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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 quadriceps muscle activation.

Purpose: To investigate whether combining a weekly lumbopelvic manipulation with strengthening exercises over six-weeks would increase quadriceps activation and force production for a longer duration than just an immediate effect.

Study Design: Randomized Controlled Trial

Objective: To determine if lumbopelvic manipulation combined with knee extensor strengthening exercises has a greater effect on voluntary activation and MVIC strength than performing exercises alone.

Subjects: Sixty-six individuals were screened for eligibility, and 24 subjects who qualified with less than 80% knee extension activation completed the study. Subjects were randomized to three separate groups: exercise plus manipulation (n= 8), exercise only (n=8), and a control group (n=8).

Methods: To determine eligibility, a Kin Com III dynamometer was used to measure knee extensor activation and a computer controlled Digitimer DS7AH stimulator was used to stimulate the participants' quadriceps muscles. Interventions were performed over a 6-week period. Exercises were performed 3 times/week using a standardized protocol. The manipulation plus exercise group received a lumbopelvic manipulation once per week. Knee extensor activation and strength were measured after the 6-week intervention by percent MVIC and peak torque production, respectively.

Results: A one-way ANOVA with post-hoc Tukey HSD determined there was a significant difference (p= 0.010) between groups for change in knee extensor activation. Mean knee extensor activation for the manipulation plus exercise group increased as compared to controls (p = 0.008). The exercise only group demonstrated a non-significant increase in activation. There was no difference between groups for knee extensor torque production.

Conclusion: Combining exercise and lumbopelvic manipulation had a larger impact on improving knee extensor activation than the control, but exercise alone did not significantly improve activation. 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; physical therapy; injury recovery; knee extensors; exercise; muscle activation

Introduction

Arthrogenic muscle inhibition is a persistent reflex response after joint injury and refers to a state in which the muscle cannot be fully contracted in spite of there being no damage to the muscle itself or its innervating nerves. [1] Knee injury or surgery can lead to arthrogenic muscle inhibition. Persistent muscle inhibition may initially serve to protect a joint after injury but can hinder return to function. Muscle inhibition is not synonymous with muscle force production, though the two are related. Stevens et al. (2003) found that changes in muscle activation following total knee arthroplasty (TKA) accounted for most of the decrease in muscle strength measured after the procedure.[2] Research indicates that strength deficits and muscle inhibition are present in patients with knee osteoarthritis (OA) before and after undergoing TKA, and voluntary muscle activation failure is a major contributor to weakness in this patient population.[3] Muscle inhibition could contribute to difficulties with rehabilitation and lead to altered biomechanics and further joint injury and degeneration.

Clinicians frequently treat patients who are at risk for persistent knee extensor inhibition. Patient populations at risk include individuals with OA, patellofemoral pain, ACL or other ligamentous injuries, and post-operative patients. Osteoarthritis of the knee may present with decreased quadriceps strength and impaired muscle activation.[4] Fitzgerald et al. (2004) found that individuals with strength deficits and quadriceps activation failure experienced more severe functional impairments than those with weakness and normal activation suggesting that higher voluntary muscle activation can improve physical function in individuals with quadriceps weakness. In a systematic review, Hart et al. (2010) found that individuals with ACL deficiency, ACL reconstruction, or anterior knee pain commonly present with quadriceps activation failure, and that this deficit is often bilateral.[1] This study also found that activation inhibition was more common among individuals with knee pain than those with ligamentous injuries, and that those who had ACL reconstruction had higher activation than those with ACL deficiencies. Stevens at al. (2003) found that patients who underwent a TKA procedure, has significantly lower voluntary quadriceps activation on the involved leg following the surgery, though there was no difference between sides prior to the arthroplasty.[2] A 17% decrease in activation accounted for 65% of the variability in strength change from pre- to post-surgery ($r^2 = 0.647$, $p < 0.001$).

