Arthritis Care & Research
Vol. 74, No. 1, January 2022, pp 70–78
DOI 10.1002/acr.24736

AMERICAN COLLEGE of RHEUMATOLOGY
Empowering Rheumatology Professionals

REHABILITATION SCIENCES AND THE RHEUMATIC DISEASES

Muscle Strength and Osteoarthritis Progression After Surgery or Exercise for Degenerative Meniscal Tears: Secondary Analyses of a Randomized Trial

Bjørnar Berg,[1] Ewa M. Roos,[2] Nina Jullum Kise,[3] Lars Engebretsen,[4] Inger Holm,[1] and May Arna Risberg[5]

Objective. To evaluate muscle strength changes following partial meniscectomy or exercise therapy for degenerative meniscal tears and the relationship between baseline muscle strength and osteoarthritis progression.

Methods. Secondary analysis of a randomized trial (n = 140 participants). Isokinetic quadriceps and hamstrings strength (peak torque [Nm/kg] and total work [J/kg]) were assessed at baseline, 3-month, 12-month, and 5-year follow-up. Between-group differences were analyzed using intent-to-treat linear mixed models. The relationship between baseline muscle strength and osteoarthritis progression (Kellgren/Lawrence ≥1 grade increase) were assessed using logistic regression models.

Results. We found statistically significant between-group differences favoring exercise therapy at 3 months (quadriceps –0.30 Nm/kg [95% confidence interval (95% CI) –0.40, –0.20]; hamstrings –0.10 Nm/kg [95% CI –0.15, –0.04]) and 12 months (quadriceps –0.13 Nm/kg [95% CI –0.23, –0.03]; hamstrings –0.08 Nm/kg [95% CI –0.14, –0.03]). At 5 years, between-group differences were –0.10 Nm/kg (95% CI –0.21, 0.01) for quadriceps and –0.07 Nm/kg (95% CI –0.13, –0.01) for hamstrings. Quadriceps muscle weakness at baseline was associated with knee osteoarthritis progression over 5 years, with adjusted odds ratio of 1.40 for every 0.2 Nm/kg decrease (95% CI 1.15, 1.71). The adjusted odds ratio for hamstrings was 1.14 (95% CI 0.97, 1.35) for every 0.1 Nm/kg decrease.

Conclusion. Exercise therapy was effective in improving muscle strength at 3- and 12-month follow-up compared to partial meniscectomy, but the effect was attenuated at 5 years. Quadriceps muscle weakness at baseline was associated with higher odds of osteoarthritis progression over 5 years.

INTRODUCTION

Knee muscle weakness is a typical feature of patients with symptomatic degenerative meniscal tears (1,2). Lower-extremity disuse and arthrogenic muscle inhibition are possible contributing factors (3,4). Following arthroscopic partial meniscectomy, surgery-induced trauma and postsurgery disuse may further augment muscular dysfunctions and prolong muscle weaknesses (1,3). A 2015 meta-analysis showed that partial meniscectomy patients had a moderate reduction in knee extensor muscle strength before surgery, at 6 months, and at 6 years postsurgery (1).

Muscle strengthening is suggested as one of the mechanisms underlying the beneficial effect of exercise therapy in knee osteoarthritis, with studies reporting a direct longitudinal association between increased knee muscle strength and reductions in activity limitations and pain (5,6). For degenerative meniscal tear patients, a 12-week exercise therapy program consisting of progressive neuromuscular and strengthening exercises significantly improved knee muscle strength (7). However, the course of

ClinicalTrials.gov identifier: NCT01002794.

Supported by the South-Eastern Norway Regional Health Authority (grant 2018023). The Odense-Oslo Meniscectomy versus Exercise trial was funded by Sophies Minde Ortopedi, the Swedish Rheumatism Association, the Swedish Research Council, the Region of Southern Denmark, the Danish Rheumatism Association, and the South-Eastern Norway Regional Health Authority. Mr. Berg's work was supported by the South-Eastern Norway Regional Health Authority.

[1]Bjørnar Berg, PT, MSc, Inger Holm, PT, PhD: Oslo University Hospital and University of Oslo, Oslo, Norway; [2]Ewa M. Roos, PT, PhD: University of Southern Denmark, Odense, Denmark; [3]Nina Jullum Kise, MD, PhD: Martina Hansens Hospital, Sandvika, Norway; [4]Lars Engebretsen, MD, PhD: Oslo University Hospital and Norwegian School of Sport Sciences, Oslo, Norway, and International Olympic Committee, Lausanne, Switzerland; [5]May Arna Risberg, PT, PhD: Oslo University Hospital and Norwegian School of Sport Sciences, Oslo, Norway.

Author disclosures are available at https://onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1002%2Facr.24736&file=acr24736-sup-0001-Disclosureform.pdf.

Address correspondence to Bjørnar Berg, PT, MSc, Division of Orthopedic Surgery, Oslo University Hospital, Post Box 4956 Nydalen, 0424 Oslo, Norway. Email: bergbj@ous-hf.no.

Submitted for publication February 25, 2021; accepted in revised form June 17, 2021.

SIGNIFICANCE & INNOVATIONS

- Twelve weeks of exercise therapy is effective in improving knee muscle strength up to 12 months compared to partial meniscectomy in middle-aged individuals with degenerative meniscal tears.
- Quadriceps muscle weakness at baseline is a risk factor for radiographic knee osteoarthritis progression over 5 years.
- Our results highlight the fact that early interventions targeting knee muscle strength should be recommended for degenerative meniscal tear patients, and the results support the ongoing shift in treatment strategy for this patient population, recommending exercise therapy over surgery.

knee muscle strength changes during the 5 years following arthroscopic partial meniscectomy or exercise therapy as treatments for degenerative meniscal tears remains unknown.

