CLINICAL SCIENCE

Muscle strength and exercise intensity adaptation to resistance training in older women with knee osteoarthritis and total knee arthroplasty

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OBJECTIVES: To analyze muscle strength and exercise intensity adaptation to resistance training in older women with knee osteoarthritis and total knee arthroplasty.

METHODS: Twenty-three community-dwelling women were divided into the following groups: older, with knee osteoarthritis and total knee arthroplasty in the contralateral limb (OKG; N = 7); older, without symptomatic osteoarthritis (OG; N = 8); and young and healthy (YG; N = 8). Muscle strength (1-repetition maximum strength test) and exercise intensity progression (workload increases of 5%–10% were made whenever adaptation occurred) were compared before and after 13 weeks of a twice-weekly progressive resistance-training program.

RESULTS: At baseline, OKG subjects displayed lower muscle strength than those in both the OG and YG. Among OKG subjects, baseline muscle strength was lower in the osteoarthritic leg than in the total arthroplasty leg. Muscle strength improved significantly during follow-up in all groups; however, greater increases were observed in the osteoarthritic leg than in the total knee arthroplasty leg in OKG subjects. Greater increases were also seen in the osteoarthritic leg of OKG than in OG and YG. The greater muscle strength increase in the osteoarthritic leg reduced the interleg difference in muscle strength in OKG subjects, and resulted in similar posttraining muscle strength between OKG and OG in two of the three exercises analyzed. Greater exercise intensity progression was also observed in OKG subjects than in both OG and YG subjects.

CONCLUSIONS: OKG subjects displayed greater relative muscle strength increases (osteoarthritic leg) than subjects in the YG, and greater relative exercise intensity progression than subjects in both OG and YG. These results suggest that resistance training is an effective method to counteract the lower-extremity strength deficits reported in older women with knee osteoarthritis and total knee arthroplasty.

KEYWORDS: Knee Osteoarthritis; Total Knee Arthroplasty; Muscle Strength; Resistance Exercise; Elderly.

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INTRODUCTION

Knee osteoarthritis (OA) is a common clinical condition that has a major impact on the functioning and independence of the elderly.[1] Knee OA patients with radiographic evidence of joint damage, moderate to severe persistent pain, and clinically significant functional limitations that diminish quality of life are candidates for total knee arthroplasty (TKA).[2] Although TKA reduces pain and improves perceived function, patients continue to exhibit reduced muscle strength, voluntary muscle activation, and functional performance even years after surgery.[3] Because of their association with functional activities (i.e., walking and stair climbing) and lower limb loading distribution,[3,4] quadriceps muscle strength deficits following TKA have considerable long-term consequences, and these deficits are even associated with the progression of OA in the uninvolved leg.[4,5]

Resistance training has been shown to be the most effective exercise for improving muscle strength.[6] Aging has not been shown to affect the ability to improve muscle strength through resistance training, and both older men and women without physical limitations have been shown to increase muscle strength and training intensity in the same way as young subjects.[7,8] However, there is a paucity of research analyzing the effects of resistance training on muscle strength of older subjects following knee replacement surgery, and the data that are available are inconclusive.[9,10] Although an individualized resistance training program (2–3 sets of 10 repetition maximum (RM)) applied four weeks after TKA was safe and effective

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for improving isometric muscle strength,[9] a standard resistance training program (three sets of 10–12 repetitions at 70% of 1-RM) failed to increase isometric muscle strength when applied one to four years after surgery.[10] Moreover, to the best of our knowledge, there are no studies analyzing the dynamic muscle strength and resistance training progression in older subjects with TKA and OA in the contralateral knee. An understanding of the musculoskeletal adaptation to resistance training in subjects with TKA and OA in the contralateral knee may inform the design of future therapeutic programs to mitigate the muscle impairments and related functional limitations in this population.

Thus, the aim of the present study was to analyze the muscle strength response and exercise intensity progression to resistance training in older women with knee OA and TKA.

