence, and accelerate return to daily activities [19,20].

4.4. Clinical Implications and Study Limitations

From a clinical standpoint, these findings advocate for shifting early post-TKA rehabilitation paradigms from exclusively low-intensity exercise toward structured, progressive resistance training [21,22]. Nevertheless, several limitations warrant consideration: (1) the study was conducted at a single institution, limiting immediate broad generalizability; (2) follow-up was restricted to 8 weeks, necessitating future evaluation of long-term outcome maintenance; and (3) blinding was restricted to outcome

assessors, as double-blinding is inherently unfeasible in exercise interventions [23–25].

5. Conclusion

Early, supervised progressive resistance training is a highly effective, safe intervention for enhancing muscular and functional recovery after Total Knee Arthroplasty. Incorporating dynamic progressive loading into standard postoperative protocols significantly attenuates quadriceps strength deficits, reduces pain, and restores mobility, supporting its routine implementation in clinical orthopedic rehabilitation.

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