Patients with knee pathology often seek physical therapy services for rehabilitation following injury or surgery, or to try to manage impairments conservatively. Physical therapy interventions often include strengthening as part of a plan of care, but improved muscle activation should be targeted as well to promote optimal recruitment of muscle fibers during strengthening exercises and functional activities. Insufficient muscle recruitment could potentially result in altered kinematics and joint loading, which could potentially lead to altered forces placed on neighboring joints. [1] It is challenging to determine the most effective interventions to promote muscle activation, but a multi-modal approach may be beneficial. It has been suggested that inhibitory stimuli from the knee joint contribute to quadriceps inhibition, and that proprioceptive afferent input from mechanoreceptors following a spinal manipulation could temporarily override knee extensor inhibition.[5] Some anecdotal evidence suggests that manipulation of the sacroiliac joint (SIJ) can improve knee extensor activation, but there is limited evidence supporting or refuting this intervention as a means for improving activation .[5]

Grind staff et al. (2012) sought to determine whether quadriceps activation and isometric force could be improved by lumbopelvic manipulation. In this study, 44 participants were divided into three groups: lumbopelvic manipulation, lumbar passive range of motion (PROM), and a prone extension group that served as a control. Researchers performed a single intervention, lasting for just a few minutes. The results revealed that the manipulation group had increased quadriceps force (3.1%) compared to the PROM group (p = 0.001, 95% CI 1/4 5.52, 19.44) and the Prone Ext group (p = 0.02, 95% CI 1/4 1.36, 15.28). [6] The mean activation also increased in the manipulation group (4.7%) as compared to the PROM group (p = 0.04, 95% CI 1/4 0.37, 9.92) and Prone Ext group (p 1/4 0.01, 95% CI 1/4 1.34, 10.90)[6]. These increases were limited in their duration and were only significant immediately after the intervention. The findings of this study suggest that lumbopelvic manipulation has the potential to positively impact quadriceps activation and force output, although manipulation alone may not be able to confer a lasting effect.

The purpose of the present study is to investigate whether combining a weekly lumbopelvic manipulation with strengthening exercises over a six-week intervention would increase quadriceps activation and force production for a longer duration than just an immediate effect found in previous research. This research aims to determine if the combination of manipulation and knee extensor strengthening exercises would be more effective in a clinical setting than exercises alone. Knee injury and knee osteoarthritis are highly prevalent conditions that are associated with impaired muscle activation, strength deficits, gait deviations, and decreased ability to perform activities of daily living. Physical therapists have the potential to facilitate improved activation and increased strength in order to promote return to optimal function. This study seeks to determine if lumbopelvic manipulation, in combination with exercise, is effective in a plan of care for patients with knee extensor activation impairments.

Methods

Participants

Sixty-six individuals were screened for eligibility, and 24 subjects that fit the inclusion/exclusion criteria were enrolled in this randomized controlled trial. Subjects were recruited via word of mouth and flyers. Subjects included an equal number of males and females. Subject characteristics are listed in Table 1 and history of musculoskeletal injury can be found in Table 2. Please refer to Table 3 for inclusion and exclusion criteria used to determine subject eligibility. All patients were given the IRB approval letter and signed the informed consent form.

Table 1: Subject characteristics

Group	Gender	Mean Age (Years)	Mean Height (cm)	Mean Mass (kg)	Mean Pre-Torque (N*m/kg)	Mean Pre- Activation %
Exercise + Manipulation	Females (n= 5) Males (n= 3)	25.88 ± 4.73	172.40 ± 9.95	71.49 ± 19.36	2.36 ± 0.94	65.19 ± 9.50
Exercise	Females (n=4) Males (n=4)	25.63 ± 3.96	170.81 ±6.56	71.49 ± 25.39	2.39 ± 0.72	69.01 ± 9.51
Control	Females (n= 3) Males (n= 5)	25.13 ± 2.80	171.03 ±6.40	72.52 ± 13.09	2.43 ± 0.41	64.08 ± 10.46

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Table 2: History of Musculoskeletal Injury The number of participants in each group with history of previous musculoskeletal injury. Injuries must not have occurred within 6 months prior to participating the study.