METHODS

Participants and Study Design

We recruited seven older women with unilateral TKA for at least 14 months (38.5±18.5 months; range, 14–66 months) due to severe OA and an established diagnosis of knee OA[11] in the contralateral limb (Kellgren/Lawrence scale grades[12] of 2–4) (OKG; 70–79 years); eight older women without symptomatic OA (OG; 65–79 years); and eight healthy young women (YG; 21–30 years). Subjects in all three groups underwent physical exercise screening for participation in the Cardiovascular and Muscular Fitness Program of the Laboratory of Kinesiology at the Institute of Orthopedics and Traumatology, Medical School, University of Sao Paulo. All volunteers were physically inactive and did not practice resistance training for at least the 12 months preceding the study. Before beginning the study, a structured history, medical record review, and physical evaluation of each the participants were performed to document symptoms, history of chronic diseases, current medications, cardiac risk factors, and cardiac events and procedures. None of the volunteers had uncontrolled cardiovascular or metabolic diseases, insulin-dependent diabetes, chronic psychological disorders and /or cardiac disease (defined as those with a history of myocardial infarction, angiographically documented coronary artery disease, coronary angioplasty, coronary bypass surgery or chronic heart failure). The OG and YG subjects also did not have any musculoskeletal limitations to physical exercise.

The demographic characteristics of the women included in the study are summarized in Table 1. Volunteers in the OKG group were more obese than those in the OG and YG groups. All OKG and OG volunteers had controlled hypertension (diuretics, n = 7; angiotensin-converting enzyme inhibitors, n = 8; calcium channel blockers, n = 4; and β-blockers, n = 2); three OKG volunteers and two OG volunteers had osteopenia (alendronate sodium, n = 5); and one OKG volunteer and two OG volunteers had dyslipidemia (simvastatin, n = 3). None of the YG women was taking any medication.

After screening, all volunteers participated in a twice-weekly lower limb resistance-training program for 13 weeks, and muscle strength and exercise intensity progression were compared between groups. Muscle strength was measured both before and after the intervention (postintervention measurements were conducted two to five days after the last exercise session) by a 1-RM strength test. Exercise training workload was monitored and recorded at each session to measure exercise intensity progression throughout the study period. The study was approved by the ethics committee at our institution. All volunteers read a detailed description of the study protocol and provided their written informed consent.

Table 1 - Subject characteristics at baseline.

Variable	OKG	OG	YG
N	7	8	8
Age (years)	75.3±3.1	70.4±5.3	23.7±3.5 [a,c]
BMI (kg/m^2)	32.4±4.8	28.1±5.2	23.0±3.4 [a,d]
Waist Circumference (cm)	107.8±12.5	92.9±11.2	81.3±8.4 [a,d]
Blood Pressure (mmHg)			
Systolic	120.2±7.7	119.3±15.0	103.4±8.1 [a,d]
Diastolic	69.7±4.7	65.3±12.7	62.1±7.3 [b]

OKG: Older knee osteoarthritis and total knee arthroplasty group. OG: Older control group. YG: Young control group. N: number of subjects; BMI: body mass index. Significantly different from OKG: [a] = $p<0.001$; [b] = $p<0.05$. Significantly different from OG: [c] = $p<0.001$; [d] = $p<0.05$.

Strength Test

To determine muscle strength and the initial workload for each resistance exercise, the 1-RM test was performed after four familiarization sessions and 2–5 days after the last exercise session, as described previously.[7,8] In brief, the 1-RM test was performed on the leg press, knee curl and calf raise using the same weight-lifting machines that were used for training (Biodelta Inc., Sao Paulo, Brazil). All volunteers performed the tests unilaterally following the exercise order described above (after proper warm-up), and both legs were tested. 1-RM workload was defined as the maximum weight that could be moved once through the full or pain-free (OA leg of OKG) range of motion with proper form and without performing the Valsalva maneuver. The muscle strength data were normalized for body mass with the allometric method (strength [kg] x body mass [kg]$^{-0.67}$) for inter- and intragroup comparisons.[13] All tests were conducted by the same investigator both before and after the exercise training period. In our laboratory, the intraclass correlation for 1-RM test-retest measures was 0.983 (95% confidence interval = 0.964–0.997).

Exercise program

The exercise training program, designed to develop muscle mass and strength, was performed twice-weekly for 13 weeks. Each exercise session was monitored by an exercise specialist and lasted for approximately 25 minutes, including warm-up and cool-down (5 minutes each). The resistance exercises consisted of two sets of 8–12 repetitions each of the same three exercises described in the explanation of the 1-RM test. The resistance exercises were performed unilaterally, and the initial workload was 60% of the 1-RM of the weaker leg. The volunteers were encouraged to perform at their maximum capacity during the sets of 8–12 repetitions prescribed, using proper form and avoiding the Valsalva maneuver. All subjects were instructed to take a 30- to 60-second rest between sets, which were performed alternately between legs.

