The Effect of Lumbopelvic Joint Manipulation and Traditional Quadriceps Strengthening on Improving Knee Extensor Muscle Activation and Torque Production: A Randomized Controlled Trial

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Abstract

Background: Many patients seen in physical therapy are at risk for developing limited quadriceps activation. Lumbopelvic manipulation has been shown to yield an immediate, but not lasting, increase in quadriceps muscle activation.

Purpose: To investigate and determine if lumbopelvic manipulation combined with knee extensor strengthening exercises has a greater effect on voluntary activation and maximal voluntary isometric contraction (MVIC) strength than performing exercises alone.

Study Design: Randomized Controlled Trial

Subjects: Sixty-six individuals were screened for eligibility; 24 subjects who qualified (i.e., less than 80% knee extension activation) were randomly assigned to one of the three groups: 1) no intervention (i.e. control group; n=8), 2) exercise (n= 8), and 3) exercise plus lumbopelvic manipulation (n=8).

Methods: Knee extensor voluntary activation (via the interpolated-twitch technique) and MVIC strength were measured before and after the 6-week interventions. Knee extensor strengthening exercises were performed 3 times/week using a standardized protocol. The manipulation plus exercise group received a lumbopelvic manipulation once per week.

Results: A one-way ANOVA revealed a significant difference (p= 0.010) in the post-intervention change in knee extensor activation among the 3 groups. Post-hoc Tukey HSD determined that the changes in knee extensor activation of the manipulation plus exercise group was significantly greater than that of the control group (p = 0.008). There was no significant difference in the changes in knee extensor MVIC strength among groups (p > 0.88).

Conclusion: Combining exercise and lumbopelvic manipulation had a larger impact on improving knee extensor activation than control subjects, while exercise alone did not significantly improve activation percentage. Further research is needed to examine the effectiveness of manipulation plus exercise, as compared to exercise alone, on long-term knee extensor activation and strength.

Keywords: Lumbopelvic manipulation; knee extensors; exercise; muscle activation

Introduction

Arthrogenic muscle inhibition is a reflex response the body produces to prevent skeletal muscle tissue from producing a full contraction. [1,2] This inhibition of the innervating nerves and fibers in the muscle can lead to a severe reduction in strength, force production, and function, while also compromising the firing capacity, thereby preventing effective strengthening during rehabilitation.[1] Acutely, muscle inhibition may serve to protect a joint following a traumatic event or surgery, but chronic inhibition can delay the healing process and eventually impair muscle function. Several studies have found that disruptions in muscle activation accounted for the observable decrease in knee extensor strength in patients with knee osteoarthritis (OA), total knee arthroplasty (TKA), and/or anterior cruciate ligament repair: [1,3-5] Stevens at al. (2003) emphasized the role muscle activation plays in strength gains and deficits between pre and post-surgery measurements, showing a 17% decrease in activation accounted for 65% of the variability between strength changes of the affected limb in patients who underwent a TKA procedure. [3] This lack of voluntary activation in musculature supporting the knee leads to an alteration in biomechanics and an increase in joint degeneration, both of which threaten successful rehabilitation for any knee pathology. Insufficient muscle recruitment can alter kinematics and joint loading, resulting in the compensatory distribution of force across adjacent joints to the knee, including the ankle, hip, and spine.[1]
Physical therapy interventions regularly include strengthening exercises to improve mobility and function in patients with knee pain, knee OA, and/or post-operatively after knee surgery (i.e., TKA or anterior cruciate ligament repair). Some studies have reported limited, if any, gains in strength of the quadriceps with a strengthening program in subjects with knee pain and injury due to neuromuscular deficits observed in the muscle group. [6,7] Traditional strengthening exercises alone may not effectively improve muscle activation in the presence of pain or injury.

Despite the lack of evidence regarding the most effective interventions to promote muscle activation, limited research suggests spinal manipulation of the sacroiliac joint (SIJ) could be an effective treatment mechanism to facilitate quadriceps muscle activation just after manipulation [8]. Manipulation can potentially alter the afferent mechanoreceptor input to the SIJ to augment the efferent pathways of the respective nerves innervating the KE muscles, thereby theoretically overriding the inhibitory effect of the quadriceps’ golgi tendon organs and enhancing quadriceps recruitment and function. [9] The anterior portion of the SIJ is innervated by the anterior primary divisions of L2 through S2, with L2 through L4 also projecting in to the femoral nerve which innervates the knee extensors. [9] A study conducted in 2012 by Grindstaff et al. (2012) investigated whether lumbopelvic manipulation, lumbar passive range of motion (PROM), or prone extension would produce greater improvement in quadriceps activation and isometric force production. A 4.7% improvement in muscle activation and 3.1% increase in isometric quadriceps force production were noted after comparing the manipulation group with the other groups, though improvements diminished after 20 minutes post intervention. [8] Considering these studies investigated the effect of manipulation alone on KE activation, further research is needed to see the effect of a combination of strengthening and manipulation. Therefore, the purpose of this study was to determine if lumbopelvic manipulation, in combination with KE strengthening exercises over a six-week testing period, was more effective than exercises alone on increasing quadriceps voluntary activation and strength in individuals with diminished knee extensor activation.

