Clinical Study Protocol

Association between changes in muscle strength and pain in persons with meniscal tear and osteoarthritis

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Objective: Strengthening-based physical therapy (PT) is frequently recommended for persons with knee osteoarthritis (OA) and meniscal tear. On average, knee OA patients experience pain improvement while undergoing PT, but whether these changes are accompanied by changes in muscle strength remains an important research question.

Design: We used data from subjects randomized to PT in the Meniscal Tear in Osteoarthritis Research (MeTeOR) trial. Key elements, measured at baseline and 3 months, included quadriceps and hamstrings strength (in pounds) and Knee Injury and Osteoarthritis Outcome Score (KOOS) Pain subscale (0–100; 100 worst). We examined the linear association between change in strength and change in pain over 3 months.

Results: 111 subjects (mean age 57.1, average baseline hamstrings strength 27.5 (SD 14.7), average baseline KOOS 48.0 (SD 17.0)) experienced an average increase in hamstring strength of 3.5 lbs (SD 9.4) and an average decrease in KOOS Pain of 17.1 points (SD 17.4). The correlation between change in hamstrings strength and change in KOOS Pain was weak (Pearson r = 0.17; 95% CI 0.016–0.345). A multivariable linear regression model adjusting for baseline pain showed that a 10-pound increase in hamstrings strength was associated with a 2.9-point (95% CI 0.05–5.9) reduction in KOOS Pain. The association between changes in quadriceps strength and pain was even weaker than that for hamstrings pain.

Conclusion: We observed small increases in strength and weak associations between strengthening and pain relief, suggesting that pain relief achieved during PT likely arises from multiple factors beyond strengthening alone.

1. Introduction

Symptomatic knee osteoarthritis (OA) is a disabling condition that affects 14 million adults in the United States [1]. Many patients with knee OA have concomitant non-traumatic degenerative meniscal tears [2]; clinicians suspect these tears give rise to symptoms in some patients. Symptomatic meniscal tear can be treated either surgically or nonoperatively [2–6]. Current clinical guidelines from professional organizations including the American Geriatric Society, American College of Sports Medicine, and American Physical Therapy Association recommend therapeutic strengthening exercise supervised by trained physical therapists as first line treatment for symptomatic meniscal tear and knee OA [7–10].

These clinical treatment guidelines are supported by several randomized controlled trials (RCT) that found similar levels of pain relief and functional improvement in subjects randomized to strengthening-based exercise programs and those randomized to arthroscopic partial meniscectomy (APM) [11–20]. While these RCTs consistently show that those participating in strengthening programs improve, on average, in both strength and pain [15–17,20], there has been little examination of the mechanism of pain relief. In particular, it is unclear whether improvement in pain is associated with improvement in strength.

Previous cross-sectional analyses of knee OA cohorts with and without meniscal tear have reported a modest linear correlation between...
strength and pain or function [21–23]. We are aware of no studies that report primary analyses of the relationship between changes in strength and changes in pain or function in subjects receiving a therapeutic strengthening intervention for symptomatic OA, with or without meniscal tear. One review reported a weak linear association between average changes in strength and average changes in pain or function during a strengthening intervention for knee OA. However, the authors did not examine patient level data and did not provide the primary data demonstrating these relationships. Further, considerable heterogeneity among the included studies limited conclusions about the relationship [24].

We examined data from a sample of subjects receiving PT for knee OA and meniscal tear from a single trial to characterize the linear relationship between change in strength over the 3-month intervention and change in pain over the same time period. We chose pain as the primary outcome variable because it is the principal reason patients seek care for this condition. We also examined the association between change in strength over 3 months and change in pain over 12 months to assess whether any observed effects of strengthening on pain relief lasted beyond the three-month intervention period.

2. Methods

2.1. Study design

This analysis utilized data from the baseline, 3-month, and 12-month timepoints of the MeTeOR (Meniscal Tear in Osteoarthritis Research) Trial (NCT00597012), a multicenter RCT comparing arthroscopic partial meniscectomy (APM) plus PT to PT alone in subjects with meniscal tear and mild to moderate osteoarthritic changes. Details of the MeTeOR Trial have been published previously [14,25]. At the time of enrollment and at the 3-month study visit, a trained research coordinator assessed subjects’ hamstrings and quadriceps strength with a handheld dynamometer. At enrollment, 3-months, and 12-months, subjects completed self-reports of pain using the Knee Injury Osteoarthritis Outcomes Score Pain Scale (KOOS Pain). No strength data were captured at 12-months. All study procedures were approved by the Partners HealthCare Human Research Committee and center-specific institutional review boards, and all participants provided written consent prior to participation.