Knee muscle weakness may be an independent risk factor for radiographic knee osteoarthritis development or progression to more severe osteoarthritis changes in the general (8,9) and degenerative meniscus population (10,11). Identifying and targeting single pathways to osteoarthritis in early disease stages is likely more effective than when the disease has progressed and become more complex (12). Degenerative meniscal tears are part of the osteoarthritic process and a precursor to radiographic knee osteoarthritis (13). Subsequent radiographic changes, such as osteophyte formation and joint space narrowing, represent more significant joint damage. The presence and progression of these radiographic features are potentially clinically relevant, for both increased pain and the risk of incident disease (14,15). Ascertaining muscle strength as a potential risk factor has at least 2 important clinical implications: 1) to facilitate the shift toward a proactive treatment approach that allows for a greater chance to prevent or slow osteoarthritis progression (12,16); and 2) to support the ongoing shift in treatment strategy for degenerative meniscal tears recommending exercise therapy over surgical treatment (17).

In the Odense-Oslo Meniscectomy versus Exercise (OMEX) trial, arthroscopic partial meniscectomy was compared to exercise therapy for degenerative meniscal tears. Between-group differences in knee muscle strength changes have been previously reported at 3- and 12-month follow-up (18). However, no longitudinal analysis including muscle strength assessment at 5 years has been performed. Furthermore, the influence of muscle strength on osteoarthritis progression was not ascertained earlier in our trial. We also extend existing knowledge by reporting body weight–normalized muscle strength, within-group changes, and absolute knee muscle strength for the involved and uninvolved leg, and the proportions of patients with clinically relevant improvements in the 2 treatment groups.

Accordingly, the aim of this 5-year follow-up study of the randomized controlled OMEX trial was to evaluate normalized knee muscle strength and longitudinal changes following arthroscopic partial meniscectomy and exercise therapy as treatments for degenerative meniscal tears. We also examined the association between baseline knee muscle strength and osteoarthritis progression over 5 years.

PATIENTS AND METHODS

Study design and participants. We conducted a randomized controlled trial involving participants ages 35–60 years with nontraumatic unilateral knee pain (>2 months), recruited from 2 orthopedic departments in Norway (October 2009 to September 2012). All participants had a degenerative medial meniscal tear verified by magnetic resonance imaging (MRI) and a Kellgren/Lawrence grade ≤2 and were considered eligible for surgery by 1 of 2 orthopedic surgeons based on patient history, physical examination, and MRI findings.

The sample size was calculated based on detecting a 10-point difference with an SD of 15 in the change in a composite score of 4 of 5 Knee injury and Osteoarthritis Outcome Score (KOOS) subscales ($KOOS_4$) at the primary endpoint (2-year follow-up) (18). Accounting for an estimated dropout rate of 15% and a 20% crossover rate, 140 participants were randomized (1:1 ratio). No a priori power calculations were performed for this 5-year follow-up study. An independent statistician determined the computer-generated randomization sequence, stratified by sex in blocs of 8, and concealed the allocations in sequentially numbered opaque envelopes. The test assessors were blinded to group allocation at baseline, 3 months, and 12 months. To preserve blinding, the participants wore long pants or neoprene sleeves. The trial was conducted according to the Declaration of Helsinki. The ethics committee of the Health Region of South-East Norway approved the trial (ref-no 2009/230). All participants gave written informed consent.

Deviations from trial registration. Muscle strength tests were registered at 3 and 24 months. Due to financial and logistic constraints, isokinetic muscle strength tests were conducted at 12 months instead of 24 months. Additionally, we included muscle strength tests at the 5-year follow-up because muscle weakness has been shown to persist for up to 4 years after partial meniscectomy (1).

Interventions. The 12-week exercise therapy program consisted of progressive neuromuscular and strengthening exercises. Experienced physical therapists at the Norwegian Sports Medicine Clinic or Gnist Trening og Helse AS followed a standardized protocol (19). The participants performed 2 to 3 sessions per week, and physical therapists supervised 1 of the weekly sessions.

Experienced surgeons performed the arthroscopic partial meniscectomy using anteromedial and anterolateral portals. A diagnostic procedure, including systematic probing of both menisci, was followed by resection of all unstable meniscal tissue. Pre- or postoperative physical therapy was not part of the intervention, but the participants were given instructions for simple home exercises to regain range of motion and reduce swelling. Both interventions have been previously described in detail (18,19).

Outcomes. *Isokinetic muscle strength testing.* Quadriceps and hamstrings muscle strength was assessed using an isokinetic dynamometer (Biodex 6000) at baseline, 3 months, 12 months, and 5 years. Both legs were tested, and the testing order was determined by randomization. The same order was applied at all follow-ups. Trained assessors followed a detailed protocol to test concentric knee extension and flexion at 60°/second in the range from 90° flexion to full extension. Visual inspection and manual palpation were used to align the anatomical axis of rotation to the dynamometer axis. Baseline chair settings were recorded to duplicate the testing position at the subsequent follow-ups. Following a 10-minute warm-up on a stationary bike, the participants were placed in an upright seated position with shoulder and abdominal straps to minimize body movements. The participants performed 4 trial repetitions, followed by 1-minute rest and 5 maximal test repetitions. We used body weight normalized peak torque (Newton meters [Nm], Nm/kg) and total work (Joules [J], J/kg) in the data analyses. Peak torque represents the highest muscular force output at any moment during the test bout, and total work represents the amount of work accomplished during the 5 maximal repetitions (20). The reliability of isokinetic knee muscle testing is high (21–23). Based on the results from the test–retest studies, we defined participants as responders for normalized quadriceps and hamstrings strength at each follow-up if a change from baseline of at least 15% for quadriceps and at least 20% for hamstrings was

