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Lumbopelvic Joint Manipulation and Quadriceps Activation of People With Patellofemoral Pain Syndrome

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Context: Quadriceps weakness and inhibition are impairments associated with patellofemoral pain syndrome (PFPS). Lumbopelvic joint manipulation has been shown to improve quadriceps force output and inhibition, but the duration of the effect is unknown.

Objective: To determine whether quadriceps strength and activation are increased and maintained for 1 hour after high-grade or low-grade joint mobilization or manipulation applied at the lumbopelvic region in people with PFPS.

Design: Randomized controlled clinical trial.

Setting: University laboratory.

Patients or Other Participants: Forty-eight people with PFPS (age = 24.6 ± 8.9 years, height = 174.3 ± 11.2 cm, mass = 78.4 ± 16.8 kg) participated.

Intervention(s): Participants were randomized to 1 of 3 groups: lumbopelvic joint manipulation (grade V), side-lying lumbar midrange flexion and extension passive range of motion (grade II) for 1 minute, or prone extension on the elbows for 3 minutes.

Main Outcome Measure(s): Quadriceps force and activation were measured using the burst superimposition technique during a seated isometric knee extension task. A 2-way repeated-measures analysis of variance was performed to compare changes in quadriceps force and activation among groups over time (before intervention and at 0, 20, 40, and 60 minutes after intervention).

Results: We found no differences in quadriceps force output ($F_{5.33,101.18} = 0.65$, $P = .67$) or central activation ratio ($F_{4.84,92.03} = 0.38$, $P = .86$) values among groups after intervention. When groups were pooled, we found differences across time for quadriceps force ($F_{2.66,101.18} = 5.03$, $P = .004$) and activation ($F_{2.42,92.03} = 3.85$, $P = .02$). Quadriceps force was not different at 0 minutes after intervention ($t_{40} = 1.68$, $P = .10$), but it decreased at 20 ($t_{40} = 2.16$, $P = .04$), 40 ($t_{40} = 2.87$, $P = .01$) and 60 ($t_{40} = 3.04$, $P = .004$) minutes after intervention. All groups demonstrated decreased quadriceps activation at 0 minutes after intervention ($t_{40} = 4.17$, $P < .001$), but subsequent measures were not different from preintervention levels (t_{40} range, 1.53–1.83, $P > .09$).

Conclusions: Interventions directed at the lumbopelvic region did not have immediate effects on quadriceps force output or activation. Muscle fatigue might have contributed to decreased force output and activation over 1 hour of testing.

Key Words: force output, knee pain, manual therapy, muscle activation

Key Points

- Interventions applied to the lumbopelvic region did not immediately affect quadriceps force output or activation.
- Local muscle fatigue might have resulted in decreased force output and activation over the 1-hour testing session.
- Changes in quadriceps force output and activation were not present in the 1 hour after high-grade or low-grade joint mobilization or manipulation directed at the lumbopelvic region.

Patellofemoral pain syndrome (PFPS) is a complex musculoskeletal occurrence that affects up to 30% of the population.[1–3] People with PFPS have been shown to demonstrate quadriceps weakness[2,4–6] and inhibition.[7–10] Pain is thought to be the underlying cause of muscle weakness and inhibition,[11–15] but researchers have found little relationship between perceived pain and muscle inhibition.[16–19] Even when pain has subsided, inhibition might be present for years after

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injury.[20–24] The persistent muscle inhibition is thought to be an underlying cause and risk factor for osteoarthritis.[25,26]

Interventions for PFPS usually focus on strengthening the quadriceps[4,27–31] and hip muscles.[32–36] Traditional strengthening interventions might not fully address muscle inhibition because it is a reflexive response to joint pathology.[15,17,37–39] Persistent inhibition might limit the advancement of rehabilitation programs,[40] and comprehensive interventions that restore optimal quadriceps strength, activation, and previous pain-free level of function must be developed to prevent future dysfunction.