Exercise intensity progression

To promote a sufficient workload to produce improvements throughout the 13 weeks of training, the exercise intensity was increased by 0.5–10 kg (5%–10%) whenever the subjects had adapted to the exercise workload. Exercise adaptation was considered to be achieved when two sets of 12 repetitions using proper form and avoiding the Valsalva maneuver were performed in both legs.

Statistical Analyses

All data are reported as the mean ± standard deviation. The statistical program SigmaStat 3.5 for Windows (Systat Software Inc., Chicago, IL USA) was used for statistical analyses. The Kolmogorov–Smirnov test was applied to ensure a Gaussian distribution of the data. Differences in the characteristics of volunteers and postexercise muscle strength improvements were analyzed by one-way ANOVA. Two-way ANOVA (group vs. time) for repeated measurements was used to analyze the 1-RM strength test data. The Bonferroni *post hoc* analysis was used to determine the significant data indicated by ANOVA. Because of its nonparametric distribution, exercise intensity progression was analyzed by the Kruskal-Wallis test, and Dunn's *post hoc* test was used to determine the significant data indicated by Kruskal-Wallis. The significance level was set at $p<0.05$.

To obtain an estimate of the size effect expected for the variables in our sample, we relied on the results of exercise training studies similar to ours.[7,8] Considering that the results of those studies produced a 17%–40% increase in muscle strength with no difference between younger and older adults, we estimated that an overall sample of 7 subjects for each age group would be required to provide a power of 80% to detect a muscle strength change of 20% with a two-sided alpha of <0.05.

RESULTS

Muscle strength

Because no significant differences were observed between the dominant and nondominant legs in the 1-RM tests (pre- and posttraining) or in the muscle strength increase between the YG and OG groups, only the dominant leg data for the YG and OG are provided in the manuscript. Data from the 1-RM tests are displayed in Table 2. At baseline, the OA leg of OKG subjects showed lower muscle strength than the dominant leg of both OG and YG subjects in all exercises ($p<0.05$). The TKA leg of OKG subjects showed lower pretraining muscle strength than the dominant leg of YG subjects in all exercises ($p<0.01$) and lower muscle strength than the dominant leg of OG subjects only in the leg press ($p=0.035$). Among the OKG subjects, the OA leg also showed lower pretraining muscle strength than the TKA leg in the leg press ($p=0.033$) but not in the knee curl and calf raise exercises.

Resistance training increased muscle strength in all groups, but the OA leg of OKG subjects showed a greater muscle strength increase than the dominant leg of YG subjects in all exercises ($p<0.05$) and than the TKA leg in the leg press exercise (Figure 1). With these greater increases, the OA leg of OKG subjects showed similar posttraining muscle strength to the TKA leg in all exercises. Moreover, the OA leg of OKG subjects also showed similar posttraining muscle strength to the dominant leg of OG subjects in both the knee curl and calf raise strength exercises. There were no significant differences between the TKA leg of OKG subjects and the dominant leg of OG subjects and YG subjects in resistance training-induced muscle strength increases.

Exercise intensity progression

Resistance exercise relative workload increase curves are displayed in Figure 2. Because exercise intensity was increased only when both legs performed two sets of 12 repetitions with the proper form and avoiding the Valsalva maneuver, the relative workload increase curves were the same for both the OA leg and the TKA leg of OKG subjects or the dominant and nondominant legs of OG and YG subjects. Despite their lower muscle strength levels, OKG subjects showed greater resistance training intensity progression than YG subjects in all exercises ($p<0.01$). The leg press and calf raise resistance training intensity progression were also greater in OKG subjects than in OG subjects ($p<0.01$). No significant differences in the resistance training intensity progression were observed between OG and YG subjects.

The exercise intensity progression method used in this study was found to be safe because no injuries, muscle damage or major muscle or joint pain were observed in the three groups during the study period.

