Reversing Muscle and Mobility Deficits 1 to 4 Years after TKA

A Pilot Study

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Abstract Muscle and mobility deficits can persist for years after a total knee arthroplasty (TKA). The purposes of this study were (1) to determine if 12 weeks of rehabilitation with resistance exercise induces increases in muscle size, strength, and mobility in individuals 1 to 4 years after a TKA; and (2) to compare the muscle and mobility outcomes of a traditional resistance exercise rehabilitation program with a rehabilitation program focused on eccentric resistance exercise. Seventeen individuals (13 women, four men; mean age, 68 years; age range, 55–80 years) with either a

unilateral or bilateral TKA (total of 24 knees) were included in this matched and randomized repeated-measures rehabilitation pilot trial. Increases in quadriceps muscle volume and knee extension strength followed 12 weeks of eccentric exercise. Improvements were also noted in four mobility tests. Similar improvements were noted in the traditional group in two mobility tests. An increase in muscle size and strength and an improvement in levels of mobility can occur after 12 weeks of resistance exercise in older individuals 1 to 4 years after TKA. When the exercise mode focuses on eccentric resistance, the muscle growth response is greater as is the improvement in important mobility tasks.

Level of Evidence: Level II, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

One year after TKA, a minority, yet clinically substantial subset of up to 15% to 30%, of patients report dissatisfaction in their physical function despite being satisfied with the resolution of their knee pain [6, 25, 39]. Long-term outcomes after TKA reinforce this notion because TKA recipients consistently indicate an improved quality of life, although their measured and perceived physical abilities remain worse than age-matched nonarthritic populations (for a recent review, see Meier et al. [18]). A number of reports suggest there is a deficit of quadriceps muscle strength of approximately 20% [1, 2, 9, 33–35] with associated functional limitations in mobility and physical activity [4, 6, 7, 27, 34, 38] that remains 6 months to 13 years after surgery.

Although the strength of the quadriceps muscle increases steadily in the first 3 to 6 months after TKA [1, 33],

these improvements taper off 6 to 12 months after surgery [21, 40]. That is, strength improves 10% to 20% from preoperative levels after TKA but rarely ever reaches the strength (reported here as torque in Newton meters [Nm]) of age-matched individuals with nonarthritic native knees (105–137 Nm) [2, 35] or the strength levels of the contralateral nonoperative knee extensor muscles (87–232 Nm) [1, 2, 16, 22, 38]. Consistent with reduced muscle strength, individuals undergoing TKA also exhibit deficits in quadriceps muscle size and neuromuscular activation. It appears that muscle atrophy, however, contributes more to the long-term quadriceps muscle weakness after TKA [17].

Physical performance measures of mobility such as gait speed, timed walking, or stairclimbing tests depict only modest improvements after TKA and substantial deficits persist when compared with age- and gender-matched nonarthritic comparison groups [7, 27, 39]. As well, approximately three of four TKA recipients report difficulty negotiating stairs, a task that is considered a high fall-risk activity, ie, the average stairclimbing speed is only half as fast compared with samples of nonarthritic counterparts [23]. Furthermore, after a peak in functional recovery 6 to 12 months after TKA, there is an accelerated decline in function relative to typical age-related decrements. These mobility deficits are positively associated with chronic quadriceps muscle weakness [29, 40] and are not related to the TKA recipients' knee range of motion nor their knee pain [19, 21, 29]. It is, however, unclear whether muscle size, strength, and mobility can improve in older individuals 1 or more years after TKA.

Therefore, the purpose of this study was twofold: (1) to determine if 12 weeks of rehabilitation with resistance exercise can induce changes in muscle size, strength, and mobility in older individuals 1 to 4 years after their TKA; and (2) to compare the muscle and mobility outcomes of a traditional rehabilitation program with a rehabilitation program focused on eccentric resistance exercise.