Joint mobilization and manipulation have been used to reduce pain[27,41,42] and increase muscle activation[8,9] in people with PFPS. Joint mobilization and manipulation stimulate sensory receptors within and around the joint.[43–45] Afferent signals from these sensory receptors synapse on interneurons at the spinal level and can affect motoneuron pool availability and efferent motor output.[40] Joint mobilization and manipulation have been shown to affect muscle activation both near[13,46–48] and distant from the site of intervention.[8,9,49,50] Similar effects on local and distant muscle activation have been demonstrated using cryotherapy.[51] Because the sacroiliac joint (L2–S3), quadriceps (L2–4), and knee joints (L2–S2) share common nerve root levels,[52] afferent information from one structure might alter efferent signals to all structures that a similar nerve root level innervates. A lumbopelvic joint manipulation has been shown to acutely reduce patellofemoral pain when people perform squats, step-ups, and step-downs[41] and to acutely increase quadriceps force output from 11% to 17%[8,9,53] and activation from 5% to 7.5%.[8,9] These studies are limited because investigators examined only immediate effects after intervention. Researchers have demonstrated that the effects of lumbopelvic joint manipulation on quadriceps activation and force output might be of limited duration (<20 minutes) in asymptomatic people.[49] No evidence exists about the duration of increased quadriceps strength or activation after lumbopelvic joint manipulation in a symptomatic population. We also do not know whether lower-grade joint mobilizations might have a similar effect. The associated neurophysiologic effect might depend on the forces (high-grade or low-grade joint mobilizations) applied during the manual intervention.[54,55] Therefore, the purpose of our study was to determine whether quadriceps strength and activation are increased and maintained for 1 hour after high-grade or low-grade joint mobilization or manipulation applied at the lumbopelvic region in people with PFPS.

METHODS

A single-blind randomized controlled trial was used to examine the effects of lumbopelvic manipulation or mobilization on quadriceps strength and activation. Independent variables included group (lumbopelvic joint manipulation, lumbar passive range of motion [PROM], or prone extension) and time (before intervention and 0, 20, 40, and 60 minutes after intervention). Outcome variables included force output and percentage of quadriceps activation.

Participants

Forty-eight people with PFPS volunteered (Table). We classified *PFPS* as self-reported insidious onset of unilateral or bilateral pain that could be reproduced with at least 2 of the following: patellar compression, squatting, prolonged sitting, walking up or down stairs, or isometric quadriceps contraction.[27,57] Exclusion criteria were symptoms for less than 1 month, ligamentous insufficiency at the knee, meniscus damage, patellar tendinitis, history of patellar subluxation or dislocation, signs or symptoms indicating nerve root compression, history of spine or lower extremity surgery, osteoporosis, pregnancy, or spinal or neurologic disorders. All participants provided written informed consent, and the study was approved by the Institutional Review Board for Health Sciences Research at the University of Virginia. Forty-one participants completed all postintervention testing intervals (Table), whereas 7 participants (6 women, 1 man) withdrew after the 0-minute (n = 5) or the 20-minute (n = 2) postintervention measurements. Data from participants who withdrew from the study were not used in the final statistical analysis.

Instrumentation

Quadriceps Force Output. Isometric quadriceps force was measured using a load cell (model 41; Sensotec, Inc, Columbus, OH) with a range of 1 to 1000 lb (0.45–453.59 kg) that was interfaced with a data acquisition system (model MP150; BIOPAC Systems, Inc, Goleta, CA) and amplifier (model DA100B; BIOPAC Systems, Inc) and sampled at 125 Hz. Participants were seated in a custom-made chair with their hips flexed to 85°, knees flexed to 90°, and arms folded across their chests. The pelvis was secured to the chair using hook-and-loop straps, and a padded ankle strap was placed 3 cm proximal to the lateral malleolus and connected to the load cell via an S hook.

Burst Superimposition Technique. Quadriceps activation was estimated by using the burst superimposition technique on a maximal voluntary isometric contraction (MVIC). The burst superimposition technique provides the muscle with a percutaneous supramaximal stimulus to recruit muscle fibers that have not been stimulated.[16,17,38,58,59] A square-wave stimulator (model S88; Grass Technologies, West Warwick, RI) and a stimulation isolation unit (model SIU8T; Grass Technologies) were used with a corresponding isolation unit that had a 125-V stimulus and two 8- × 14-cm rubber-carbon electrodes to deliver the electric stimuli over the quadriceps. Electrode surfaces were

Table. Participant Demographics (Mean ± SD)[a]

Characteristic	Total (N = 48)	Manipulation (n = 16)	Passive Range of Motion (n = 16)	Prone Extension (n = 16)
Age, y	24.6 ± 8.9	25.4 ± 7.7	25.1 ± 9.6	24.6 ± 7.4
Height, cm	174.3 ± 11.2	173.5 ± 9.1	175.5 ± 11.2	173.9 ± 13.4
Mass, kg	78.4 ± 16.8	73.0 ± 10.2	78.1 ± 21.4	84.1 ± 16.0
Lower Extremity Functional Scale[56] score (maximum possible, 80)	65.5 ± 12.4	64.3 ± 12.6	64.6 ± 16.1	67.0 ± 10.7

[a] Indicates that no differences existed among groups ($P > .05$).

covered with conductive gel and secured with an elastic bandage over the proximal lateral aspect and the distal medial aspect of the quadriceps muscle.