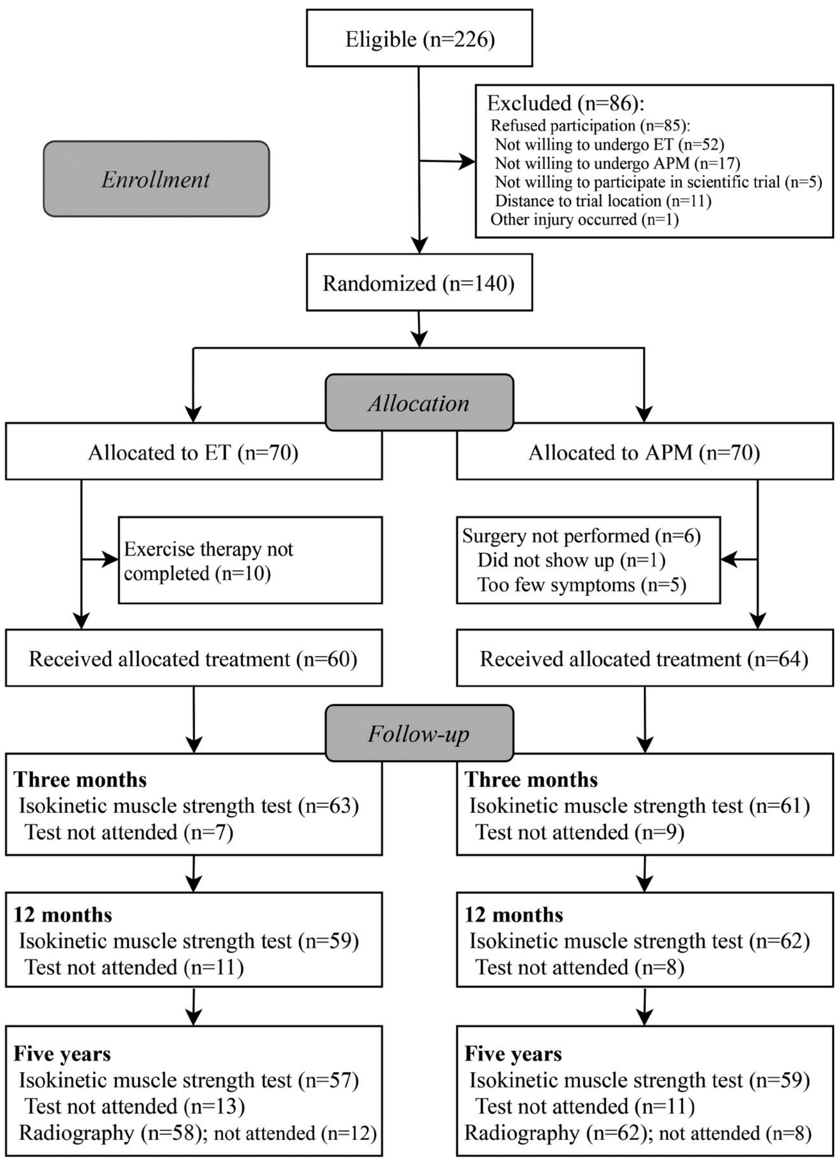

Figure 1. Study flow chart. APM = arthroscopic partial meniscectomy; ET = exercise therapy.

detected. A change of 15% for quadriceps strength has previously been used as a clinically important cutoff for knee osteoarthritis patients (24).

Knee osteoarthritis progression. Radiographs were acquired at baseline (recruiting hospitals) and 5 years (private radiology clinic) using a standardized protocol (25). The protocol included posteroanterior radiographs, 10° caudal x-ray beam angulation, and the use of a Synaflexer (Synarc) positioning frame (26). Two experienced radiographic readers, blinded to clinical data, graded all radiographs according to the Kellgren/Lawrence classification (0–4, normal to severe) (27). The radiographs were reread in cases of between-reader discrepancy and discussed until consensus was reached. Interrater reliability for the 2 readers has been previously evaluated for the Kellgren/Lawrence classification (weighted κ = 0.67) (28). We defined osteoarthritis progression as an increase of ≥1 grade from baseline to 5 years (dichotomous outcome: yes or no). Participants undergoing an osteotomy or total knee replacement were also considered to have progressed radiographically.

Patient involvement. There was no patient involvement in the planning or conduct of the study, but user involvement was included in implementation of the exercise therapy program. User experiences and results from the OMEX trial are disseminated to clinicians and patients through AktivA, a nationally implemented osteoarthritis treatment program (29).

Statistical analysis. The primary analyses of knee muscle strength changes were performed on an intent-to-treat basis. We used linear mixed models to analyze between-group differences in change from baseline to each follow-up. The outcomes were normalized quadriceps and hamstrings muscle strength (peak torque and total work) at 3 and 12 months and 5 years. The models were adjusted for sex (randomization stratification variable) and baseline value of the outcome. Participants were included as random effect with random intercept and slopes, and time point (baseline, 3 months, 12 months, and 5 years), time × treatment interaction, and sex as fixed effects. One outcome variable (hamstrings total work) was modeled with random intercept due to convergence difficulties. To adjust for baseline differences, we did not include a main effect for the treatment group in the model (30). From the fitted models, we present estimated mean change values and 95% confidence intervals (95% CIs) at each follow-up for both treatment groups and between-group differences in change from baseline. We also report absolute knee muscle strength in the involved and uninvolved leg at each time point for the 2 treatment groups.

Proportions in the 2 treatment groups with improvements >15% for quadriceps and >20% for hamstrings (responders) were compared at each follow-up using the chi-square test. For these analyses, participants with incomplete outcome data were excluded from the actual time point with missing data.

For our secondary aim, normalized quadriceps and hamstrings muscle strength (Nm/kg) at baseline were the exposures, and osteoarthritis progression (Kellgren/Lawrence increase of ≥1 grade) over 5 years was the outcome. A complete-case analysis was applied, excluding participants with missing outcome data at the 5-year follow-up (n = 20). We pooled data from both treatment groups because preliminary analyses showed no significant treatment × quadriceps interaction or treatment × hamstrings interaction. Separate logistic regression analyses were conducted for quadriceps and hamstrings peak torque to avoid multicollinearity. Models were adjusted for sex, baseline Kellgren/Lawrence grade, and the baseline pain subscale of the KOOS (31). Model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test. Continuous variables were linearly related to the logit of the dependent variable (assessed using the Box-Tidwell approach). There were no standardized residuals with a value of ±2 SDs. Analyses were performed using Stata software, version 16.1.