DISCUSSION

To the best of our knowledge, this is the first study that focused on analyzing the muscle strength response to resistance training and exercise intensity progression in older women with TKA and symptomatic OA in the contralateral knee. The primary findings of the present study are as follows: a twice-weekly resistance training program was effective in improving the muscle strength of older women with TKA and knee OA, the muscle strength

Table 2. 1-repetition maximum strength test before and after 13 weeks of exercise training.

Exercise	Leg Press (kg.kg$^{-0.67}$)		Knee Curl (kg.kg$^{-0.67}$)		Calf Raise (kg.kg$^{-0.67}$)	
	Pre	Post	Pre	Post	Pre	Post
OKG (N = 7)						
OA	1.23 ± 0.15	1.91 ± 0.21 [d]	0.31 ± 0.06	0.53 ± 0.09 [d]	1.35 ± 0.41	2.21 ± 0.63 [d]
TKA	1.74 ± 0.09 [a]	2.20 ± 0.19 [d]	0.37 ± 0.09	0.57 ± 0.12 [d]	1.64 ± 0.30	2.43 ± 0.36 [d]
OG (N = 8)	2.02 ± 0.15 [a,b]	2.77 ± 0.34 [a,b,d]	0.47 ± 0.15 [a]	0.66 ± 0.14 [d]	2.15 ± 0.49 [a]	2.89 ± 0.47 [d]
YG (N = 8)	2.75 ± 0.79 [a,b,c]	3.28 ± 0.81 [a,b,d]	1.04 ± 0.13 [a,b,c]	1.36 ± 0.12 [a,b,c,d]	3.68 ± 0.83 [a,b,c]	4.52 ± 0.65 [a,b,c,d]

OKG: Older knee osteoarthritis and total knee arthroplasty group. OG: Older control group. YG: Young control group. OA: Lower limb with knee osteoarthritis. TKA: lower limb with total knee arthroplasty. [a]: difference from OA limb at the same period (P < 0.05). [b]: difference from TKA limb at the same period (P<0.05). [c]: difference from OC at the same period (P<0.05). [d]: difference from pre-exercise at same group (P<0.001).

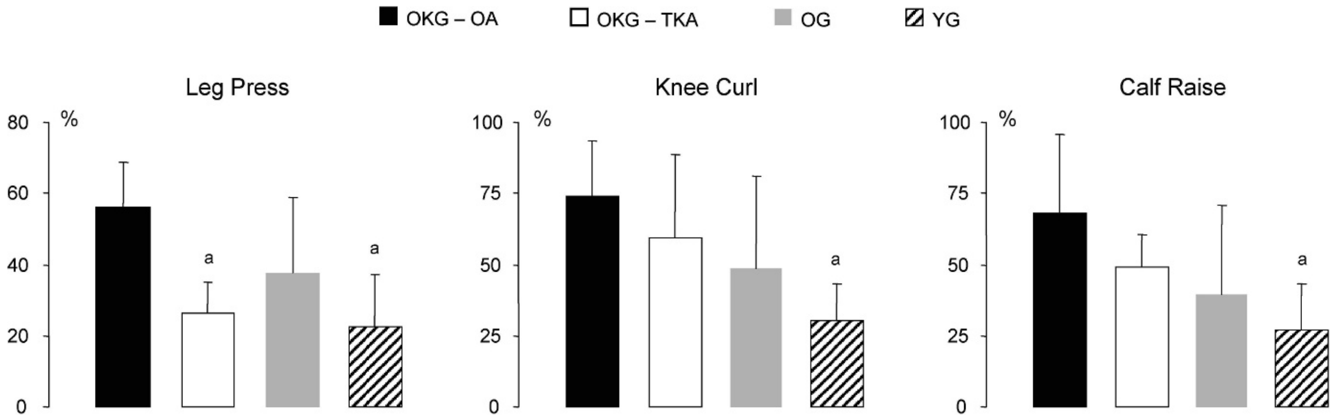

Figure 1 - Muscle strength (1-RM test) increase after 13 weeks of resistance training. OKG: Older knee osteoarthritis and total knee arthroplasty group. OG: Older control group. YG: Young control group. OA: Lower limb with knee osteoarthritis. TKA: lower limb with total knee arthroplasty. [a] denotes significant difference between TKA and OA legs ($p<0.05$).

improvements observed in the OA limb were greater than those in the TKA limb, and the muscle strength improvements observed in the OA limb were greater than those observed in both young and older women without OA who performed the same exercise program. The present study also showed greater resistance exercise intensity progression in older women with TKA and knee OA than in younger and older women without OA. The greater muscle strength increases in the OA leg resulted in restored muscle strength deficits between the OA and TKA legs of OKG subjects. Moreover, the OA leg knee curl and calf raise muscle strength were restored to levels similar to those of OG subjects.