2.2. Participants

Interested subjects 45 years and older with MRI-based evidence of a meniscal tear and either MRI or radiographic evidence of osteoarthritic changes were enrolled in the MeTeOR Trial from seven different academic medical centers between 2008 and 2012. Details of the trial, including inclusion and exclusion criteria, and intervention protocols have been published previously [25]. For this analysis, we focused exclusively on subjects randomized to PT who did not receive any knee surgery, including APM, during the first 3 months of the trial. We chose to focus on subjects treated nonoperatively so that the effects of surgery would not confound our findings. We included subjects in the analytic cohort if they had complete baseline and 3-month data on hamstrings and quadriceps strength and KOOS Pain. For multivariable models, we included all subjects with complete data for the parameters (baseline KOOS pain, musculoskeletal functional limitation) included in the model.

2.3. Strength and performance assessments

The protocols for assessing hamstrings and quadriceps strength are described in detail elsewhere [21,25] and summarized here. We captured maximal voluntary isometric quadriceps and hamstrings muscle strength with a hand-held dynamometer. Participants were seated on an examination table with knees flexed to 60° and feet off the ground. The dynamometer was secured with an inelastic strap and held in position by a trained study staff member. Subjects were instructed to extend (for quadriceps) or flex (for hamstrings) their knee “as hard as possible” into the dynamometer for 4 s after which the maximum force exerted was recorded. Assessors performed three trials at both the baseline and 3-month study time points, and we averaged the force exerted (lbs of force) across the trials at each timepoint for every participant.

2.4. Self-reported pain

We assessed baseline, 3-month, and 12-month patient-reported pain using the Pain subscale of KOOS, a valid and reliable instrument for assessing knee pain [26,27]. Scores were scaled to a 100-point range where 0 represented no pain impairments and 100 represented the worst pain score possible.

We also captured the musculoskeletal (MSK) functional limitation index at baseline. The MSK limitation scale is a validated self-administered questionnaire in which subjects indicate the degree of limitation (a lot (2 points), a little (1), not at all (0)) because of joint problems in six body regions (knees, hips, ankles, back, neck, upper extremities) [28]. The items scores were averaged across the body regions yielding potential values from 0 to 2. Average values reported by each participant were categorized into an ordinal variable of 0, 0.01–1, or >1.

Other covariates captured at baseline included gender, mental health inventory (MHI-5) (dichotomized at 68, a level used in screening for depression) [29], body mass index (BMI; dichotomized at 30), and Kellgren Lawrence (KL) radiographic grade. We also created a 4-level variable describing baseline quadriceps and hamstrings strength, dichotomized at the gender-specific median, for women and men.

2.5. Statistical analysis

The primary outcome was change in KOOS Pain from baseline to 3-months. Change in KOOS Pain from baseline to 12-months was included as a secondary analysis. Change in strength between baseline and 3-months was the primary independent variable. We calculated all change variables such that improvement in the variable between the corresponding follow up time and baseline (pain, strength, etc.) was a positive value. We assessed the linear association between changes in pain and strength using the Pearson correlation coefficient. 95% confidence intervals were calculated using Fisher’s Z transformation [30]. We excluded outliers, defined as subjects with change in KOOS Pain or hamstrings or quadriceps strength values lying outside 1.5 times the interquartile range (IQR). Outliers were included in sensitivity analyses reported in the appendix.

We used multivariable linear regression to assess the linear association between the change in pain and strength. We identified covariates to include in the model by performing bivariate linear regressions between several covariates and change in KOOS Pain over 3 months. These covariates included age, BMI, baseline KOOS, baseline hamstrings/quadriceps strength, gender, KL grade, mental health inventory (MHI-5), musculoskeletal functional limitation index categories [28], obesity status, and baseline hamstrings/quadriceps strength median stratified by gender. Covariates were advanced to the multivariable model if they exhibited a bivariate association with the outcome at a level of P < 0.10. We also only ran models in the event change in strength vs. change in pain had p < 0.10. We then used a multivariable linear model to examine the association between absolute change in hamstrings or quadriceps strength and absolute change in KOOS Pain between baseline and 3-months, adjusting for those covariates associated with change in pain in the bi-variate analyses.