A superimposed burst, which consisted of 100 pulses per second, a pulse duration of 600 microseconds, and 10 pulse tetanic trains at 125 V for 100 milliseconds, was applied manually to the quadriceps approximately 2 seconds after the beginning of the MVIC when the experimenter (T.L.G.) determined a plateau in force had occurred. The burst superimposition technique has been shown to be highly reliable with repeated testing of healthy participants (intraclass correlation coefficient [ICC] = 0.98).[60] The amount of muscle activation was quantified by using the central activation ratio (CAR) and was calculated by dividing the volitional MVIC force by total force ($CAR = F_{volitional}/F_{volitional+electrical}$).[61] A CAR of 1.0 indicates *complete activation*; from 0.95 to 1.0, *normal activation*.[16,17,62–65]

Procedures

Participants underwent a standard initial physical evaluation, including assessment of the lumbar spine, sacroiliac joint, and knee joints. This allowed the examiner (J.R.B. or E.M.M.) to screen for exclusionary criteria. All interventions and testing were performed on the ipsilateral side of pain or dysfunction. If the participant had bilateral patellofemoral pain, he or she was instructed to determine which lower extremity was more symptomatic. If the participant could not differentiate between limbs, then a coin toss determined the test limb.

Next, a separate examiner (T.L.G.) who was blinded to treatment group allocation measured baseline quadriceps strength and activation. Participants performed a warmup consisting of 4 submaximal isometric contractions (50%–75% MVIC) with submaximal electric stimulation of the quadriceps, 1 MVIC with submaximal electric stimulation, and 1 MVIC without stimulation to orient them to the test procedures and ensure that an MVIC could be obtained.[66]

After warmup procedures, participants performed 3 MVICs with supramaximal stimuli. Oral encouragement and visual feedback of real-time force output were given. The MVIC contraction during the warmup served as a target to ensure that participants were exerting maximal effort. Participants were instructed to build up force slowly and hold the MVICs for 3 to 5 seconds. Approximately 2 seconds after the MVIC began, a supramaximal electric stimulus, which consisted of 100 pulses per second, a pulse duration of 600 microseconds, and 10 pulse tetanic trains at 125 V for 100 milliseconds, was applied manually to the quadriceps muscle to recruit muscle fibers that had not been stimulated.[16,17,38] If force did not plateau, a stimulus was not given, and the test was repeated. A 90-second rest period was given between MVICs. Three trials were performed, and the average MVIC and CAR were used for data analysis.

After baseline assessment of quadriceps activation, participants jogged for 5 minutes and ran for 2 to 3 minutes on a treadmill. This portion of testing was part of a larger trial in which we examined running biomechanics and which we will report in a subsequent study. After running, participants were assigned randomly to 1 of 3 treatment groups: lumbopelvic joint manipulation (grade V), side-lying lumbar midrange flexion and extension PROM (grade II) for 1 minute, or prone extension on the elbows for 3 minutes (Figure 1). Lumbopelvic joint manipulation was selected as a high-grade mobilization, whereas lumbar PROM was selected as a lower-grade (grade II) joint mobilization. The intervention in which participants were positioned prone on their elbows was selected because it is used