Muscle strength impairment is of particular concern after TKA. Although hamstring strength deficits are reported after TKA, quadriceps weakness has received greater attention because of its strong association with normal functional activities, such as walking and stair climbing.[3] Quadriceps muscle strength improvements do occur during the first year after surgery, but residual strength deficits persist for years in individuals following TKA.[3] Previous studies comparing TKA individuals with healthy age-matched subjects have shown 19%–35% deficits in quadriceps muscle strength measured 1.7–2.8 years after TKA.[14,15] In the present study, the approximately 13.9% baseline leg press 1-RM strength deficit observed in the TKA leg of OKG subjects compared with OG subjects was lower than the deficits observed in these previous studies. However, the methodology used to analyze muscle strength (isokinetic knee extension or isometric contraction *vs.* leg press 1-RM strength) might explain this lower deficit. Another interesting finding of the present study was that the contralateral leg showed 29.6% $\pm$ 6.7% lower leg press 1-RM strength than the TKA leg, whereas previous studies have shown 12%–31% greater quadriceps muscle strength in the contralateral leg.[3,15] The probable explanation for this discrepancy is the population studied. Previous studies have analyzed quadriceps muscle strength in TKA individuals without symptomatic OA in the contralateral knee,[3,15] and we studied only TKA women with symptomatic OA in the contralateral knee. Thus, it is possible that the damage in the OA knee explains its lower muscle strength.

Resistance training is the most effective intervention for improving muscle strength and has been recommended in guidelines for knee OA management[16,17] and in clinical reviews for TKA rehabilitation.[3] Previous studies have shown a 6%–46% increase in the quadriceps and hamstring strength of subjects with knee OA performing moderate- to high-intensity resistance exercise programs.[18-20] These increases are lower than the 56%–74% increase observed in the OA leg of OKG subjects in the present study. The different exercise type and intensity performed, as well as the different methods used to analyze muscle strength, are possible explanations for the greater muscle strength

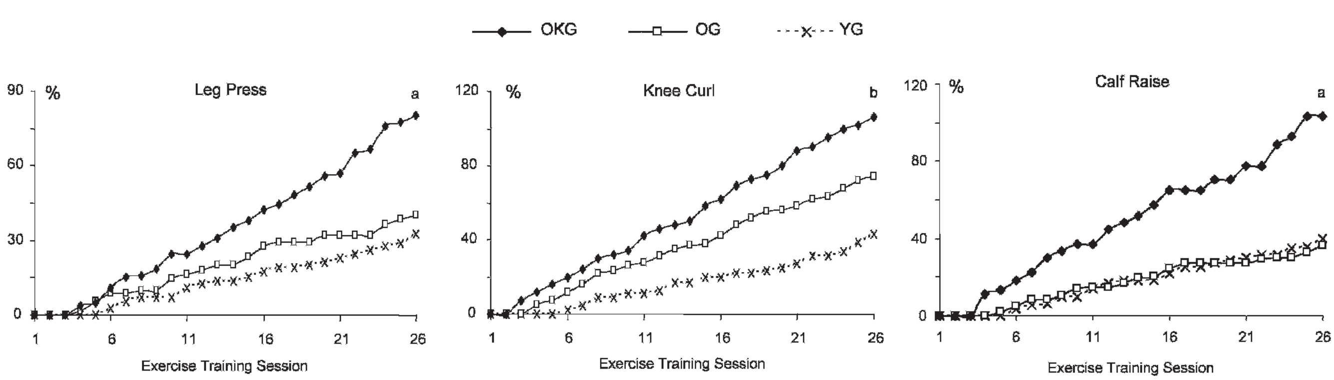

Figure 2 - Relative workload increase curves. OKG: Older knee osteoarthritis and total knee arthroplasty group. OG: Older control group. YG: Young control group. [a] denotes significant difference from OKG - OA ($p<0.05$). [b] denotes significant difference from YG ($p<0.01$).