All analyses were performed using SAS 9.4 statistical software (SAS
at either baseline or 3-months and 9 were outliers (1.5x IQR). The pri-
months of the trial and were excluded from this analysis. An additional 
analysis are presented in Appendix Table 1. As these tables show,
characteristics of the subjects randomized to PT but not included in this 

3. Results

3.1. Sample characteristics: primary analysis cohort

177 of 351 participants enrolled in the MeTeOR trial were random-
ized to receive PT only. Of these, 30 crossed over to APM in the first 3 
months of the trial and were excluded from this analysis. An additional 
27 were missing data for KOOS pain or hamstrings or quadriceps strength 
at either baseline or 3-months and 9 were outliers (1.5x IQR). The pri-
mary analytic cohort included 111 subjects. Subjects with missing 12-
month KOOS Pain values were excluded from 12-month analyses (an 
additional 8 with Pain missing).

Characteristics for the analytic cohort are presented in Table 1 and 
characteristics of the subjects randomized to PT but not included in this 
analysis are presented in Appendix Table 1. As these tables show,

baseline characteristics for the analytic cohort and for all subjects ran-
domized to PT but not included in this analysis were similar. The mean 
age of the analytic cohort was 57 years (standard deviation (SD) 6.4) and 
mean baseline KOOS Pain was 48.0 (SD 17.0). The mean baseline ham-
strings strength was 27.5 lbs (SD 14.7) and mean baseline quadriceps strength 
was 34.4 lbs (SD 18.5).

3.2. Changes in pain and strength

Pain, and strength improved on average over three months. KOOS Pain 

improved by 17.1 points (SD 17.4) while hamstring strength increased on 
average by 3.5 lbs (SD 9.4) and quadriceps strength by 3.6 lbs (SD 11.2) (Table 1). 26 subjects (22%) experienced an improve-
ment in hamstrings strength greater than 10 lbs and 10 subjects (8%) 
greater than 20 lbs.

3.3. Associations between change in strength and change in Pain

The Pearson correlation between change in hamstrings strength and 
change in KOOS Pain between baseline and 3-months was 0.17 (95% 
Confidence Interval (CI) 0.016 – 0.345) (Table 2). The Pearson 
correlation between changes in quadriceps strength and KOOS Pain was 0.10 
(95% CI 0.088 – 0.281) (Table 2). Change in strength from baseline to 
3-months and change in KOOS Pain from baseline to 12-months were 

essentially uncorrelated, with Pearson correlations coefficients for these 
relationships ranging from 0.04 to 0.06 (Table 2). Because none of the 
strength variables had clinically relevant or statistically significant 
associations with any of the 12-month outcomes, we did not perform 
multivariable modeling using 12-month data.

Analyses were also performed with outliers included (Appendix 
Table 2). These relationships yielded Pearson correlation coefficients of a 
similar magnitude to those of the primary analyses, which excluded 
outliers.

3.4. Multivariable associations of change in strength and changes in pain

We performed a multivariable linear regression model of absolute 
change in KOOS Pain from baseline to 3-months, with the change in 
hamstring strength as primary independent variable. Baseline KOOS Pain 
and MSK index category were included as covariates (Table 3) because 
they exhibited an association with change in KOOS pain from baseline to 
3-months at a level of $P < 0.10$. The multivariable model indicated that, 
after adjusting for baseline KOOS pain and baseline MSK index, every 10-

pound increase in hamstring force over the 3-month intervention was 
associated with a 2.9-point (95% Confidence Interval (CI) –0.05 –5.9) 
improvement in KOOS Pain (Table 3). Additional analysis were per-
formed with outliers (Appendix Table 3); the association between change 
in hamstrings strength and change in KOOS Pain were similar to those 
observed in the primary analyses, which excluded outliers.

Change in quadriceps strength from baseline to 3 months did not meet 
the threshold for statistical significance ($P < 0.10$) that we established for 
multivariable modeling; thus, we did not conduct a multivariable anal-
ysis with change in quadriceps strength as the primary variable of 
interest.

4. Discussion

The cohort used for this analysis experienced a large and clinically 
meaningful change in KOOS Pain score (over 17 points; approximately 
one standard deviation of the baseline value) over a 3-month strengthening-based PT program (Table 1) [14]. In contrast, the sub-
jects had small average improvements in hamstrings strength (3.5 lbs, 
approximately 1/3 standard deviation of baseline hamstrings strength) 
and quadriceps strength (3.6 lbs, approximately 1/3 standard deviation 
of baseline quadriceps strength) (Table 1). The linear association be-
tween improvement in hamstrings strength over 3 months and changes in

Table 1

Descriptive statistics of subjects included in the primary analysis cohort 
(N = 111).