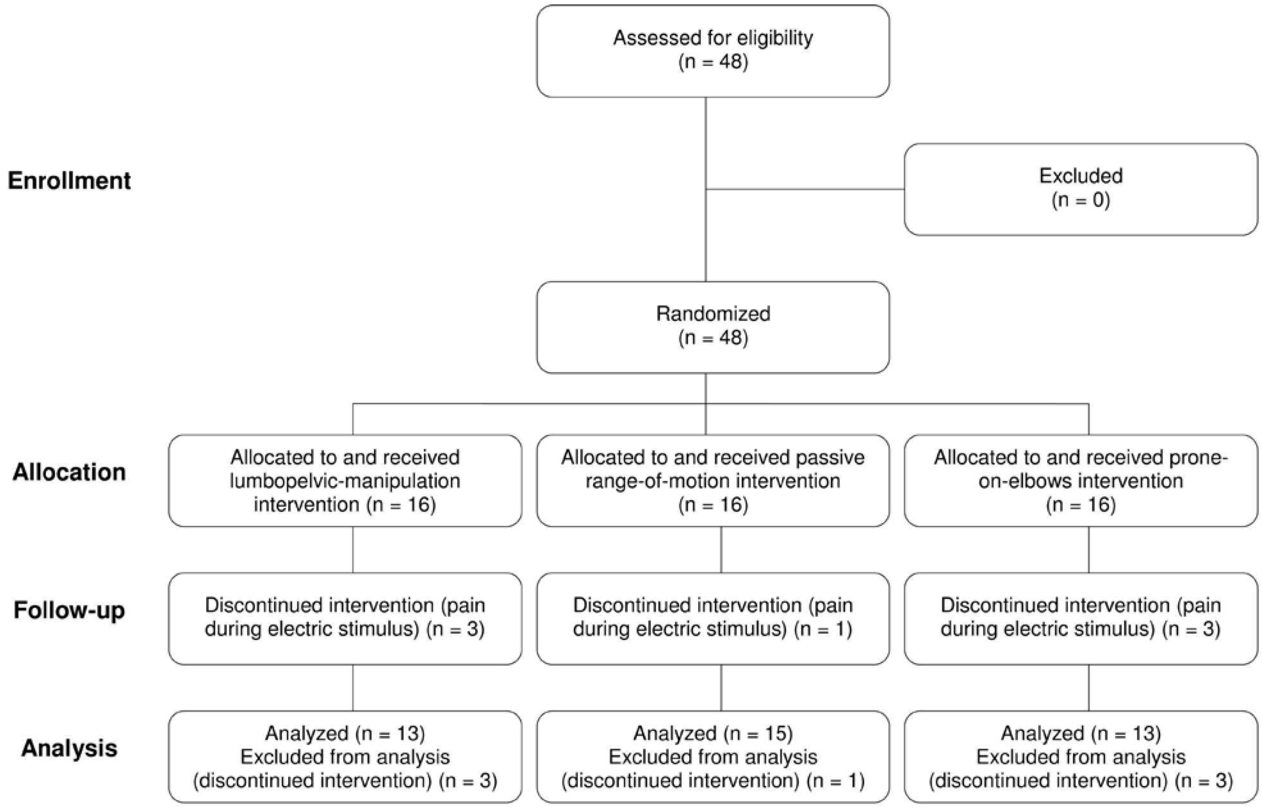

Figure 1. Flow diagram.[67]

commonly for people with low back pain but does not require physical contact. The total duration to set up and perform each of the 3 interventions was estimated to be 3 minutes and included participant positioning and intervention. The examiner (T.L.G.) obtaining quadriceps force output and activation values was blinded to treatment group allocation.

After experimental treatment, participants again ran for 2 to 3 minutes, then we reassessed quadriceps force output and activation using similar methods. Testing was performed immediately after intervention (0 minutes) and at 20, 40, and 60 minutes after intervention. During rest periods between testing intervals, participants were instructed to remain seated and quiet. Testing concluded after the 60-minute postintervention data were collected.

Lumbopelvic Joint Manipulation. The lumbopelvic joint manipulation (Grade V) was performed on the ipsilateral side of the test limb (Figure 2). The term *lumbopelvic* was used to describe the targeted region because this manipulation technique is not exclusively specific to the lumbar, sacroiliac, or pelvic regions.[68] The manipulation procedure we used was consistent with previously used methods[41,49,68–70] and was performed by 1 of 2 physical therapists (J.R.B. or E.M.M.) with advanced training in manual therapy. Participants were positioned supine on a treatment table while the physical therapist stood on the opposite side that would be manipulated. The participant was side bent passively toward and rotated away from the selected lumbopelvic region. Next, a posteroinferior force was delivered through the opposite anterosuperior iliac spine. If a cavitation was not heard or felt by the patient or examiner, the technique was repeated. If the second attempt did not produce cavitation, the procedure was repeated on the contralateral side using similar methods. If cavitation was not heard or felt by the participant or examiner after the second attempt on the contralateral side, the participant proceeded with the assessment of quadriceps strength and activation as usual.

