AN ACUTE BOUT OF SELF-MYOFASCIAL RELEASE INCREASES RANGE OF MOTION WITHOUT A SUBSEQUENT DECREASE IN MUSCLE ACTIVATION OR FORCE

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ABSTRACT

MacDonald, GZ, Penney, MDH, Mullaley, ME, Cuconato, AL, Drake, CDJ, Behm, DG, and Button, DC. An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *J Strength Cond Res* 27(3): 812–821, 2013. Foam rolling is thought to improve muscular function, performance, overuse, and joint range of motion (ROM); however, there is no empirical evidence demonstrating this. Thus, the objective of the study was to determine the effect of self-myofascial release (SMR) via foam roller application on knee extensor force and activation and knee joint ROM. Eleven healthy male (height 178.9 ± 3.5 cm, mass 86.3 ± 7.4 kg, age 22.3 ± 3.8 years) subjects who were physically active participated. Subjects' quadriceps maximum voluntary contraction force, evoked force and activation, and knee joint ROM were measured before, 2 minutes, and 10 minutes after 2 conditions: (a) 2, 1-minute trials of SMR of the quadriceps via a foam roller and (b) no SMR (Control). A 2-way analysis of variance (condition × time) with repeated measures was performed on all dependent variables recorded in the precondition and postcondition tests. There were no significant differences between conditions for any of the neuromuscular dependent variables. However, after foam rolling, subjects' ROM significantly ($p < 0.001$) increased by 10° and 8° at 2 and 10 minutes, respectively. There was a significant ($p < 0.01$) negative correlation between subjects' force and ROM before foam rolling, which no longer existed after foam rolling. In conclusion, an acute bout of SMR of the quadriceps was an effective treatment to acutely enhance knee joint ROM without a concomitant deficit in muscle performance.

KEY WORDS myofascial release, foam rolling, quadriceps, force, range of motion

INTRODUCTION

Fascial restrictions often occur in response to injury, disease, inactivity, or inflammation, causing fascial tissue to lose elasticity and become dehydrated. When fascia loses its elasticity and becomes dehydrated, fascia can bind around the traumatized areas, causing a fibrous adhesion to form. Fibrous adhesions are known to be painful, prevent normal muscle mechanics (i.e., joint range of motion [ROM], muscle length, neuromuscular hypertonicity, and decreased strength, endurance, and motor coordination) and decrease soft-tissue extensibility (5,15,35).

Myofascial release (MFR) therapy is a manual-therapy technique developed by Barnes (5), to help reduce restrictive barriers or fibrous adhesions seen between layers of fascial tissue. A new technique of MFR termed self-induced myofascial release (SMR) has become of increasingly common practice for treating soft-tissue restrictions. The SMR works under the same principles as myofascial release. The difference between the 2 techniques is that instead of a therapist providing manual therapy to the soft tissue, individuals use their own body mass on a foam roller to exert pressure on the soft tissue. The SMR technique involves small undulations back and forth over a dense foam roller, starting at the proximal portion of the muscle, working down to the distal portion of the muscle or vice versa (27). The small undulations place direct and sweeping pressure on the soft tissue, stretching the tissue, and generating friction between the soft-tissue of the body and the foam roller. The friction generated from the undulations causes warming of the fascia, promoting the fascia to take on a more fluid-like form (known as the thixotropic property of the fascia), breaking up fibrous adhesions between the layers of fascia and restoring soft-tissue extensibility (31).