| Variable | Primary analysis cohort (N = 111) |
|----------|----------------------------------|
|          | Mean (SD) | Min–Max |
| Age      | 57.1 (6.4) | 46–73   |
| Body Mass Index | 30.4 (6.4) | 19.7–53.2 |
| Baseline KOOS Pain | 48.0 (17.0) | 8.3–91.7 |
| Baseline KOOS Activities of Daily Living | 38.6 (18.9) | 2.9–88.2 |
| Baseline mean hamstrings muscle strength (lbs) | 27.5 (14.7) | 4.2–84.6 |
| Baseline mean quadriceps muscle strength (lbs) | 34.4 (18.5) | 4.7–105.7 |
| Absolute change in quadriceps strength (lbs) between baseline and 3 months | 17.1 (17.4) | –16.7–63.9 |
| Absolute change in KOOS Pain between baseline and 3 months | 27.1 (20.4) | –22.2–77.8 |
| Absolute change in KOOS Activities of Daily Living between baseline and 3 months | 15.8 (18.3) | –32.4–61.8 |
| Absolute change in quadriceps strength (lbs) between baseline and 12 months | 22.9 (19.1) | –16.2–67.6 |
| Absolute change in hamstrings strength (lbs) between baseline and 12 months | 3.5 (9.4) | –20.4–46.9 |
| Absolute change in quadriceps strength (lbs) between baseline and 3 months | 3.6 (11.2) | –28.1–30.7 |

* SD indicates standard deviation
* KOOS indicates Knee Injury and Osteoarthritis Outcomes Score; scaled 0–100, 100 worst

Table 2

Pearson correlation coefficients reflecting the correlation between absolute 
change in hamstrings or quadriceps strength from baseline to 3-months and 
absolute change in KOOS Pain from baseline to 3-months or from baseline to 
12-months excluding outliers.

| Comparison | Correlation coefficient | P- Value | 95% Confidence interval |
|------------|------------------------|----------|------------------------|
| Knee Injury and Osteoarthritis Outcomes (KOOS) Pain: 0–3 months (N = 111) | | | |
| ΔHamstrings Strength 0–3mo VS. 0–3mo | 0.17 | 0.069 | –0.016 to 0.345 |
| ΔKOOS Pain 0–3mo VS. 0–3mo | 0.10 | 0.290 | –0.088 to 0.281 |
| ΔQuadriceps Strength 0–3mo VS. 0–3mo | 0.06 | 0.548 | –0.135 to 0.25 |
| ΔKOOS Pain 0–3mo VS. 0–12mo | –0.04 | 0.695 | –0.231 to 0.154 |

ΔKOOS Pain 0–3mo VS. 0–12mo

KOOS Pain: 0–12 months (N = 103) | | | |
| ΔHamstrings Strength 0–12mo VS. 0–3mo | 0.12 | 0.465 | –0.743 to 0.976 |
| ΔQuadriceps Strength 0–12mo VS. 0–3mo | 0.18 | 0.224 | –0.083 to 0.455 |
| ΔKOOS Pain 0–3mo VS. 0–12mo | 0.12 | 0.465 | –0.743 to 0.976 |

ΔKOOS Pain 0–12mo VS. 0–3mo
KOOS Pain was weak ($r = 0.17$) as was the linear relationship between the change in quadriceps strength and KOOS pain over 3 months ($r = 0.10$) (Table 2).

Our data suggest that the modest improvements in strength in this cohort explain little of the improvement in pain. Furthermore, our multivariable models suggest that even a 20 lb increase in strength (an improvement only 8% of subjects achieved) would translate to a difference in KOOS Pain of just 5.8 points (20 lbs/0.29 KOOS points/lb = 5.8 points), less than the clinically important difference in the KOOS Pain score of 8–10 points [26]. These observations suggest that factors other than improvement in strength underlie the pain relief observed in those undergoing. Such factors might include the natural history of pain in OA and symptomatic meniscal tear, improvements in range of motion, decrease in edema, activity modification, and contextual factors [31–33].

These observations support and expand upon previous work done in subjects with knee OA without meniscal tear. A recent review by Bartholdy and colleagues identified an association between improvements in knee strength and improvements in knee pain in symptomatic knee OA [24]. However, conclusions from this review were limited by variability in the strength of the relationship between change in strength and change in pain across trials ($I^2 = 67.4\%$ across studies). While the improvements in strength observed in the MeTeOR trial were modest (1/3 standard deviation), the level of strength improvement in MeTeOR was similar to improvements in strength documented in the majority of studies included in the Bartholdy review.