Group	Foot/Ankle Injury	Lower Leg Injury	Knee Injury	Thigh Injury	Hip Injury	Spine Injury
Exercise+ Manipulation	2	1	3	2	-	1
Exercise	2	2	4	-	-	1
Control	-	-	4	-	1	-

Table 3: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• Healthy individuals between the ages of 18-50 years old • Less than 80% average maximal voluntary isometric contraction	• Individuals under 18 or over 50 years old • Injury/surgery in the past 6 months • Fibromyalgia • Neuropathy or neurologic condition • Previous spinal surgery • Osteoporosis • Allergy to nickel

Testing Procedure

A Kin Com III dynamometer was used to measure knee extensor activation and a computer controlled Digitimer DS7AH stimulator was used to briefly stimulate the participants' quadriceps muscles. The participant was seated in a kincom III dynamometer (Chattecx, Chattanooga, TN) in a semi-reclined position with 70° of knee flexion. 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 torque production and activation using an interpolated twitch technique. [7,8]

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. An example of the testing set-up is pictured in Figure 1. 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.

Figure 1: Dynamometer set-up used in MVIC testing procedure

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 seconds until the peak contraction torque plateaued. The activation was determined by a decrease in torque on two consecutive stimulations. The current which caused the highest peak torque was used for the remainder of the test session.

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 torque was normalized to body mass (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

Twenty-four subjects (mean age: 25.5 and range of 22-37) were identified as having below 80% knee extensor activation during an MVIC and randomly assigned to one of 3 groups: no intervention, knee extensor strengthening, or knee extensor strengthening plus lumbopelvic manipulation. Each group was comprised of eight subjects.

Interventions

Exercise Only

Interventions were performed over a 6-week period. Exercise was performed 3 times/week and exercises included 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 ability to be performed without the need for much equipment and evidence supporting effectiveness for quadriceps strengthening. [9,10] Subjects were supervised and corrected in technique for two (2) exercise sessions every week. Figure 2 illustrates the exercises performed by subjects receiving the two interventions. All subjects were provided with the exercise hand out in Appendix B and instructions about managing delayed onset muscle soreness (DOMS) in the event that they experienced it.

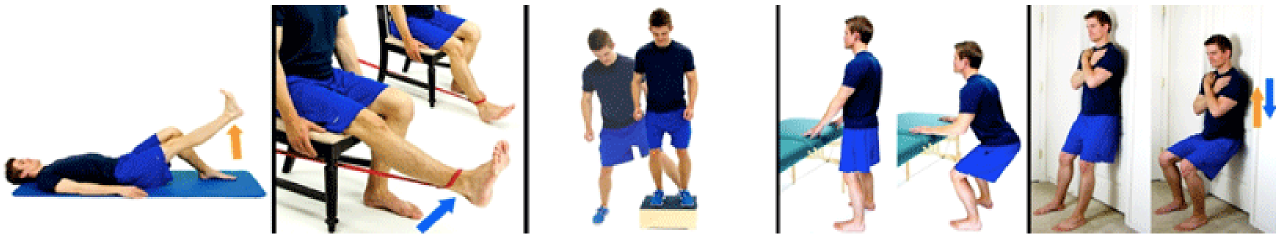

Figure 2: Knee Extensor Strengthening Exercises

Exercise and Manipulation

The manipulation group followed the same exercise protocol as the exercise only group but received the additional lumbopelvic manipulation (Chicago manipulation) once per week prior to an exercise session. The Chicago lumbopelvic manipulation is performed by having the subject positioned supine on a treatment table with their hands behind their neck. The therapist stands opposite to the side being manipulated. The subjects were positioned side-bent towards and rotated away from the side selected for manipulation. The therapist stabilized the upper body while delivering a posterior/inferior force through the opposite anterior superior iliac spine. If cavitation/"pop" was not heard by the therapist or subject, the technique was repeated up to one time on each side. The lumbopelvic manipulation was performed on each side. Figure 3 depicts this manipulation technique.