**Methods**

**Participants**

Sixty-six individuals were screened for eligibility, and 24 subjects, fitting the inclusion/exclusion criteria, were enrolled in this randomized controlled trial. Subjects were recruited via word of mouth and flyers. Subject characteristics are shown in Table-1 and history of musculoskeletal injury can be found in Table-2. Inclusion and exclusion criteria used to determine subject eligibility is listed in Table-3. All subjects completed a health history form that included orthopedic history and an activity questionnaire prior to participating. This study was approved by the Georgia State University Institutional Review Board and all subjects provided written informed consent.

<table>
<thead>
<tr>
<th>Table 1: Subject characteristics of the three groups (values indicate mean ± standard deviation). There was no significant difference in subject characteristics among the three groups ($p ≥ 0.583$).</th>
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<td><strong>Group</strong></td>
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<td>Gender (Women/Men)</td>
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<td>Age (years)</td>
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<td>Body Height (cm)</td>
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<td>Body Mass (kg)</td>
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<tr>
<td>Pre-Training Quadriceps Strength (Nm/kg)</td>
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<td>Pre-Training Quadriceps Activation (%)</td>
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<th>Table 2. The number of participants with history of previous musculoskeletal injuries (injuries must not have occurred within 6 months prior to participating the study) in each of the 3 groups.</th>
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<tr>
<td><strong>Group</strong></td>
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<td>Foot/Ankle Injury</td>
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<td>Lower Leg Injury</td>
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<td>Knee Injury</td>
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<td>Thigh Injury</td>
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<td>Hip Injury</td>
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<td>Spine Injury</td>
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To assess knee extensor activation, the interpolated twitch technique was performed as we have described previously. [10] The participant was seated in a KinCom III dynamometer (Chattecx, Chattanooga, TN) in a semi-reclined position with 70° of knee flexion. The subject’s knee joint line was aligned with the servomotor. A two-part testing protocol used by Collier et al. (2016) and Cureton et al. (2007) was used to determine the current needed for maximum torque production and subsequently measure voluntary MVIC muscle strength/torque and activation. [11,12]

### Part 1

Two adhesive electrodes were placed on the skin overlying the thigh, one over the distal vastus medialis muscle and the other over the proximal vastus lateralis muscle in order to capture the knee extensor muscle activation. The electrodes were connected to a constant-current stimulator (Digitimer model DS7AH, Hertfordshire, England) that was controlled using a 667-MHz Pentium computer; an A/D- and D/A-interface board (Keithley Instruments model KPCI-3108, Cleveland, OH), and custom-written software created with Test Point version 7.0 (Capital Equipment Co., Billerica, MA). The software and interface board also sampled the torque output signal from the KinCom III dynamometer at 5 kHz.

To determine the stimulation current needed for the interpolated-twitch contractions, electrically-stimulated isometric contractions of the knee extensors was performed with a 20mA increase in current on successive stimulations. The stimulator current was initially set to 100 mA and stimulations were given once every 20 s until the peak contraction torque plateaued. The was determined by a decrease in torque on two consecutive stimulations. The current which caused the highest peak torque was used for the second part of the testing.

### Part 2

Subjects were instructed to perform a 3-second MVIC on a Kin-Com dynamometer (Isokinetic International, Chattanooga TN). Auditory cues elicited by the software and verbal cues provided by the researchers were used to signal the participant to begin and end the contraction. At 2.5 seconds into MVIC, the knee extensor muscle group was stimulated with a paired-pulse stimulation, and the increase in torque over the MVIC level was measured. At 2 and 4 seconds following the MVIC, the subject was instructed to relax the muscle and a paired-pulse stimulation was delivered to determine peak electrically-evoked torque (EET). The percentage muscle activation during MVIC was calculated as 100% x (1 – (ITT/EET)). The interpolated twitch technique was performed six times per leg with a 1-minute rest interval between trials.

Data from the three best attempts were averaged together and used in the data analyses. The three best attempts were defined as the three trials with the highest voluntary activations that also had minimal variation across the plateau of the voluntary torque–time curve graph. MVIC torque/strength prior to twitch was measured by taking the average torque that occurred from 2-2.5 seconds. The MVIC muscle strength was normalized to body mass (i.e., Nm/kg). For subjects with two qualifying legs, the data was averaged between the two legs rather than treating each leg as another participant. A post-test using the same protocol was administered at the end of 6 weeks.