In the past decade, therapists and fitness professionals have implemented SMR via foam rolling as a recovery and

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maintenance tool to aid in the process of soft-tissue healing. It has been postulated that fascia can form abnormal crosslinks and have changes in the ground substance viscosity, changing from a gel to a more solid state (4,33). These changes may cause the fascia to become less pliable, potentially restricting movement patterns and muscular forces because of a lack of movement in response to injury or inactivity (4). Foam rolling can be implemented into a number of different rehabilitation and training programs to promote soft-tissue extensibility, potentially enhancing joint ROM and promoting optimal skeletal muscle function. Furthermore, advocates (5,15,35) believe that foam rolling corrects muscular imbalances, alleviates muscle soreness, relieves joint stress, improves neuromuscular efficiency, and improves ROM. Unfortunately, the literature on foam rolling is rudimentary; thus, there are no peer-reviewed empirical data to support such beliefs. To our knowledge, there was only one nonpeer-reviewed research study on foam rolling and ROM (22). Miller and Rockey (22) investigated the chronic effects of an 8-week foam rolling program on hamstring flexibility. They found that the foam rolling program was ineffective in increasing ROM of the hamstring muscles. Curran et al. (15) determined that myofascial rollers made of harder material (a hollow polyvinyl chloride [PVC] pipe surrounded by a thin layer of neoprene) significantly increased soft-tissue pressure and better isolated contact area on the soft tissue in comparison to foam rollers made of softer material (uniform polystyrene foam). Thus, when using SMR, a foam roller made of hard material may be more beneficial to optimize muscle function.

There is little empirical evidence supporting SMR, and the literature that does exist mainly reports the chronic, but not the acute effects, of myofascial release on muscle performance. The objectives of this study were twofold. The first objective was to determine if an acute bout of SMR via a high-pressure foam roller affects volitional and evoked quadriceps muscle force. The second objective was to determine if foam rolling improves knee joint ROM. In this study, the term "acute" refers to the period immediately after foam rolling (2 and 10 minutes). These time points were chosen to demonstrate how foam rolling could be used as part of a warm-up for a muscular performance event. We hypothesized that there would be an increase in knee joint ROM and a decrease in quadriceps force output. Our hypothesis was based on results from previous massage (by a therapist) research that demonstrated increased ROM after massage (2,20,38), and decreased muscle electromyography (3) and spinal motoneuron excitability (17,23,34) during massage. A part of these results have been reported elsewhere in abstract form (28).

METHODS

Experimental Approach to the Problem

A within-subject design was used to examine the acute effects of self-induced myofascial release of the quadriceps muscles on: ROM, maximum voluntary force, muscle activation, tetanic force, twitch force and half relaxation time, and rate of force development (RFD). The subjects performed the experimental conditions over 4 sessions, with 24–48 hours of rest between each session (Figure 1 for details). Conditions were divided by intervention and measure. Conditions 1 and 2 measured ROM and force, respectively, during the control intervention, whereas conditions 3 and 4 measured ROM and force, respectively, during the foam roller intervention. During each experimental condition, all dependent variables were measured precondition and 2 and 10 minutes postcondition. Condition 1 (control ROM) was used as a testing and familiarization day. The subjects were tested for ROM before 2 minutes of rest and again 2 and 10 minutes postrest. After ROM measurements, the subjects were familiarized with the myofascial foam rolling technique, performed the maximum voluntary contraction (MVC) with the interpolated twitch technique (ITT), and received a 100-Hz tetanic muscle stimulation. A single familiarization session for foam rolling was enough for the participants to learn the proper foam rolling technique. After experimental condition 1 was complete, the order in which the subjects completed the remaining 3 testing conditions was randomized. During condition 2 (control force), the subjects performed an MVC and received a tetanus before 2 minutes of rest and again 2 and 10 minutes postrest. During conditions 3 (foam roller ROM) and 4 (foam roller force), the subjects were tested for ROM and MVC, twitch force, and tetanus, respectively, before 2 minutes of foam rolling and again 2 and 10 minutes postfoam rolling. The subjects foam rolled the right quadriceps for 2, 1-minute bouts with 1-minute rest between bouts. This time was chosen based on previous literature, which suggests that a constant pressure should be applied to the muscle from 60 to 90 seconds up to 5 minutes or until a release is felt (27,33).