Overall, our results extend these observations to the segment of the OA population with meniscal tear and indicate that while improvements in strength may explain a small portion of the improvements in pain associated with PT interventions, other factors underlie the pain relief observed in those undergoing PT. These studies also highlight the modest increases in strength actually achieved in these programs. Indeed, the modest extent of strengthening may be one of the reasons strengthening has a weak relationship with pain relief.

The results of this study must be interpreted in the context of several limitations. First, under 30% of subjects who were eligible for the MeTeOR Trial elected to participate, potentially limiting generalizability [14]. Furthermore, each PT session was 30 min in duration and the average strength improvement was less than 5 lbs for both quadriceps and hamstrings. It is possible that the intervention may not have been intense enough to yield sufficient strengthening to translate to clinically meaningful changes in pain. Additionally, 38% of the trial cohort showed poor exercise adherence (completed less than 50% of assigned exercise sessions) [34].

Current guidelines for PT programs in this patient population include strengthening as a primary focus [7–10]. Our findings suggest that the extent of strengthening actually achieved is modest and that strengthening appears to play a minor role in explaining the variability in improvement of pain in a knee OA population. Future work is needed to devise strategies to augment the extent of strengthening achieved in this population and to identify which components of PT interventions underlie the substantial pain relief associated with PT interventions in many conditions.

Author contributions

James K. Sullivan: Conceptualization, methodology, writing – original draft, writing – review and editing, and visualization. Swastina Shrestha: Methodology, formal analysis, writing – review and editing. Jamie E. Collins: Methodology, writing – review and editing. Clare E. Safran-Norton: Validation, writing – review and editing. Elena Losina: Methodology, formal analysis, writing – review and editing. Jeffrey N. Katz: Conceptualization, methodology, validation, writing – review and editing, supervision, funding acquisition.

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Declaration of competing interest

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Table 1 (continued)

| Variable | Included in primary analysis (N = 111) | Excluded from analysis (N = 66) |
|----------|----------------------------------------|---------------------------------|
|          | Mean (SD*) | Min-Max | Mean (SD*) | Min-Max |
| Baseline mean quadriceps muscle strength (lbs) | 34.4 (18.5) | 4.7-105.7 | 33.0 (15.6) | 8.8-75.0 |
| Baseline Timed Up and Go (seconds) | 10.2 (3.5) | 4.9-26.1 | 9.3 (3.5) | 3.9-18.4 |

a SD indicates standard deviation.
b KOOS indicates Knee Injury and Osteoarthritis Outcomes Score.

Table 2
Outliers Included. Pearson correlation coefficients reflecting the correlation between absolute change in hamstrings or quadriceps strength from baseline to 3-months and absolute change in KOOS Pain from baseline to 3-months or from baseline to 12-months including outliers.

| Comparison | Correlation coefficient | P-value | 95% Confidence interval |
|------------|-------------------------|---------|------------------------|
| ΔHamstring Strength 0–3mo VS ΔKOOS Pain 0–3mo | 0.22 | 0.017 | 0.041 to 0.386 |
| ΔQuadriceps Strength 0–3mo VS ΔKOOS Pain 0–3mo | 0.19 | 0.040 | 0.009 to 0.359 |
| ΔHamstring Strength 0–12mo VS ΔKOOS Pain 0–12mo | 0.10 | 0.305 | -0.088 to 0.281 |
| ΔQuadriceps Strength 0–12mo VS ΔKOOS Pain 0–12mo | 0.05 | 0.639 | -0.138 to 0.235 |

Table 2
Outliers Included. Multivariable linear model of change in Knee Injury and Osteoarthritis Outcomes Score (KOOS) pain. Independent variables include change in hamstring strength between baseline and 3-months, baseline KOOS Pain, and musculoskeletal (MSK) index score categories including outliers (N = 117).

| Parameter | Estimate | 95% Confidence interval | P-value |
|-----------|----------|-------------------------|---------|
| Intercept | -19.26 | -32.58 to (-)4.94 | 0.008 |
| ΔHamstring Strength 0–3mo | 0.34 | 0.10 to 0.59 | 0.006 |
| Baseline KOOS Pain | 0.46 | 0.08 to 0.29 | <0.0001 |
| MSK Index | 0 | 5.76 to 29.93 | 0.004 |
| 0.01-1 | 12.29 | 0.61 to 23.96 | 0.039 |
| >1 | Reference | Reference | Reference |

a The MSK index ordinal variable was derived from the average values reported by each participant across 6 body regions assessed by the MSK functional limitation scale. Possible responses for each body region indicated that region’s degree of limitation as “a lot” (2 points), “a little” (1), or “not at all” (0).

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