Therapist provided the manipulation

The operator is a licensed Physical Therapist in the State of Georgia with 18 years of experience in orthopedic and manual therapy, a graduate degree in Doctor of Physical Therapy, a Board Certified Orthopedic Specialist (OCS), certified in Dry Needling and Spinal Manipulative Therapy with the Spinal Manipulation Institute and is enrolled as Fellow-in-Training in the American Academy of Manipulative Therapy's Orthopedic Manual Physical Therapy Fellowship Program.

Data Analysis

A one-way ANOVA (difference in pre-post values) was performed for the variables of activation percentage and peak torque prior to twitch. Tukey HSD post-hoc tests were conducted to assess where the difference between groups occurred.

Results

Muscle Activation

There was a significant difference ($p= 0.010$) between groups for the change in knee extensor activation from baseline measurements to those following the intervention. Mean knee extensor activation for the manipulation plus exercise group increased as compared to controls ($p = 0.008$). Although the exercise only group demonstrated an increase in activation, this improvement was not significant. There was no difference for change in activation percentage between the exercise only and the exercise plus manipulation groups. Figure 4a, 4b provides a descriptive of these changes.

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Figure 3: Lumbopelvic Manipulation

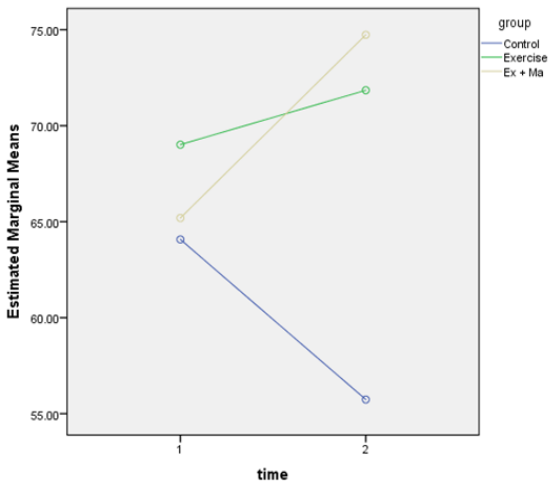

Figure 4a: Change in knee extensor activation (%) from pre-test to post-test (p = 0.010) for the exercise plus manipulation, exercise, and control groups. There was a difference between the exercise plus manipulation group and controls (p = 0.008)

Torque Production

There was no significant difference between any of the groups for the change in knee extensor torque production. Refer to Figure 4b for a descriptive of torque production for the three groups.

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

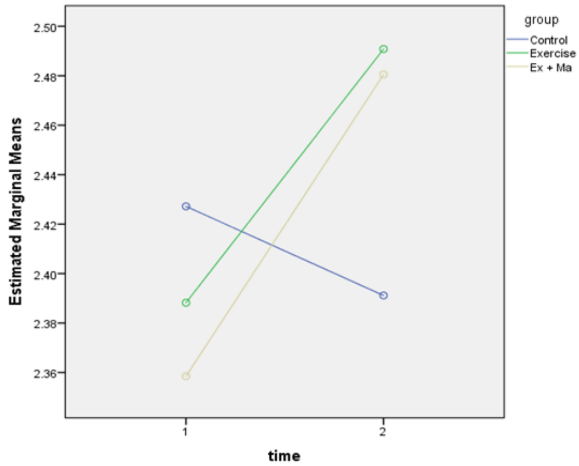

Figure 4b: Torque prior to twitch (N.m/kg) from pre-test to post-test (p > 0.05) for the exercise plus manipulation, exercise, and control groups.

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 peak torque prior to twitch were not aligned with what was expected. Subjects in the two intervention groups demonstrated improvements, 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.[11] 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+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 torque 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 mean torque prior to twitch 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 torque production. Additional research is needed to examine the potential impact of exercise plus manipulation compared to exercise alone on increasing knee extensor torque. One possible future direction of this research is investigating the implications of knee extensor activation on sport performance among college athletes.

Acknowledgements

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).

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