Passive Range of Motion. Participants were positioned side lying on the opposite side of the test limb (Figure 3). The experimenter (J.R.B. or E.M.M.) held both knees with 1 arm while placing the opposite hand on the participant's lumbar spine. The experimenter performed 1 minute of flexion and extension PROM without reaching physiologic end range (grade II) in either direction.

Prone Extension on Elbows. Participants were positioned prone with the lumbar spine in extension, and they used their elbows for support to maintain the position for 3 minutes (Figure 4). No contact occurred between the participant and physical therapist.

Statistical Analysis

Participant demographics were compared using a 1-way analysis of variance (ANOVA). A 2-way, repeated-measures ANOVA was performed to compare quadriceps force output and CAR values among groups (lumbopelvic joint manipulation, lumbar PROM, or prone extension on elbows) across time (before intervention and at 0, 20, 40, and 60 minutes after intervention). Degrees of freedom were corrected using the Greenhouse-Geisser method if the Mauchly sphericity test revealed differences. Degrees of freedom used for the corrected *F* test were not necessarily whole numbers. The α level was set a priori at .05. If we observed differences among groups, we used post hoc *t* tests. Statistical analyses were performed with SPSS (version 16.0; SPSS Inc, Chicago, IL).

Figure 2. Lumbopelvic joint manipulation with side bending and rotation in supine position.

Figure 3. Lumbar passive range of motion.

Figure 4. Prone extension on elbows.

An a priori sample size calculation was performed using an expected change in quadriceps activation of 7.5%[8,9] and a standard deviation of 10%.[49] Based on these values, we calculated that 15 participants per group were necessary to have an 80% chance of detecting a difference in quadriceps activation with an α level of .05.

RESULTS

We found no differences among any of the participant group demographics ($F_{2,40}$ range, 0.08–2.52, $P>.05$) (Table). Lumbopelvic joint cavitation was achieved in 53.8% of the participants (all on 1 attempt). Six of the participants in the manipulation group could not achieve joint cavitation after 4 attempts (2 per side) but were retained in the statistical analysis because cavitation might not be necessary to achieve clinically relevant changes.[68,71]

Quadriceps force output ($F_{5.33,101.18}=0.65$, $P=.67$, $1-\beta=.29$) and activation ($F_{4.84,92.03}=0.38$, $P=.86$, $1-\beta=.18$) values were not different among groups across time (Figures 5 and 6). When groups were pooled, we found differences across time for quadriceps force output ($F_{2.66,101.18}=5.03$, $P=.004$, $1-\beta=.88$) and activation ($F_{2.42,92.03}=3.85$, $P=.02$, $1-\beta=.74$). Quadriceps force output did not change at 0 minutes postintervention ($t_{40}=1.68$, $P=.10$) but decreased at 20 ($t_{40}=2.16$, $P=.04$), 40 ($t_{40}=2.87$, $P=.01$), and 60 ($t_{40}=3.04$, $P=.004$) minutes postintervention. All groups demonstrated decreased quadriceps activation at 0 minutes postintervention ($t_{40}=4.17$, $P<.001$), but subsequent measures were not different from preintervention levels (t_{40} range$=1.53$–1.83, $P>.09$).

DISCUSSION

Our results indicated that changes in quadriceps force output and activation were not present over the course of 1 hour after high-grade or low-grade joint mobilization or manipulation directed at the lumbopelvic region. This finding differs from the findings reported in other studies that suggested an immediate