### Randomization

Among the 66 individuals who were screened, 24 subjects were identified as having a knee extensor voluntary activation below 80% and thus were randomly assigned to one of the following 3 groups: 1) control group (i.e., no intervention), 2) exercise group (i.e., 6-week knee extensor strengthening), or 3) exercise plus manipulation group (i.e., 6-week knee extensor strengthening combined with lumbopelvic manipulation).

### Interventions

#### Exercise Only

The strengthening exercises were performed 3 times per week and included the following: straight leg raises, lateral step-ups, single-leg wall squats, bodyweight squats, and seated knee extensions using resistance bands. These exercises were selected based on evidence supporting their efficacy in quadriceps strengthening [13,14] and capacity to be performed at home, as part of a home exercise program. Subjects were supervised and corrected in technique for two exercise sessions every week and performed one session independently. All subjects were given an exercise hand out with images (Appendix A) and information regarding delayed onset muscle soreness (DOMS).

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<table>
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<th>Inclusion Criteria</th>
<th>Exclusion Criteria</th>
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<td>Healthy individuals between the ages of 18-50 years old</td>
<td>Injury/surgery in the past 6 months</td>
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<tr>
<td>Less than 80% average maximal voluntary isometric contraction (MVIC) measured via interpolated twitch technique</td>
<td>Fibromyalgia</td>
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<tr>
<td>Neuropathy or neurologic condition</td>
<td>Neuropathy or neurologic condition</td>
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<tr>
<td>Previous spinal surgery</td>
<td>Previous spinal surgery</td>
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<tr>
<td>Less than 80% average maximal voluntary isometric contraction (MVIC) measured via interpolated twitch technique</td>
<td>Osteoporosis</td>
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<td>Allergy to nickel</td>
<td>Allergy to nickel</td>
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Exercise and Manipulation

The exercise and manipulation group followed the same exercise protocol as the exercise only group, but also received the additional lumbopelvic manipulation (Chicago manipulation) once per week prior to an exercise session. The lumbopelvic manipulation chosen was the same manipulation utilized in the study by Grindstaff et al. (2009). [8] The subject was positioned supine on a treatment table, clasping their hands behind their neck. The physical therapist stood opposite of the side being manipulated. The subjects were then passively positioned side-bent towards and rotated away from the side selected for manipulation. The therapist then stabilized the upper body while delivering a posterior/inferior force through the opposite anterior superior iliac spine. If cavitation was not heard by the therapist or subject, the technique was repeated up to one time per side. The lumbopelvic manipulation was performed bilaterally.

Statistical Analysis

The changes in knee extensor voluntary activation and MVIC strength between the pre- and post-training tests were calculated for the three groups. A one-way ANOVA was performed to examine the differences in the change in voluntary activation and MVIC strength among the three groups. Tukey HSD analyses were used for post-hoc pairwise comparisons. An alpha level of 0.05 was used for all tests (SPSS v. 25, IBM, Armonk, NY, USA).

Results

Knee Extensor Voluntary Activation

Results of the one-way ANOVA revealed a significant difference in the post-training changes in knee extensor voluntary activation among the three groups (p = 0.010; Figure-1). Posthoc Tukey HSD indicated that the exercise plus manipulation group demonstrated a significantly greater improvement in the voluntary activation post-training than the control group (9.5% vs. -8.3%; p = 0.008). The exercise only group also demonstrated a greater improvement in the muscle activation than the control group but this difference was not statistically significant (2.8 vs. -8.3%; p = 0.114). There was no significant difference between the exercise only and exercise plus manipulation groups (p = 0.432).

Knee Extensor MVIC Strength

Results of the one-way ANOVA revealed no statistically significant difference in the post-training changes in knee extensor MVIC strength among the three groups (p = 0.870; Figure-2).

Figure 1: Pre- and post-training knee extensor voluntary activation (%) of the three groups. * denotes a significantly greater improvement in voluntary activation of the exercise plus manipulation group when compared to the control group (p = 0.008).
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Figure 2: Pre- and post-training knee extensor MVIC strength (Nm/kg) of the three groups. There was no significant difference in the post-training change in knee extensor strength among the three groups ($p = 0.870$).

Discussion

The results for the outcome of percent activation suggests that the combination of quadriceps exercises and lumbopelvic manipulation had a favorable impact on improving knee extensor activation. As predicted, the exercise and manipulation group demonstrated an increase in activation percentage as compared to controls. However, it was not significantly more beneficial than exercise alone. The subjects who received the exercise only intervention did not experience improvements in activation when compared to controls. It is possible that the lack of change for the exercise only group was due to these participants starting with a slightly higher activation percentage than those in the other two groups. Another possibility is that exercise alone has little effect on muscle activation. One unexpected result was the mean decrease in muscle activation for control subjects. This may have been due to a lack of motivation to improve at the post-test follow up.