Materials and Methods

We recruited 17 older (mean age, 68 years; range, 55–80 years), moderately obese (mean body mass index [kg/m²], 32.9; range, 25.9–39.7) individuals who underwent either a unilateral (n = 10) or bilateral (n = 7) TKA. All patients undergoing TKA who were recruited constituted a sample of convenience from an orthopaedic surgeon's (CP) list of followup patients who were at least 12 months post-TKA (mean, 21 months; range, 12–53 months) and were medically cleared by their physician for physical exercise and lived in the Salt Lake valley region. Any previous revision to a TKA, clinical signs of rheumatoid arthritis, a

Table 1. Subject characteristics*

Group	Eccentric (n = 9)	Traditional (n = 8)
Age (years)	67 (8.8)	68 (8.7)
Women/men	7/2	6/2
Total TKA procedures	13	11
Body mass index (kg/m ²)	32.4 (4.4)	33.5 (5.4)
KOOSymptoms	61.2 (10.5)	55.2 (14.7)
Pain	80.8 (25.8)	79.5 (19.5)
ADL	84.2 (23.9)	82.3 (20.8)
Sports and recreation	58.2 (34.3)	63.1 (29.3)
Quality of life	59.1 (28.0)	64.0 (28.9)
SF-36		
PCS	46.6 (13.3)	40.7 (9.9)
Physical function	67.7 (30.5)	58.6 (20.9)
Bodily pain	73.7 (24.1)	62.0 (27.2)

* Mean (± standard deviation) age, body mass index, KOOS, and SF-36 of the individuals, males and females, who had a TKA; KOOS = Knee injury and Osteoarthritis Outcome Score; ADL = activities of daily living; PCS = Physical Component Scale.

progressive neurologic disorder, or a previous cerebrovascular incident constituted reasons for excluding subjects from participating. As well, any subject currently participating in a regular (two to three times per week) resistance exercise program was also excluded. There were 13 women and four men enrolled in the study. The participants' pain, activity, recreation level, and health-related quality of life are similar to that previously reported (Table 1) [21, 31]. The University of Utah's Institutional Review Board approved this study. All subjects were informed and provided their written consent for participation in this study.

All TKA procedures were performed through a minimedial parapatellar arthrotomy with minimal patella eversion [15, 28]. A conventional tricompartmental replacement was performed in all cases with the Biomet Vanguard knee system (Biomet, Warsaw, IN). After TKA, all subjects underwent inpatient care and home health physical therapy visits for the first 2 weeks after surgery. Thereafter, guidelines for outpatient physical therapy and independent exercises were provided to the subjects [30]. Outpatient physical therapy sessions of 1 hour two to three times per week for 4 to 6 weeks were suggested. This included exercises (one to three sets of 10–15 repetitions) in seated, supine, and standing positions for knee range of motion; and neuromuscular electrical stimulation to augment quadriceps muscle activation, gait training, and walking in an obstacle course. A 10- to 15-minute stationary bicycling session was also suggested.

We attempted to match subjects by gender and whether they had received a unilateral or bilateral TKA, although with an odd number of bilateral TKA recipients (n = 7), the matched grouping was uneven and one group included

an additional subject who had bilateral TKAs. First, the group of 17 patients was divided into seven pairs that were matched by gender and by whether the TKA was unilateral or bilateral plus one trio that consisted of one bilateral patient and two unilateral patients. Then a patient in each pair was randomly assigned to one of the two treatments, and within the trio, the bilateral patient was assigned to the traditional (TRAD) group ($n = 8$) and the two unilateral patients were assigned to the eccentric (ECC) lower extremity resistance exercise group ($n = 9$) for 12 weeks of rehabilitation. All participants were tested by one investigator (WM) before and after 12 weeks of training.

Both groups performed their respective lower extremity resistance exercise program for 30 minutes per session, 3 days per week, for 12 weeks. Compliance with the exercise program was based on the percentage of exercise sessions completed out of a total of 36 sessions over the 12-week period. Individuals were required to complete a minimum of 80% of the sessions to be included in the analyses. Before each training session, a 5- to 10-minute warmup on a standard cycle ergometer was performed. The TRAD group then performed four lower extremity resistance exercises (leg press, leg extension, leg curl, and calf raise) on weight training machines at 70% of their one-repetition maximum for three sets of 10 to 12 repetitions. Every other week, one-repetition maximum was reassessed and the exercise prescription was continued at a new resistance level commensurate to 70% of one-repetition maximum. Other traditional physical therapy exercises, ie, 4-inch stepups and wall squats, were incorporated into the exercise program using body weight as resistance at three sets of 10 to 12 repetitions.

The ECC group performed lower extremity resistance exercises exclusively on a recumbent eccentric resistance exercise stepper device described previously [5, 12]. The recumbent eccentric stepper is powered by a 3-horsepower motor that drives the foot pedals in a “backward” direction, ie, toward the individual. Eccentric muscle contractions occurred when the individual attempted to resist this motion by pushing on the pedals (with verbal instructions to “try to slow down the pedals”) as they moved toward them. Because the magnitude of the force produced by the stepper exceeds that of the individual, the pedals continue to move toward the participant at a constant velocity, resulting in eccentric contractions of the knee and hip extensors, including the quadriceps muscles (Fig. 1).