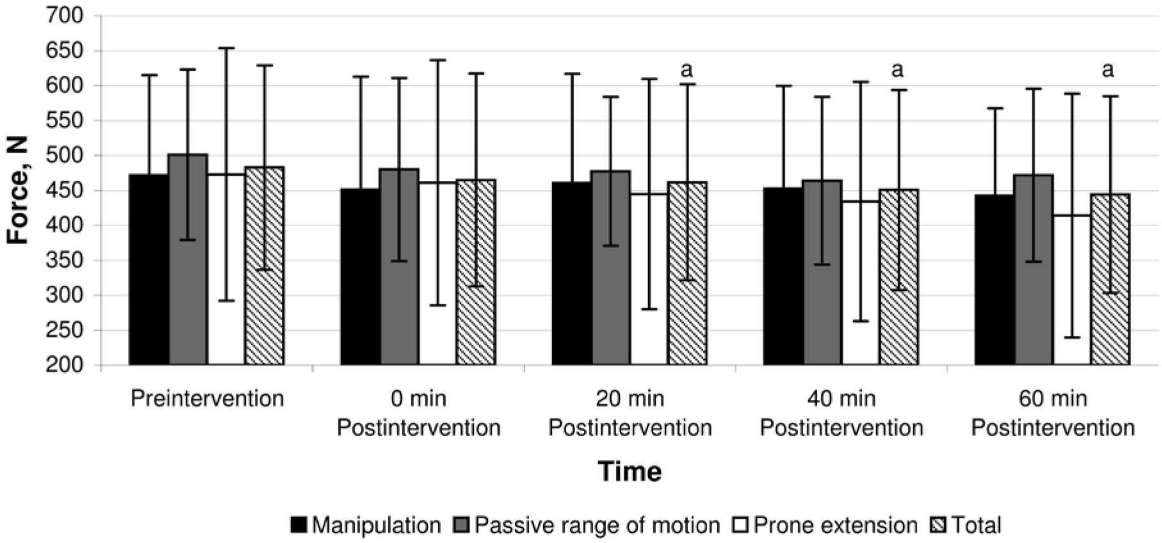

Figure 5. Immediate effects of quadriceps force output at 60 minutes after intervention. [a]Indicates decrease in force output compared with preintervention values ($P<.04$).

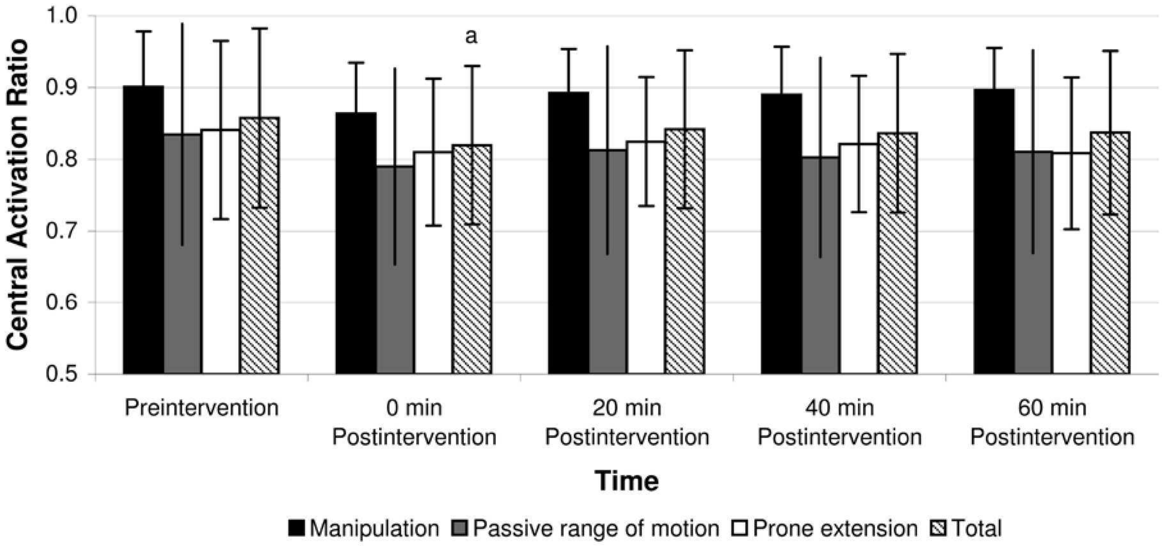

Figure 6. Immediate effects of quadriceps activation at 60 minutes postintervention. [a]Indicates decrease in quadriceps activation compared with preintervention values ($P<.001$).

increase in quadriceps force output[8,9,53] and activation[8,9] after lumbopelvic joint manipulation. (Our participants were not actively seeking medical care for PFPS but did have deficits in quadriceps activation and self-reported function; the latter were identified using the Lower Extremity Functional Scale[56]). Investigators[8,9,41] have demonstrated improvements in quadriceps activation and function after manual interventions directed at the spine in people who are seeking medical care for PFPS. All people with PFPS might not be candidates for lumbopelvic manipulation. Researchers demonstrating increased quadriceps force output and activation have included people with sacroiliac joint dysfunction who are symptomatic or asymptomatic.[8,9,53] In addition, a subset of people with PFPS who have internal rotation asymmetry in the hip greater than 14° are thought to be 5 times more likely to experience pain relief after a lumbopelvic joint manipulation.[41] The relationship with the hip and PFPS is consistent with findings in previous studies[32,72–79] but might be associated with other causes, such as malalignment, muscle imbalances, patellar tracking, and cumulative microtrauma.[4,27] We did not attempt to categorize people with PFPS into treatment based on classification systems. Although treatment-based classification systems have been used to manage low back pain,[80,81] the use of classification systems to manage PFPS is new and has not been validated.[41,82,83]