RESULTS

All 140 participants were included in the primary analyses (Figure 1). In the exercise group, 10 participants declined exercise therapy. Four of these participants and 10 participants who participated in the exercise therapy program crossed over to receive partial meniscectomy. Six participants in the partial meniscectomy

Table 1. Baseline characteristics of participants randomized to exercise therapy (ET) or arthroscopic partial meniscectomy (APM)*

Characteristic	ET group (n = 70)	APM group (n = 70)
Men, no. (%)	43 (61)	43 (61)
Age, years	50.2 ± 6.4	48.9 ± 6.3
Body mass index, kg/m^2	26.5 ± 4.3	26.0 ± 3.7
Pain duration, median [IQR] months	9.5 [13.6]	6.0 [7.0]†
Kellgren/Lawrence grade, no. (%)		
0	49 (70.0)	48 (68.6)
1	20 (28.6)	19 (27.1)
2	1 (1.4)	3 (4.3)
Quadriceps peak torque, Nm/kg		
Involved leg	1.95 ± 0.57	2.03 ± 0.59
Uninvolved leg	2.22 ± 0.51	2.27 ± 0.51
Quadriceps total work, J/kg		
Involved leg	9.57 ± 2.83	9.85 ± 2.91
Uninvolved leg	10.63 ± 2.44	10.89 ± 2.40
Hamstrings peak torque, Nm/kg		
Involved leg	1.02 ± 0.32	1.10 ± 0.29
Uninvolved leg	1.07 ± 0.28	1.11 ± 0.28
Hamstrings total work, J/kg		
Involved leg	5.50 ± 2.06	6.15 ± 1.9
Uninvolved leg	5.84 ± 1.81	6.22 ± 1.67

* Values are the mean ± SD unless otherwise stated. IQR = interquartile range; Nm/kg = Newton meter/kilogram; J/kg = Joule/kilogram.
† Missing data from 1 participant.

Table 2. Estimated change from baseline to follow-up and between-group differences in knee muscle strength for the exercise therapy (ET) and arthroscopic partial meniscectomy (APM) group*

	3 months' difference			12 months' difference			5 years' difference		
	ET (n = 63)	APM (n = 61)	Δ	ET (n = 59)	APM (n = 62)	Δ	ET (n = 57)	APM (n = 59)	Δ
Quadriceps									
Peak torque	0.26	–0.04	–0.30	0.24	0.12	–0.13	0.13	0.03	–0.10
95% CI	0.19, 0.34	–0.11, 0.04	–0.40, –0.20	0.17, 0.32	0.04, 0.19	–0.23, –0.03	0.05, 0.20	–0.05, 0.10	–0.21, 0.01
Total work	1.04†	–0.35	–1.39	1.11	0.36	–0.74	0.48	0.15	–0.34
95% CI	0.68, 1.40	–0.70, 0.01	–1.89, -0.88	0.74, 1.47	0.01, 0.72	–1.25, –0.24	0.11, 0.86	–0.22, 0.51	–0.86, 0.18
Hamstrings									
Peak torque	0.16	0.06	–0.10	0.14	0.06	–0.08	0.04	–0.02	–0.07
95% CI	0.12, 0.20	0.02, 0.11	–0.15, –0.04	0.10, 0.19	0.02, 0.10	–0.14, –0.03	0.00, 0.09	–0.07, 0.02	–0.13, –0.01
Total work	1.00†	0.30	–0.70	0.86	0.33	–0.54	0.30	–0.20	0.50
95% CI	0.73, 1.27	0.03, 0.57	–1.08, –0.32	0.59, 1.14	0.06, 0.60	–0.92, –0.15	0.02, 0.58	–0.47, 0.08	–0.89, –0.11

* Values are the mean with the 95% confidence interval (95% CI). APM group is the reference. Δ = between-group difference in change; peak torque = Newton meter/kilogram; total work = Joule/kilogram.
† n = 62.

group did not undergo surgery. One participant who crossed over from the exercise group and 1 participant in the partial meniscectomy group received a high tibial osteotomy 4–6 months after the index partial meniscectomy. Three participants in the partial meniscectomy group underwent another partial meniscectomy at 12, 15, and 36 months after the index partial meniscectomy. One participant in the partial meniscectomy group received a total knee replacement 34 months after the index partial meniscectomy. Table 1 gives patient characteristics at baseline for the participants in the 2 treatment groups.

Knee muscle strength change. Table 2 shows estimated change in normalized quadriceps and hamstrings strength at 3 and 12 months and 5 years. Changes in normalized quadriceps and hamstrings peak torque are also shown in Figure 2. At 3 months, we found statistically significant between-group differences for change in normalized quadriceps (–0.30 Nm/kg [95% CI –0.40, –0.20]) and hamstrings peak torque (–0.10 Nm/kg [95% CI –0.15, –0.04]) favoring the exercise group (Table 2). A total of 44% of the exercise group participants were classified as responders for normalized quadriceps peak torque (≥15% change from baseline) compared to 16% in the partial meniscectomy group ($P \leq 0.001$ for between-group difference). The proportion of responders for normalized hamstrings peak torque (≥20% change from baseline) was 35% in the exercise group and 18% in the partial meniscectomy group ($P = 0.033$) (see Supplementary Table 1, available on the *Arthritis Care & Research* website at http://onlinelibrary.wiley.com/doi/10.1002/acr.24736/abstract).

At 12 months, the exercise group had maintained the improvements that were achieved at 3 months. Between-group differences at 12 months were statistically significant in favor of the exercise group for changes in normalized quadriceps (–0.13 Nm/kg [95% CI –0.23, –0.03]) and hamstrings peak torque (–0.08 Nm/kg [95% CI –0.14 to –0.03]) (Table 2). In the exercise group, 42% and 34% of the participants were responders for normalized quadriceps and hamstrings peak torque, respectively. The corresponding numbers for the partial meniscectomy group were 26% and 19% (P for between-group difference 0.054 [quadriceps] and 0.070 [hamstrings]) (see Supplementary Table 1, available on the *Arthritis Care & Research* website at http://onlinelibrary.wiley.com/doi/10.1002/acr.24736/abstract).