Preceding the start of all experimental sessions, the subjects performed a warm-up on a Monark cycle ergometer for 5 minutes at an intensity of 1 kp and 60 rpm. Dependent variables related to muscle force and muscle contractile properties were measured during different sessions than ROM measures because static stretching, even for short durations, has been shown to cause impairments in force production (8,29). The subjects were instructed to refrain from heavy exercise 24 hours before testing and followed the Canadian Society for Exercise Physiology (CSEP) preliminary instructions (no eating, drinking caffeine, smoking, or drinking alcohol for 2, 2, 2, or 6 hours, respectively) before the start of each intervention.

Subjects

Eleven healthy male (height 178.9 ± 3.5 cm, mass 86.3 ± 7.4 kg, age 22.3 ± 3.8 years) subjects from the university population volunteered for the study. All the subjects were recreational resistance trainers and would be classified by the CSEP as moderate to very physically active. The subjects were verbally informed of all procedures, and if willing to participate, read and signed a written consent form and

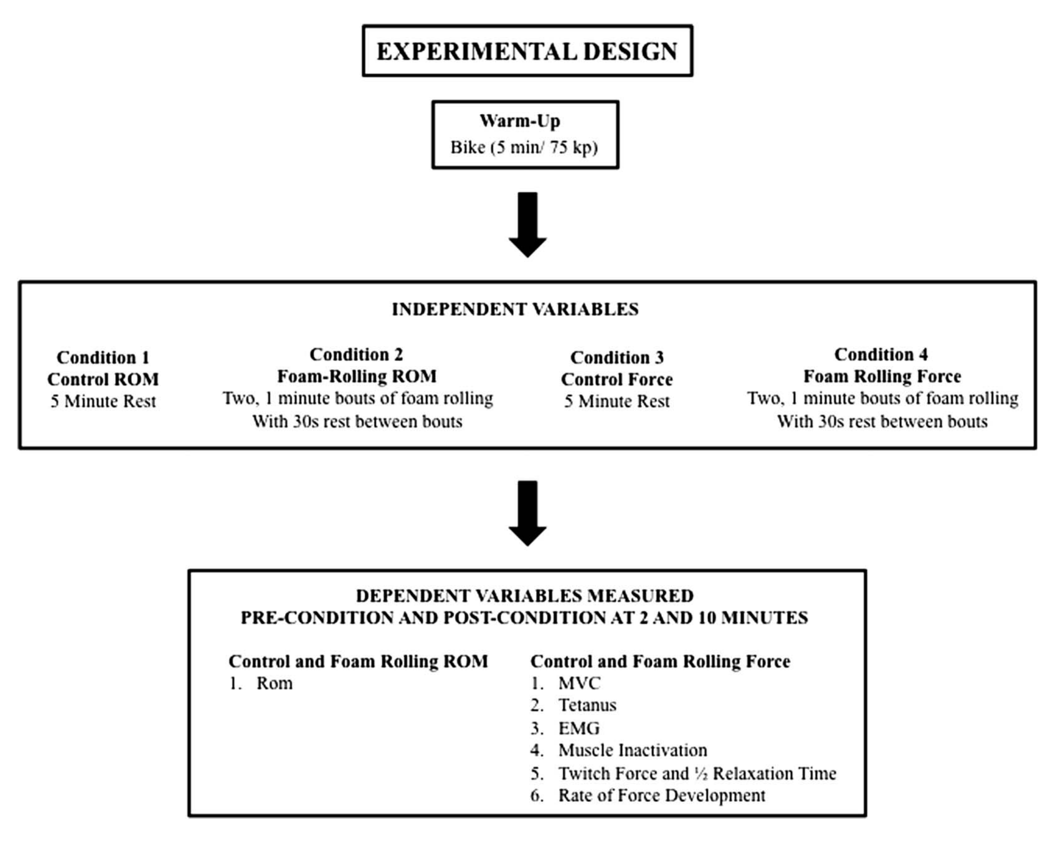

Figure 1. Experimental design. The chart illustrates the experimental setup, conditions, and independent variables that were measured precondition and postcondition at 2 and 10 minutes.

a Physical Activity Readiness Questionnaire before participation. The Memorial University of Newfoundland Human Investigation Committee approved this study.