ECC subjects began with a 5-minute session on the stepper and progressed to a maximum of 20 minutes over the next 3 to 4 weeks at a self-selected range of 15 to 25 rotations per minute. The progression of the eccentric exercise work rate was dictated by the exercise protocol and determined as a function of the rating of perceived

Fig. 1 High muscle forces are generated on an eccentric stepper powered by a 3-horsepower motor that drives the pedals. As the pedals move toward the participant (largest arrow), the rider resists by applying force to the pedals (arrow at foot level). Because the magnitude of force produced by the motor exceeds that produced by the rider, the leg extensors (arrows in thigh) work eccentrically (lengthening), creating negative work.

exertion based on the perceived exertion scale of Noble et al. [26]. A “target” workload, at a constrained rating of perceived exertion level, was visible to the ECC group participant on a computer monitor and the goal was to achieve ever-increasing total amounts of negative work per session despite the constrained temporal and exertion levels. In the ECC group, the protocol dictated that the perceived exertion during exercise would progress from a “very, very light” [26] exertion level for 5 to 11 minutes during the first week. During Week 2 (Sessions 4 to 6), the participants’ perceived exertion increased to a “very light” exertion level and 3 minutes of training time was added to each session until a maximum 20 minutes of training was achieved. In Week 3, ECC training was increased to a “fairly light” exertion level for 20 minutes. In the last 8 weeks of training, the perceived exertion was between a “fairly light” and “somewhat hard” level with each session being 20 minutes in length. It is our experience that during any form of exercise, this population will exert to a level consistent with the perception of exercising “somewhat hard.” Therefore, once a rating of perceived exertion level of “somewhat hard” was achieved, participants were instructed to maintain that exertion level throughout the remaining weeks of training. Immediately after each training session, the total negative work in kilojoules (kJ) was recorded and averaged over the number of exercise sessions per week.

Both thighs of all patients underwent MRI 1 week before and 1 week after the 12 weeks of exercise to assess the muscle volume of the quadriceps as previously described [5, 37]. Participants were placed supine in the MRI unit with the legs relaxed. All scans were performed on one 1.5-Tesla whole-body MRI unit (Signa Lightning LX 8.4;

General Electric Medical Systems, Milwaukee, WI). To establish the region of interest, a coronal fast spoiled gradient echo scout scan was used to identify the superior and inferior boundaries of the scans (the femoral head to the TKA knee system component parts representing the tibio-femoral joint line). Once the region of interest was established, axial T1-weighted images were acquired in the standard body coil using a fast spin echo sequence: 8-mm slice thickness, 15-mm interslice distance, and a 320×320 matrix. Depending on thigh length, the number of sections acquired ranged from 17 to 22. (Note: the identical number and location of slices were used in the comparison from pre- to posttraining.) The axial MRI images were then digitized and saved to compact disc for later analysis.

After electronic data transfer of images, muscle volume measurements and calculations were performed by use of custom-written image analysis software (MatLab; Mathworks, Inc, Natick, MA) on a desktop personal computer. For each image, the quadriceps muscle of interest, eg, vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris (independent of skin, bone, and fat), were identified from the displayed images. One of the authors (WM) manually traced the muscle outlines using a computer mouse, allowing overall muscle volume to be automatically computed. Muscle volume was determined by summing the volumes from each slice (cross-sectional area $\times$ slice thickness) to give total volume as described by previous researchers [37]. The same investigator, blinded to time point of the scan and slice location, performed measurements of individual participants' quadriceps muscle before and after training. To establish intrainvestigator reliability of the muscle volume measurement, the same investigator performed two separate measurements of quadriceps muscle volume of 18 different images on six individuals. The average interclass correlation coefficient across the 18 images was 0.99. The validity of the volume measurement was determined by analysis of images obtained from a cadaveric thigh phantom that approximated the size of the quadriceps femoris muscle group. The volume of the phantom, measured by water displacement 5 hours after MRI scanning, was 100.7% of the MRI-determined value. There was a 0.012% difference between repeat volume displacement measurements of the phantom by the same investigator [5].