At 5 years, we found a statistically significant between-group difference for change in normalized hamstrings peak torque in favor of the exercise group, but the difference was small (–0.07 Nm/kg [95% CI –0.13, –0.01]). We found no statistically significant between-group difference for normalized quadriceps peak torque (–0.10 Nm/kg [95% CI –0.21, 0.01]) (Table 2). Muscle strength declined in both groups from 12 months to 5 years. However, normalized quadriceps strength at 5 years was higher compared to baseline in the exercise group (0.13 Nm/kg [95% CI 0.05, 0.20]) and equal in the partial meniscectomy group (0.03 Nm/kg [95% CI –0.05, 0.10]). For normalized hamstrings strength, differences were small compared to baseline; a slight improvement in the exercise group (0.04 Nm/kg [95% CI 0.00, 0.09]) and no difference for the partial meniscectomy group (Nm/kg –0.02 [95% CI –0.07, 0.02]). In all, 28% in the exercise group and 20% in the partial meniscectomy group were responders for normalized quadriceps peak torque ($P = 0.331$). The proportion of responders for normalized hamstrings peak torque was 23% (exercise group) and 10% (partial meniscectomy group) ($P = 0.066$) (see Supplementary Table 1, available on the *Arthritis Care & Research* website at http://onlinelibrary.wiley.com/doi/10.1002/acr.24736/abstract). Absolute knee muscle strength for the involved and uninvolved leg at all follow-ups is shown in Supplementary Table 2, available at http://onlinelibrary.wiley.com/doi/10.1002/acr.24736/abstract.

Association between baseline knee muscle strength and radiographic progression. Of 120 participants, 65 (54%) were defined as having progressed radiographically: 31 in the exercise group and 34 in the

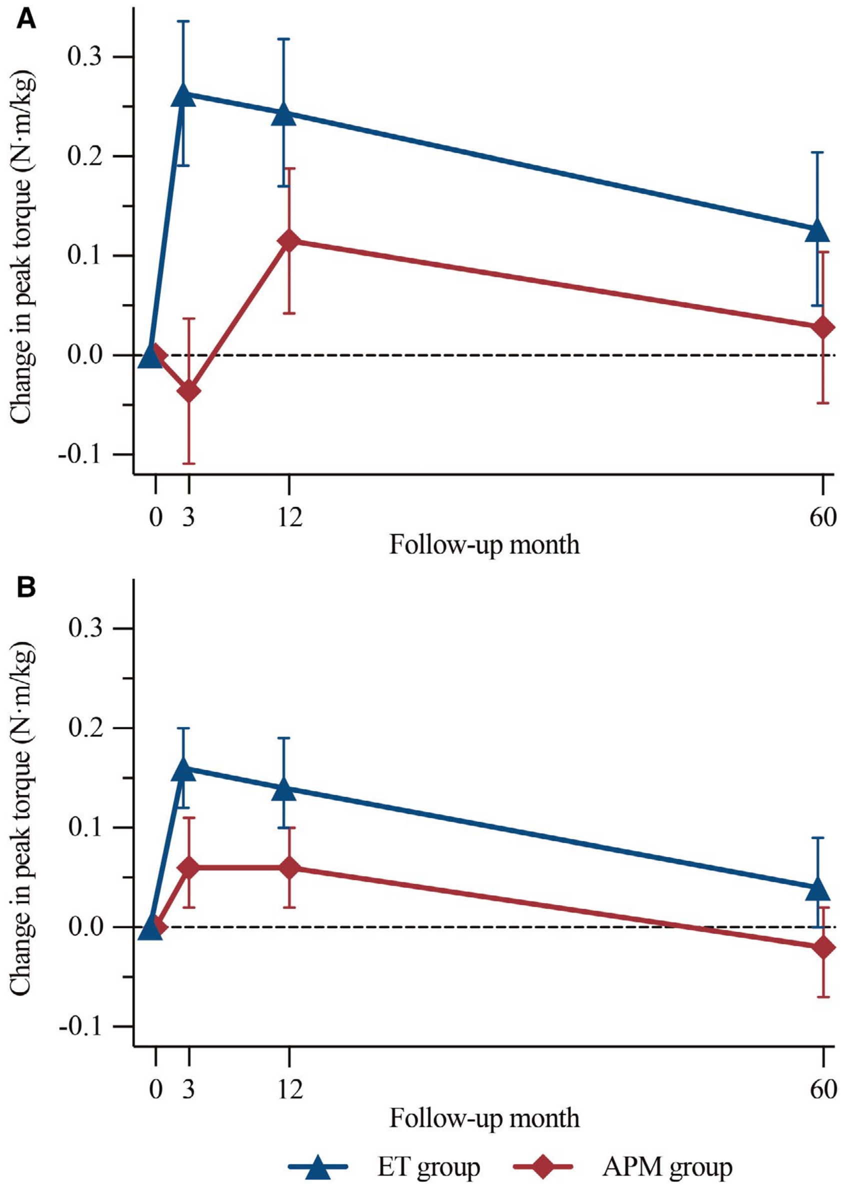

Figure 2. **A**, Change in normalized quadriceps peak torque; **B**, Change in normalized hamstrings peak torque (involved leg) for the exercise therapy (ET) and arthroscopic partial meniscectomy (APM) groups. Whiskers indicate 95% confidence intervals. The broken line indicates no change from baseline.

partial meniscectomy group. Overall, the proportion of women was higher in the progression group (43%) compared to the nonprogression group (33%). Participants with progression also had slightly higher body mass index and more knee pain at baseline (see Supplementary Table 3, available on the *Arthritis Care & Research* website at http://onlinelibrary.wiley.com/doi/10.1002/acr.24736/abstract). We found that quadriceps muscle weakness at baseline was significantly associated with increased odds of radiographic progression. In the crude model adjusted only for sex, the odds of radiographic progression increased by 33% for every 0.2 Nm/kg decrease in quadriceps strength (odds ratio [OR] 1.33 [95% CI 1.13, 1.58]). In the model adjusted for sex, knee pain, and Kellgren/Lawrence grade at baseline, the odds increased by 40% for every 0.2 Nm/kg decrease in quadriceps strength (OR 1.40 [95% CI 1.15, 1.71]). The crude and adjusted ORs for every 0.1 Nm/kg decrease in hamstrings strength were 1.14 (95% CI 0.99, 1.32) and 1.14 (95% CI 0.97, 1.35), respectively (Table 3). The goodness-of-fit test for crude and adjusted models for quadriceps and hamstrings showed that the models were adequate ($P > 0.05$).