Independent Variables

Foam Roller and Foam Rolling Technique. The subjects foam rolled on a custom-made foam roller that was constructed of a hollow PVC pipe (10.16-cm outer diameter and 0.5-cm thickness) surrounded by neoprene foam (1-cm thickness). This type of foam roller was used because it places more pressure on the myofascia compared with a Bio-foam roller made from uniform polystyrene foam (15.24-cm diameter) (15). Thus, hereafter, all foam rolling in this study will be considered high pressure. For the myofascial foam rolling technique, the subjects were instructed to begin in a plank position, with the foam roller at the most proximal portion of the quadriceps of the right leg with their left leg crossed over the right (Figure 2). They were told to place as much of their body mass as possible onto the foam roller. They were instructed to roll the foam roller down the quadriceps of the right leg using short kneading-like motions until the foam roller was just above the patella. Once the foam roller reached the patella, the subjects were told to quickly roll the foam roller back to the initial position in one fluid motion. They repeated this for 1 minute, rested for 30 seconds, and then repeated the procedure for

Figure 2. Picture illustrating the foam rolling procedure. The subjects placed all or almost all of their body mass on the high-density foam roller and only the quadriceps muscles of the right leg were in contact with the foam roller. Foam rolling started at the most proximal portion of the quadriceps, and the subjects foam rolled down the quadriceps using short kneading-like motions until the foam roller was just above the patella. This was repeated throughout 2, 1-minute repetitions.

another minute. The subjects rolled out the quadriceps 3–4 times during each minute of foam rolling.

Dependent Variables

Knee Extensor Force. To determine right knee extensor MVC force production, the subjects were seated on a knee extension table with the knee and hip flexed at 90°. Restraints were placed around their upper leg and trunk, and an adjustable backrest was used to provide support. The ankle was inserted into a padded strap, attached by a high-tension wire that measured force using a Wheatstone bridge configuration strain gauge (Omega Engineering Inc. LCCA 250, Don Mills, Ontario, Canada). The subjects performed a 4.5-second isometric MVC with all forces detected by a strain gauge, amplified (Biopac Systems Inc. DA 150 and analog to digital [A/D] converter MP100WSW; Hilliston, MA, USA) and displayed on a computer monitor. Data were sampled at 2,000 Hz. The subjects were instructed to give maximal effort and to produce force as quickly as possible, allowing maximal RFD to be measured. Verbal encouragement was given to all the subjects during the MVC to provide motivation.

Rate of Force Development. The RFD (newtons per second) was measured as the amount of force (newtons) that was generated in the first 200 milliseconds of MVC and then converted to the amount of force generated in 1 second. The maximal rate of rise in muscle force (RFD) has important functional consequences in neuromuscular performance because it determines the force that can be generated in the early phase of muscle contraction (0–200 milliseconds) (1).

Muscle Activation. Before attempting maximal contractions, the subjects would perform approximately 3–5 submaximal knee extension isometric contractions. During the precondition test, the subjects performed 2 MVCs (with 5 minutes of rest between each MVC) to determine their maximum isometric force output. To ensure a consistent maximal effort, the subjects proceeded with the ITT if there was <5% difference between the 2 MVCs (13). The ITT was used as a measure of the central nervous system ability to fully activate the contracting muscle and has been extensively described previously (7,11,12). The ITT was performed with 4 evoked twitches at 2-second intervals throughout a 9.5-second data collection trial as suggested by (32) (Figure 3). Before performing an MVC, the subjects were administered an initial doublet twitch, relaxed, and then told to maximally contract their quadriceps. Doublets rather than single stimuli were used to increase the signal-to-noise ratio (10). During the MVC, the subjects received 2 additional doublet twitches and then were instructed to relax. A fourth potentiated twitch was administered 1.5 seconds after the completion of the MVC. An interpolated twitch ratio was calculated comparing the amplitude of the interpolated twitch with the potentiated twitch to estimate the extent of inactivation during a voluntary contraction (interpolated doublet force/potentiated doublet force × 100 = percent of muscle inactivation) (10).