Lower extremity knee extension strength was quantitatively assessed by unilateral maximal voluntary isometric force on a KinCom dynamometer (Chattanooga Inc, Hixson, TN). Previous research has supported the reliability of this measure [3, 21, 22, 36]. Both lower extremities were tested and these strength measures were assessed before and 2 to 5 days after the training interventions. Participants were seated and their knees were fixed at 75° of flexion. Before testing, participants practiced submaximal contractions at

50% and 75% of their maximal effort. One practice trial was then performed. After a brief rest period, three separate maximal contractions were performed, each held for 5 seconds with a 3-minute rest between trials. The outcome variable muscle torque was calculated as the peak torque of three trials. The order of testing (more affected versus less affected limb as determined by the subject's perception of leg impairment) was randomized among subjects. Subjects were stabilized by chest and thigh straps and asked to fold their arms across their chest while performing these tests.

A battery of three reliable mobility tasks regularly used with older individuals and responsive to detecting change [10] was used to determine the functional relevance of any muscle strength changes. All mobility measurements were performed by one investigator (WM). All participants underwent this series of tests before and after (within 2–5 days) 12 weeks of training. The timed up and go test is a timed (s) test in which participants begin in a seated position in an armchair and then rise, go forward 3 m, turn around, and sit back down. The timed up and go test can discriminate between older individuals who have fallen and those who have not fallen. The 6-minute walk test, a measure of the distance (m) an individual walks in 6 minutes [11], was used to assess overall locomotor ability and locomotor fatigue. Participants were asked to cover as much distance as possible within 6 minutes. The stair ascent and descent time tests (s) [3] were used to assess functional mobility and the use of concentric and eccentric lower extremity muscle force production abilities, respectively. Participants were asked to ascend and descend one flight of stairs under close or contact supervision as quickly and safely as possible. Time was recorded to the nearest 0.01 second from a verbal go signal to final foot placement on a standard flight of 10 stairs and the average of three trials was recorded. Previous research has supported the validity of these measures [29, 40] and reported quadriceps muscle strength as being positively correlated 12 months after TKA with faster times during the timed up and go and stairclimbing tests and greater distances covered during the 6-minute walk test [29, 40].

Because no previous studies have examined the practicality of eccentric exercise in older individuals after TKA, as control variables, we documented the ECC group participants' subjective interpretation of whether the eccentric training induced any leg muscle pain and/or any knee pain. A 10-cm visual analog scale (0 cm = no pain, 10 cm = worst possible pain) for both the leg muscles and knee were filled out by the participant before each training session (to document residual pain from previous sessions).

Descriptive statistics were calculated for demographic variables and dependent measures. In the analysis of the dependent measures, the assumptions underlying parametric tests, normality, and homogeneity of variance were

met. In accordance with the dual purpose of the study, we evaluated: (1) whether 12 weeks of resistance exercise, as part of a rehabilitation program, can induce changes in muscle size, strength, and mobility in older individuals 1 to 4 years after their TKA; and (2) whether the effect of the type of resistance exercise (ECC versus TRAD) influenced muscle and mobility outcomes. To determine within-group pre- to posttraining changes in muscle and mobility, we used a one-way repeated-measures analysis of variance. To determine between-group differences in the pre- to posttraining changes in muscle and mobility, we used a two-way repeated-measures analysis of variance with particular attention paid to the time by group interaction effects because a significant result would reflect a differing response of groups over time. Significant interactions ($p < 0.05$) were then assessed through a pairwise comparison test using a Bonferroni correction. Data were analyzed with Sigma Stat Version 3.5 (Chicago, IL).

Results

All 17 individuals completed the 12 weeks of resistance training. Each group (ECC and TRAD) had similar compliance records having completed an average of 32 exercise training sessions (range, 29–33 sessions) for an overall compliance level of 89%. Before participating in the resistance exercise regimen, we found no differences between the groups on any of the muscle size, muscle strength, or mobility measures.

Rehabilitation using 12 weeks of resistance exercise induced improvements in quadriceps muscle size, knee

extension strength, and mobility in individuals 1 to 4 years after TKA (Table 2). The ECC group increased quadriceps muscle size ($p < 0.001$) by 11% and knee extension muscle strength ($p = 0.005$) by 15%. The TRAD group, however, did not experience an increase in quadriceps muscle size ($p = 0.16$) nor knee extension strength ($p = 0.52$). The ECC group experienced a 20% collective average improvement in all of the mobility tasks, ie, timed up and go ($p = 0.01$), 6-minute walk ($p = 0.048$), stair ascent ($p = 0.001$), and stair descent ($p = 0.001$). The TRAD group experienced a 16% average improvement in two of the four mobility tasks, ie, timed up and go ($p = 0.002$), 6-minute walk ($p = 0.14$), stair ascent ($p = 0.007$), and stair descent ($p = 0.14$).