DISCUSSION

Twelve weeks of twice-weekly exercise therapy effectively improved quadriceps and hamstrings muscle strength in

Table 3. Association between baseline knee muscle strength (Nm/kg) and radiographic knee osteoarthritis progression over 5 years*

	Knee osteoarthritis progression		
	Progressors (n = 65)	Nonprogressors (n = 55)	*P*
Quadriceps strength (0.2 Nm/kg decrease)			
Crude odds ratio†	1.33 (1.13, 1.58)	1.0 (ref.)	0.001
Adjusted odds ratio‡	1.40 (1.15, 1.71)	1.0 (ref.)	0.001
Hamstrings strength (0.1 Nm/kg decrease)			
Crude odds ratio†	1.14 (0.99, 1.32)	1.0 (ref.)	0.073
Adjusted odds ratio‡	1.14 (0.97, 1.35)	1.0 (ref.)	0.115

* Values are the odds ratio (95% confidence interval) unless indicated otherwise. Ref. = reference.
† Model adjusted for sex.
‡ Model adjusted for sex, baseline Kellgren/Lawrence grade, and baseline Knee Injury and Osteoarthritis Outcome Score pain subscale score.

degenerative meniscal tear patients compared to arthroscopic partial meniscectomy alone up to 12 months. While participants in the exercise group still had greater quadriceps strength at 5 years compared to baseline, there was no longer any statistically significant between-treatment group difference. We also found that for middle-aged individuals with degenerative meniscal tears and without radiographic osteoarthritis, lower quadriceps strength at baseline increased the odds of radiographic osteoarthritis progression over 5 years by 40% (for every 0.2 Nm/kg decrease).

Consistent with a previous investigation (2), muscle strength at baseline in the 2 treatment groups was 11–14% lower for quadriceps compared to the contralateral leg and 1–7% lower for hamstrings. Interestingly, muscle strength in the involved leg at baseline (Table 1) was equivalent to normative age-matched data for quadriceps peak torque (1.98 Nm/kg) but lower for hamstrings peak torque (1.17 Nm/kg) (32).

At 3 months, we found between-group differences of 15% for change in normalized quadriceps peak torque and 10% for normalized hamstrings peak torque. Following a slight decline in normalized quadriceps strength at 3 months, improvements were also seen for the partial meniscectomy group at 12 months, but between-group differences were still statistically significant. A previous investigation found no bilateral differences in quadriceps strength 12 months postoperatively (2). However, our partial meniscectomy group's affected leg was 6% weaker than the uninvolved leg at 12 months, and only 1 in 4 participants was defined as a responder (cutoff of 15% change).

Muscle strength declined from 12 months to 5 years in both treatment groups. This finding is expected because the mean age at inclusion was 50 years; the threshold when age-related declines in strength generally commence (33). We also saw a similar decline in the uninvolved leg, which corroborates the decline as age-related. Still, 5-year absolute muscle strength was 4–6% higher than baseline for the exercise group and between 1% higher to 3% lower for the partial meniscectomy group. Although this finding may partly be explained by disuse before study inclusion, our OMEX trial included highly physically active individuals; ~8 in 10 participated in sport or exercise activities ≥150 minutes/week before their knee problems (34). Moderate-to-vigorous physical activity is beneficially associated with lower-extremity muscle strength (35). In a previous study that also included individuals reporting a high physical activity level before diagnosis, no difference in muscle strength compared to healthy controls was found 2 years after partial meniscectomy or in changes from 2 to 4 years (36,37). In contrast, in persons not participating in any sporting activities, 24% lower quadriceps strength than matched controls has been found 4 years postsurgery (38). This finding may indicate that in physically inactive persons with potentially less spare muscle capacity at diagnosis, surgery and the extended period of inactivity could have more detrimental effects on muscle strength that are difficult to restore without a structured intervention program focusing on knee muscle strength.

Knee muscle weakness alters the mechanical environment and may affect cartilage integrity negatively (39). Our results support this idea and indicate that quadriceps muscle strength is important for the risk of progression to more severe osteoarthritis changes in middle-aged individuals with degenerative meniscal tears. A recent small study found that lower knee muscle strength 4 years after partial meniscectomy was associated with more severe osteoarthritis changes 11 years later (11). Our larger study complements these findings by identifying baseline muscle weakness as a risk factor for progression to more severe osteoarthritis changes 5 years later. Identification of a modifiable pathway to osteoarthritis in this patient population known to already be at increased risk for disease development indicates that early interventions addressing knee muscle strength should be recommended for all individuals with degenerative meniscus.

The mean difference in normalized quadriceps peak torque at baseline between participants with and without radiographic progression was almost 0.4 Nm/kg. For men and women, respectively, the deficit was 15% and 22% compared to those without progression. The adjusted OR for every 0.2 Nm/kg decrease was 1.40 (95% CI 1.15, 1.71); the odds of radiographic progression increased by 40%. While we found improvements in the current study in quadriceps strength following 12 weeks of exercise therapy of >0.2 Nm/kg, participants with radiographic progression over 5 years were well balanced concerning treatment received (48% from the exercise group). Thus, participants in the exercise group with osteoarthritis progression probably did not achieve adequate quadriceps strength following the intervention to fully eliminate quadriceps muscle weakness as a risk factor for progression. For instance, progressors in the exercise group had a mean deficit of ~10% at 3 months compared to the uninvolved leg. In comparison, nonprogressors had equal quadriceps strength in the affected and uninvolved leg at the same time point. To achieve positive effects on muscle strength, adherence to exercise is essential. Clinicians are important facilitators to promote adherence through individually tailored exercises, patient education, and patient involvement (40).

The current study has limitations. No power calculations were performed a priori for this 5-year follow-up study. However, for between-group differences in knee muscle strength changes at 5 years, the CIs of the effect estimates do not include our predefined threshold for clinically relevant improvement, indicating that our results are conclusive (41). We evaluated peak torque and total work, but other parameters such as angle-specific torque may provide additional information in individuals with degenerative meniscus (42). Six participants in each group did not receive any treatment, and 14 (20%) crossed over from exercise to partial meniscectomy. However, we believe this result reflects clinical practice. We included middle-aged physically active individuals, and the results are not generalizable to older, less physically active individuals with concomitant osteoarthritis. Finally, the sample size prevented us from stratifying osteoarthritis progression analyses by sex.