increase observed in the present study. There is a lack of information regarding the appropriate intensity of resistance training in patients with knee OA.[21] In the present study, the OKG subjects trained at the same intensity as that recommended for younger and older people without limitations,[6,22] and no adverse events due to the exercise protocol were observed. Moreover, OKG subjects showed a greater leg press muscle strength increase in the OA leg than the TKA leg and a greater muscle strength increase in the OA leg than the dominant leg of YG subjects in all exercises. The OA leg of OKG subjects also showed a greater muscle strength increase than the dominant leg of OG subjects in all exercises. Although these greater increases did not reach statistical significance, they were enough both to increase the OA leg knee curl and calf raise muscle strength of OKG subjects to levels similar to those of OG subjects and to reduce the leg press muscle strength deficit between the OA leg of OKG subjects and the dominant leg of OG subjects. The low baseline muscle strength levels in the OA leg of OKG subjects, which is generally a consequence of disuse due to OA pain,[23] may explain the greater muscle strength increase in the OA leg found in the present study.

Although muscle weakness is of particular concern after TKA, and interventions to improve muscle strength in subjects with TKA are recommended,[3] there are few studies analyzing the effects of resistance training in this population.[9,10,24] Most studies have assessed TKA outpatients who initiated rehabilitation soon after discharge from the hospital,[9,24] and the greater muscle and mobility impairments in the early postoperative phase makes comparison with the present results unreasonable. The only study analyzing the effects of resistance training in subjects at least one year after TKA compared the effects of an eccentric versus traditional (concentric/eccentric) resistance training program in subjects with TKA (one to four years after surgery) and found an approximate 12.7% increase in isometric muscle strength after 12 weeks of eccentric resistance training. No significant differences were observed after traditional resistance training.[10] The inclusion of subjects with unilateral and bilateral TKA, the use of bilateral exercises and the methodology used to analyze muscle strength are possible explanations for the lower muscle strength increase observed in the previous study compared with the increases observed here.

Another important finding of the present study was that resistance exercise intensity progression was greater in OKG subjects than in OG and YG subjects. Resistance exercise recommendations for both younger and older people include 1–3 sets of 8–12 repetitions of 8–10 exercises, 2–3 days/week.[6,22] However, it has been generally suggested that resistance exercise intensity should have a slower and decreased rate of progression in older adults than in younger adults, mainly in older adults with physical limitations.[6,22] Previous studies from our group do not support this recommendation, showing that healthy older subjects who were previously sedentary are able to increase resistance exercise intensity in the same way as younger subjects when the same resistance training program is performed.[7,8] Moreover, we have shown that older men who are trained aerobically are able to increase resistance exercise intensity even more than sedentary young men.[7] The present study confirms the ability of healthy older women to safely increase resistance exercise intensity in the same manner as younger women and further suggests that older women with knee OA and TKA can safely increase resistance exercise intensity more than both older and younger women without musculoskeletal limitations. It is important to note that no injuries, muscle damage or major muscle or joint pain were observed in the OKG subjects.

Because muscle strength may play an important protective role in the progression of knee OA,[16,18] and muscle weakness is strongly associated with the physical function of both knee OA and TKA individuals,[3,25,26] the training-induced muscle strength increases observed in the OKG subjects may have important prognostic implications for older women with knee OA and TKA. Future investigations addressing knee OA progression and physical functioning in this population are necessary.

The statistical power of the present study is adequate for the outcome being evaluated (muscle strength increase); however, caution must be taken in generalizing the present results. The small number of women studied may not represent the greater population of patients with knee OA and TKA. Although we demonstrated the short-term efficacy and safety of a resistance training program in improving the muscle strength of patients with knee OA and TKA, future larger studies with a control group and long-term follow-up, focused on analyzing end-points such as radiographic evaluation of disease progression or a second TKA, would offer additional compelling evidence for the validity of the present findings.

In summary, OKG subjects displayed a greater muscle strength increase and resistance exercise intensity progression than OG and YG subjects. The exercise intensity and criteria adopted for workload progression did not promote any injury, muscle damage or major muscle or joint pain in our study population. These results suggest that resistance training is an effective method to counteract the lower-extremity strength deficits reported in older women with knee OA and TKA.

AUTHOR CONTRIBUTIONS

EG Ciolac participated in the study design, data collection and analysis, and manuscript preparation. JMD Greve participated in the study design and manuscript preparation.

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