These improvements in quadriceps muscle size, strength, and mobility after 12 weeks of resistance exercise training were most evident in the ECC group when compared with the TRAD group. The ECC group's improvements were better than the TRAD group's in terms of the increase in quadriceps muscle size ($p = 0.01$) and the stair descent ability ($p = 0.04$). A trend ($p = 0.08$) toward greater improvement in knee extension strength after ECC versus TRAD was also noted.

Clinical variables such as pain and negative work values were monitored in the ECC group as a result of eccentric exercise being a novel form of rehabilitation after TKA. The average leg muscle pain and knee pain at the initiation of the 12 weeks of ECC resistance training was 3.0 cm and 2.2 cm, respectively (on the 10-cm visual analog scale) and decreased to less than 1.0 cm over the last 5 weeks of training. Mean leg muscle and knee pain (cm) values for Week 3 were 1.96 and 1.08; Week 6, 1.42 and 1.20; Week

Table 2. Mean ($\pm$ standard deviation [SD]) and probability values for muscle size, strength, and mobility outcomes for the eccentric and traditional resistance exercise groups

	Eccentric		Interaction Group $\times$ time F score	Traditional	
	Pre Mean (SD)	Post Mean (SD)		Pre Mean (SD)	Post Mean (SD)
Quadriceps volume (cm ³)	979.4 (255)	1091.4 (270)	8.85	1074.5 (374)	1105.0 (339)
		* $p < 0.001$	($p = 0.01$) [†]		$p = 0.16$
Knee extension strength (N/m)	102.3 (32)	117.2 (31)	3.37	113.3 (42)	116.2 (37)
		* $p = 0.005$	($p = 0.08$)		$p = 0.52$
Timed up and go (s)	8.5 (2.7)	6.6 (1.1)	1.28	7.7 (1.7)	6.6 (1.6)
		* $p = 0.01$	($p = 0.27$)		* $p = 0.002$
Six-minute walk (m)	525.3 (117)	575.9 (95)	0.03	523.2 (142)	568.0 (153)
		* $p = 0.048$	($p = 0.88$)		$p = 0.14$
Stair ascent (s)	7.4 (1.8)	5.6 (1.0)	1.33	7.8 (3.8)	6.5 (2.9)
		* $p = 0.001$	($p = 0.26$)		* $p = 0.007$
Stair descent (s)	6.4 (2.0)	4.9 (1.0)	4.76	7.0 (4.0)	6.5 (4.6)
		* $p = 0.001$	($p = 0.04$) [†]		$p = 0.14$

* Significant within group pre- to posttraining changes; [†]significant between group pre- to posttraining changes.

9, 0.32 and 0.63; and Week 12, 0.48 and 0.79. Overall, the negative work values increased progressively through the 12 weeks of ECC training. After a 2-week “ramp-up” phase of ECC ergometry, negative work almost doubled (ie, increased 1.97 times) by the completion of the training program; mean work (kJ) values for Week 3 were 44,003; Week 6, 55,768; Week 9, 79,733; and Week 12, 86,480.

Discussion

Decrements in muscle size and strength and concomitant mobility limitations are inevitable consequences the first few months after TKA [1, 16, 23, 36]. Muscle and mobility improvements do occur during the first 6 to 12 months after surgery, but residual deficits persist for years thereafter [1, 2, 4, 6, 7, 9, 27, 32–35, 38]. In a test of whether these deficits can be mitigated years after TKA, we pilot-tested the following: (1) if 12 weeks of rehabilitation with resistance exercise can induce changes in muscle size, strength, and mobility in older individuals 1 to 4 years after their TKA; and (2) a comparison of muscle and mobility outcomes of a TRAD rehabilitation program to a rehabilitation program focused on ECC resistance exercise.