In conclusion, 12 weeks of exercise therapy was effective in improving quadriceps and hamstrings muscle strength compared to arthroscopic partial meniscectomy for middle-aged patients with degenerative meniscal tears. We found statistically significant differences in change from baseline to 3 and 12 months in favor of the exercise group. At 5 years, between-group differences were attenuated and no longer statistically significant for quadriceps strength. We also found evidence to suggest that lower quadriceps strength at baseline is associated with radiographic knee osteoarthritis progression over 5 years.

ACKNOWLEDGMENTS

We thank Cathrine Nørstad Eftang, Akershus University Hospital, for reading and scoring the radiographs. We also thank Cathrine Brunborg at the Oslo Centre for Biostatistics and Epidemiology for statistical advice. Further, we thank research coordinator Kristin Bolstad for her role in the organization of the participants and assistance in the data collection, Silje Stensrud, a former PhD student in the OMEX trial, and physical therapists Marte Lund, Karin Rydevik, and Christian Vilming for assistance in the data collection. Finally, we thank the Norwegian Sports Medicine Clinic for contributing with rehabilitation facilities and research staff, the Division of Orthopedic Surgery, Oslo University Hospital, and the Department of Orthopedic Surgery, Martina Hansens Hospital, for providing access to the outpatient clinics and surgical teams and facilities.

AUTHOR CONTRIBUTIONS

All authors were involved in drafting the article or revising it critically for important intellectual content, and all authors approved the final version to be submitted for publication. Mr. Berg had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study conception and design. Berg, Roos, Holm, Risberg.
Acquisition of data. Berg, Roos, Kise, Engebretsen, Holm, Risberg.
Analysis and interpretation of data. Kise, Engebretsen, Risberg.

REFERENCES

1. Hall M, Juhl CB, Lund H, Thorlund JB. Knee extensor muscle strength in middle-aged and older individuals undergoing arthroscopic partial meniscectomy: a systematic review and meta-analysis. Arthritis Care Res (Hoboken) 2015;67:1289–96.
2. Ganderup T, Jensen C, Holsgaard-Larsen A, Thorlund JB. Recovery of lower extremity muscle strength and functional performance in middle-aged patients undergoing arthroscopic partial meniscectomy. Knee Surg Sports Traumatol Arthrosc 2017;25:347–54.
3. Akima H, Hioki M, Furukawa T. Effect of arthroscopic partial meniscectomy on the function of quadriceps femoris. Knee Surg Sports Traumatol Arthrosc 2008;16:1017–25.
4. Rice DA, McNair PJ. Quadriceps arthrogenic muscle inhibition: neural mechanisms and treatment perspectives. Semin Arthritis Rheum 2010;40:250–66.
5. Hall M, Hinman RS, van der Esch M, van der Leeden M, Kasza J, Wrigley TV, et al. Is the relationship between increased knee muscle strength and improved physical function following exercise dependent on baseline physical function status? Arthritis Res Ther 2017;19:271.
6. Knoop J, Steultjens MP, Roorda LD, Lems WF, van der Esch M, Thorstensson CA, et al. Improvement in upper leg muscle strength underlies beneficial effects of exercise therapy in knee osteoarthritis: secondary analysis from a randomised controlled trial. Physiotherapy 2015;101:171–7.
7. Stensrud S, Risberg MA, Roos EM. Effect of exercise therapy compared with arthroscopic surgery on knee muscle strength and functional performance in middle-aged patients with degenerative meniscus tears: a 3-mo follow-up of a randomized controlled trial. Am J Phys Med Rehabil 2015;94:460–73.
8. Oiestad BE, Juhl CB, Eitzen I, Thorlund JB. Knee extensor muscle weakness is a risk factor for development of knee osteoarthritis: a systematic review and meta-analysis. Osteoarthritis Cartilage 2015;23:171–7.
9. Segal NA, Glass NA, Torner J, Yang M, Felson DT, Sharma L, et al. Quadriceps weakness predicts risk for knee joint space narrowing in women in the MOST cohort. Osteoarthritis Cartilage 2010;18:769–75.
10. Thorlund JB, Felson DT, Segal NA, Nevitt MC, Niu J, Neogi T, et al. Effect of knee extensor strength on incident radiographic and symptomatic knee osteoarthritis in individuals with meniscal pathology: data from the Multicenter Osteoarthritis Study. Arthritis Care Res (Hoboken) 2016;68:1640–6.
11. Ericsson YB, Roos EM, Owman H, Dahlberg LE. Association between thigh muscle strength four years after partial meniscectomy and radiographic features of osteoarthritis 11 years later. BMC Musculoskelet Disord 2019;20:512.