The results for the outcome of the knee extensor MVIC strength were not aligned with what was expected. Subjects in the two intervention groups demonstrated improvements in MVIC strength, but these were not significant. The selected exercises were intended to target quadriceps strengthening, but they may not have provided enough of a load to lead to gains in torque production. One potential explanation is that performing the selected exercises alone without a comprehensive strengthening program may not have been a sufficient challenge to result in muscle hypertrophy or strength gains. During a strengthening intervention of similar duration, researchers found that neural factors were responsible for initial strength gains, but hypertrophy became more important after 3-5 weeks. [15] The lack of significant strength gains among both intervention groups suggests that any hypertrophy which may have occurred was insufficient for resulting in increased torque production. The exercise plus manipulation group’s increase in activation without increased torque production is clinically significant because it indicates that improving neuromuscular activation must be accompanied by adherence to a quality strengthening program in order to capitalize on activation gains.

The lack of significant changes in muscle strength may have been due to the exercises themselves or to lack of compliance. Although subjects were supervised during two sets of weekly exercises, it was difficult to ensure that they were completing the additional set independently or with correct form. The control group’s MVIC strength also decreased at follow-up, which was not predicted. This may have been due to a lack of motivation or perhaps due to an average decrease in activity over the course of the study. Many of the participants were graduate students, whose physical activity may fluctuate during the course of a semester.

Conclusion

The findings of this study indicate that combining lumbopelvic manipulation with exercise may be beneficial for improving...
quadriceps activation. However, due to the small sample size and use of convenience sampling, further research is needed to determine if there is any difference between exercise plus manipulation and exercise alone. There were several variables in this study that were difficult to control for, thus making it difficult to draw any meaningful conclusions about the effects of these interventions on knee extensor MVIC strength. Additional research is needed to examine the potential impact of exercise plus manipulation compared to exercise alone on increasing knee extensor strength. One possible future direction of this research is investigating the implications of knee extensor activation on sport performance among college athletes.

Acknowledgements

We would like to thank Michael Theobald, Blake Buchanan and Thomas McLeod for assistance in data collection, and Grace M. White for literature review. We did not receive any funding for this study.

IRB Approval Number: H14423 Georgia State University

Declarations

Clinical Trial Registration: This study was approved by the Georgia State University Institutional Review Board and written informed consent was obtained from the patient for conducting this study/publication of this original research. Editor-in-Chief of this journal will be provided with a copy of the written consent for review (on request).

Appendix A

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Wt.</th>
<th>Rep</th>
<th>Set</th>
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<th>Wt.</th>
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<tbody>
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<td>Straight Leg Raise</td>
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<td>Lateral Step Up</td>
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<td>Single Leg Wall Squat</td>
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<td>Body Weight Squat</td>
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Each exercise will be performed for 3 sets of 12 reps.

* For straight leg raises, you will be lying on your back with the exercising leg fully extended, the exercising foot should have the toes pointed at the ceiling at the beginning and remain in that position throughout the set, and the other knee flexed to 60 degrees. You will then contract your quadriceps, lift the exercising leg to the level of the opposite knee, and then return the exercising leg to the table. Once thighs are parallel, you will hold this contraction for one second and then slowly lower leg back to table, while continuing to contract quadriceps and keep knee straight.
• For lateral step-ups, you will stand with exercising leg resting on stair/platform at height of 8 inches, non-exercising leg will be resting on the floor, feet should be placed a little narrower than shoulder width apart. You should push through exercising leg, lift your body up while extending the knee. Once full extension is achieved, repetition will be completed by slowly lowering non-exercising leg back to ground.

• For single-leg wall squat, you will stand with back flat against the wall. You will then bring one foot off of the ground, center weight over the exercising leg, and then slowly lower yourself using exercising leg until your knee is almost parallel to the ground. Try and maintain your knee alignment directly in line with your foot. Then, you should push back through exercising leg in order to fully extend the knee and return to standing.

• For the body weight squat, you will start with feet shoulder width apart and facing completely forward. You will then slowly lower yourself into a squat position until both knees are parallel to the ground. You will then slowly raise yourself back into a standing position, pushing through hips and thigh.
• The knee extensions will be performed while you sit with upright posture on a table of sufficient height so that feet are not contacting floor and your knees are parallel to the ground. A theraband will be attached to exercising leg to provide resistance. The theraband will either be held by another person for resistance or tied off to a stationary object nearby. You will slowly extend knee against resistance until almost full extension is obtained. Then, you will slowly return to the starting position controlling decent.

References