Considering the small sample size and variability in the amount of time since TKA, and the inclusion of both unilateral and bilateral TKAs, this pilot study is underpowered and our participants should be considered a heterogeneous cohort; hence, attempts at generalizing the results should be made with caution. Furthermore, despite a programmatic approach to rehabilitation during the first 3 to 4 months after TKA, it is not clear what fraction of participants were compliant with this program, although no muscle or mobility differences existed between groups 1 to 4 years after TKA, ie, at the start of this clinical trial. Despite the apparent heterogeneity among our

participants, the TKA cohort’s muscle strength resembles that of TKA recipients typically depicted in the literature 1 year after surgery and they are weaker than age-matched nonarthritic individuals with native knees [18]. As well, their general measure of health and physical domains (eg, SF-36) is reflective of TKA recipients reported previously [21]. Considering impairments in muscle and mobility peak 6 to 12 months after surgery [21, 40], and the remaining deficits continue to be present over subsequent years [18, 22], we made an a priori decision to include only those individuals more than 12 months after TKA. Finally, considering the short-term followup in our study, it is unclear whether any of the muscle and/or mobility changes were maintained.

Our pilot study suggests long-term muscle and mobility impairments are reversible with resistance exercise. When coupled with the greater increase in muscle size and strength in the ECC group, as compared with the nonsignificant changes in TRAD, it suggests the higher force-producing ability of eccentric resistance exercise is both feasible and a potent stimulus to muscle in those with a TKA. The overall improvement in two of the four mobility tasks in the TRAD group is encouraging, although the improvement in all mobility tasks in the ECC group was greater. These outcomes suggest there is potential for resistance exercise with greater intensity after the inpatient phase of rehabilitation, although this must be tested formally because very few studies have used a traditional progressive resistance exercise approach.

The results of the resistance exercise regimens reported here 1 to 4 years after TKA should not be compared with those of studies assessing TKA outpatient rehabilitation initiated soon after discharge from the hospital. This is an unreasonable comparison because the TKA recipients’ muscle and mobility status is much more impaired early after TKA as compared with 12 months after surgery,

Table 3. Calculated mean strength and mobility values of TKA recipients from earlier studies at a minimum of 12 months after TKA*

Reference, time since TKA	Knee extension strength (N/m)	Timed up and go (s)	Six-minute walk (m)	Stair (ascend + descend) test (s)
Berman et al. [1], 12 months	50.5			
Berth et al. [2], 33 months	84.8			
Mizner et al. [22], 12 months		7.5		11.6
Moffet et al. [24], 12 months			385	
Rossi et al. [32], 12 months	104.6			
Silva et al. [35], 34 months	94.7			
Walsh et al. [38], 12 months	59.1			
Yoshida et al. [40], 12 months	143.4	6.8	630	10.1
Current study	107.4	8.1	524	14.3

* For comparison purposes, the strength and mobility values in the current study are in the bottom row.

although the effectiveness of physical therapy exercise during this early phase does result in short-term benefit (for a systematic review and meta-analysis, see Minns Lowe et al. [20]). However, our muscle strength and mobility data are generally comparable to that reported 1 year after TKA [1, 2, 22, 24, 32, 35, 38, 40] (Table 3).

For individuals with muscle and mobility impairments more than 1 year after TKA, the high force-producing characteristic of eccentric exercise may have a greater clinical influence as has been demonstrated by two- to fourfold greater muscle and mobility responses in other older patient populations [5, 12]. These amplified improvements after eccentric resistance exercise apparently stem from the ability of muscle to achieve higher forces at low perceived exertion levels, thereby inducing muscle and mobility responses that exceed those of traditional resistance exercise [8, 13, 14]. It is tempting to compare our findings with the recent descriptions of higher intensity, ie, approximately 6 weeks of progressive resistance exercise, in the early (1–2 months after TKA) postoperative phase [21, 24, 29], but caution should be exerted when making such comparisons because our findings are from an eccentric high-force exercise instituted 1 to 4 years after TKA. Like our results, however, these more intensive rehabilitation exercise interventions enhance outcomes compared with historical TKA outcomes with the most recent report depicting a 21% greater restoration of quadriceps muscle strength and 15% to 44% greater functional mobility [29]. Again, caution should be exerted when comparing studies that initiated an intervention early after TKA versus an intervention reported here that induced a 15% strength and 20% mobility improvement but was initiated more than 1 year after TKA. It seems clear, however, that the muscle impairments and functional limitations can be reversed early after TKA and, perhaps more surprisingly, can improve 1 to 4 or more years after TKA.

In summary, this pilot study demonstrates an increase in muscle size and strength and an improvement in levels of mobility can occur after 12 weeks of resistance exercise in older individuals 1 to 4 years after TKA. When the exercise mode focuses on eccentric resistance, the muscle growth response appears greater as does the improvement in important mobility tasks. Further research is required to determine if these improvements are long-lasting and whether they impact an individual's quality of life.

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