12. Luyten FP, Bierma-Zeinstra S, Dell'Accio F, Kraus VB, Nakata K, Sekiya I, et al. Toward classification criteria for early osteoarthritis of the knee. Semin Arthritis Rheum 2018;47:457–63.
13. Englund M, Guermazi A, Roemer FW, Aliabadi P, Yang M, Lewis CE, et al. Meniscal tear in knees without surgery and the development of radiographic osteoarthritis among middle-aged and elderly persons: the Multicenter Osteoarthritis Study. Arthritis Rheum 2009;60:831–9.
14. Neogi T, Felson D, Niu J, Nevitt M, Lewis CE, Aliabadi P, et al. Association between radiographic features of knee osteoarthritis and pain: results from two cohort studies. BMJ 2009;339:b2844.
15. Hart DJ, Spector TD. Kellgren & Lawrence grade 1 osteophytes in the knee: doubtful or definite? Osteoarthritis Cartilage 2003;11:149–50.
16. Hunter DJ. Lower extremity osteoarthritis management needs a paradigm shift. Br J Sports Med 2011;45:283–8.
17. Siemieniuk RA, Harris IA, Agoritsas T, Poolman RW, Brignardello-Petersen R, van de Velde S, et al. Arthroscopic surgery for degenerative knee arthritis and meniscal tears: a clinical practice guideline. Br J Sports Med 2018;52:313.
18. Kise NJ, Risberg MA, Stensrud S, Ranstam J, Engebretsen L, Roos EM. Exercise therapy versus arthroscopic partial meniscectomy for degenerative meniscal tear in middle aged patients: randomised controlled trial with two year follow-up. BMJ 2016;354:i3740.
19. Stensrud S, Roos EM, Risberg MA. A 12-week exercise therapy program in middle-aged patients with degenerative meniscus tears: a case series with 1-year follow-up. J Orthop Sports Phys Ther 2012;42:919–31.
20. Biodex Medical System. System 4 clinical resource manual: isokinetic testing and data interpretation. New York: Biodex Medical System. p. 18–20. URL: https://www.biodex.com/physical-medicine/products/dynamometers/system-4-pro/clinical-resources.
21. Sole G, Hamren J, Milosavljevic S, Nicholson H, Sullivan SJ. Test-retest reliability of isokinetic knee extension and flexion. Arch Phys Med Rehabil 2007;88:626–31.
22. Harding B, Black T, Bruulsema A, Maxwell B, Stratford P. Reliability of a reciprocal test protocol performed on the kinetic communicator: an isokinetic test of knee extensor and flexor strength. J Orthop Sports Phys Ther 1988;10:218–23.
23. Pincivero DM, Lephart SM, Karunakara RA. Reliability and precision of isokinetic strength and muscular endurance for the quadriceps and hamstrings. Int J Sports Med 1997;18:113–7.
24. Bacon KL, Segal NA, Øiestad BE, Lewis CE, Nevitt MC, Brown C, et al. Concurrent change in quadriceps strength and physical function over five years in the Multicenter Osteoarthritis Study. Arthritis Care Res (Hoboken) 2019;71:1044–51.
25. Kothari M, Guermazi A, von Ingersleben G, Miaux Y, Sieffert M, Block JE, et al. Fixed-flexion radiography of the knee provides reproducible joint space width measurements in osteoarthritis. Eur Radiol 2004;14:1568–73.
26. Berg B, Roos EM, Englund M, Kise NJ, Tiulpin A, Saarakkala S, et al. Development of osteoarthritis in patients with degenerative meniscal tears treated with exercise therapy or surgery: a randomized controlled trial. Osteoarthritis Cartilage 2020;28:897–906.
27. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis 1957;16:494–502.
28. Culvenor AG, Engen CN, Oiestad BE, Engebretsen L, Risberg MA. Defining the presence of radiographic knee osteoarthritis: a comparison between the Kellgren and Lawrence system and OARSI atlas criteria. Knee Surg Sports Traumatol Arthrosc 2015;23:3532–9.
29. Holm I, Pripp AH, Risberg MA. The Active with OsteoArthritis (AktivA) physiotherapy implementation model: a patient education, supervised exercise and self-management program for patients with mild to moderate osteoarthritis of the knee or hip joint. A national register study with a two-year follow-up. J Clin Med 2020;9:3112.
30. Twisk J, Bosman L, Hoekstra T, Rijnhart J, Welten M, Heymans M. Different ways to estimate treatment effects in randomised controlled trials. Contemp Clin Trials Commun 2018;10:80–5.
31. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee Injury and Osteoarthritis Outcome Score (KOOS): development of a self-administered outcome measure. J Orthop Sports Phys Ther 1998;28:88–96.
32. Danneskiold-Samsøe B, Bartels EM, Bülow PM, Lund H, Stockmarr A, Holm CC, et al. Isokinetic and isometric muscle strength in a healthy population with special reference to age and gender. Acta Physiol (Oxf) 2009;197 Suppl 673:1–68.
33. Lindle RS, Metter EJ, Lynch NA, Fleg JL, Fozard JL, Tobin J, et al. Age and gender comparisons of muscle strength in 654 women and men aged 20–93 yr. J Appl Physiol (1985) 1997;83:1581–7.
34. Berg B, Roos EM, Kise NJ, Engebretsen L, Holm I, Risberg MA. On a trajectory for success: 9 in every 10 people with a degenerative meniscus tear have improved knee function within 2 years after treatment: a secondary exploratory analysis of a randomized controlled trial. J Orthop Sports Phys Ther 2021;51:289–97.
35. Foong YC, Chherawala N, Aitken D, Scott D, Winzenberg T, Jones G. Accelerometer-determined physical activity, muscle mass, and leg strength in community-dwelling older adults. J Cachexia Sarcopenia Muscle 2016;7:275–83.
36. Thorlund JB, Aagaard P, Roos EM. Thigh muscle strength, functional capacity, and self-reported function in patients at high risk of knee osteoarthritis compared with controls. Arthritis Care Res (Hoboken) 2010;62:1244–51.
37. Thorlund JB, Aagaard P, Roos EM. Muscle strength and functional performance in patients at high risk of knee osteoarthritis: a follow-up study. Knee Surg Sports Traumatol Arthrosc 2012;20:1110–7.
38. Becker R, Berth A, Nehring M, Awiszus F. Neuromuscular quadriceps dysfunction prior to osteoarthritis of the knee. J Orthop Res 2004;22:768–73.
39. Hall M, Wrigley TV, Metcalf BR, Hinman RS, Dempsey AR, Mills PM, et al. A longitudinal study of strength and gait after arthroscopic partial meniscectomy. Med Sci Sports Exerc 2013;45:2036–43.
40. Gay C, Chabaud A, Guilley E, Coudeyre E. Educating patients about the benefits of physical activity and exercise for their hip and knee osteoarthritis: systematic literature review. Ann Phys Rehabil Med 2016;59:174–83.
41. Walters SJ. Consultants' forum: should post hoc sample size calculations be done? Pharm Stat 2009;8:163–9.
42. Eitzen I, Grindem H, Nilstad A, Moksnes H, Risberg MA. Quantifying quadriceps muscle strength in patients with ACL injury, focal cartilage lesions, and degenerative meniscus tears: differences and clinical implications. Orthop J Sports Med 2016;4:2325967116667717.