Quadriceps force output began to decrease 20 minutes after intervention. The amount of decreased force output was not dependent on treatment group allocation. Obtaining valid and reliable force output and activation values depends on participants producing maximal effort[84] and sufficient warmup.[66] Despite encouraging participants to give 100% effort during all trials, we found that force output declined from baseline by approximally 4% to 5%. A warmup consisting of progressive isometric knee extension exercises was performed only during the preintervention testing period. Participants also performed a 5-minute jogging bout and two 2-minute to 3-minute running bouts on a treadmill before the immediate postintervention (0 minutes) acquisition of quadriceps force output and activation data. As noted, the jogging and running bouts were part of a larger study in which we investigated changes in running mechanics. Warmup bouts were not performed during other postintervention periods (20, 40, and 60 minutes). The muscles might have cooled down during the rest periods, and this cooling might have affected quadriceps force output values. Alternatively, decreased force output also might have been attributed to fatigue associated with a combination of running (approximately 10 minutes) and performing 15 MVICs augmented with a supramaximal electric stimulus over 60 minutes.[85] Participants also were instructed to sit quietly during rest periods. Unfortunately, because of the study design, we could not differentiate between the effects of intervention and running because a true control (ie, no intervention or running) was not used. Whether this fatigue was related to peripheral or central mechanisms is not known. Electromyographic analysis of median frequency of muscle might help quantify peripheral muscle fatigue associated with repeated MVICs.[86,87] We examined participants 60 minutes after intervention to determine whether changes in muscle force output and activation could be sustained over a period that was consistent with rehabilitation programs. In future studies, researchers might consider examining similar time intervals while having participants perform activities, such as therapeutic exercises, commonly used in clinical settings.

Quadriceps activation decreased at 0 minutes postintervention, but values obtained 20, 40, and 60 minutes postintervention were not different from preintervention values. A brief bout of running might acutely decrease quadriceps activation. Investigators[8,9,49] have determined that a lumbopelvic joint manipulation immediately affects quadriceps activation. The typical increase in muscle activation (range, 5%–7.5%)[8,9,49] after lumbopelvic joint manipulation might have been attenuated by a decrease in muscle activation due to fatigue associated with running.[65] If running attenuated the typical increase in quadriceps force output and activation, the clinical utility of this intervention might be limited. Our participants were part of a larger trial in which we concurrently examined changes in running mechanics. We did not control for the effects of the running variable on quadriceps force output and activation, so we could not determine the effects of the running bout on muscle activation. In future studies, researchers should quantify the amount of change in quadriceps muscle activation due to running.

A limitation of our study was that 7 participants (6 women, 1 man) withdrew from the study because of discomfort associated with burst superimposition testing. Five of these 7 participants withdrew immediately after the first postintervention (0 minutes) measurement, and 2 withdrew after the 20-minute postintervention measurement. Miller et al[88] reported that participants described the pain associated with burst superimposition testing as mild to moderate and rated it as 3.5/10 on a visual analog scale. Perceived discomfort is thought to decrease in consecutive trials.[88] Although the discomfort was not quantified, participants who withdrew appeared to experience anxiety or apprehension during burst superimposition testing. These people tended to be female and had activation levels greater than 0.90.

The purpose of our study was to examine changes in quadriceps force output and activation after a manual therapeutic intervention directed at the lumbopelvic region. This mechanistic study was designed to evaluate only 1 intervention. Lumbopelvic joint manipulation might address specific impairments associated with PFPS (decreased quadriceps activation, asymmetries in hip rotation) but might need to be used as an adjunctive intervention that is part of a comprehensive rehabilitation program.

CONCLUSIONS

Based on our findings, we demonstrated that interventions applied at the lumbopelvic region did not have an immediate effect on quadriceps force output or activation. Local muscle fatigue might have been responsible for decreased force output and activation over the 1-hour testing session.

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