Superimposed stimulation was accomplished with bipolar surface stimulating electrodes, 4–5 cm in width. Electrodes were secured over the proximal and distal portion of the quadriceps. Stimulating electrodes were constructed from aluminum foil, coated with conduction gel (Eco-Gel 200, Eco-Med Pharmaceutical Inc., Mississauga, Ontario, Canada), wrapped with a paper towel, and then immersed in water. The electrode length was sufficient to cover the width of the muscle belly. To determine the doublet twitch voltage and amperage, subjects' peak twitch torques were evoked with electrodes connected to a high-voltage stimulator (Stimulator Model DS7AH+; Digitimer, Welwyn Garden City, Hertfordshire, United Kingdom). The amperage (10 mA–1 A) and duration (50 microseconds) was kept constant throughout. Voltage ranged from 100 to 300 V and was progressively increased until a maximum twitch torque was achieved. Once the settings for peak twitch torque were achieved, it remained the same when the subject was administered the ITT.

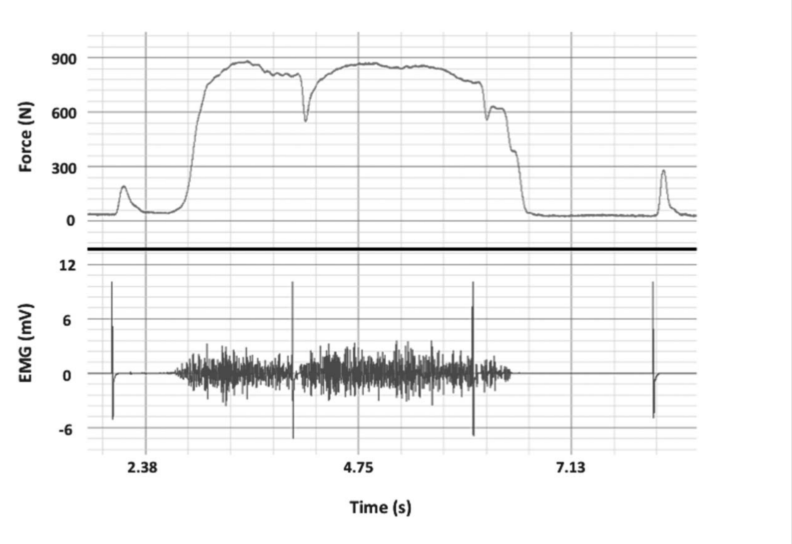

Figure 3. Maximum voluntary contraction force, evoked twitches, and electromyography raw data from 1 participant.

Figure 4. Picture illustrating the quadriceps and knee joint range of motion (ROM) test. The subjects performed a modified kneeling lunge. They positioned themselves so that the right hip was stretched to the point of discomfort. After proper positioning, the subject's right knee was passively flexed until the participant reached a point of discomfort. The change in the angle at the knee was the ROM measurement.

Electromyography (EMG) activity was used as a measure of peripheral muscle activation. Surface EMG recording electrodes (MediTrace Pellet Ag/AgCl electrodes, disc shape, and 10 mm in diameter, Graphic Controls Ltd., Buffalo, NY, USA) were placed over the muscle belly of the rectus femoris, measured by half the distance between the anterior superior iliac spine and the patella, as suggested by Mesin et al. (21). A ground electrode was secured on the fibular head. Thorough skin preparation for all electrodes included shaving hair off the desired area, removal of dead epithelial cells from the desired area with abrasive sand paper, followed by cleansing with an isopropyl alcohol swab. The EMG activity was sampled at 2,000 Hz, with a blackman -61-dB band pass filter between 10 and 500 Hz, amplified (bipolar differential amplifier, input impedance $= 2\ \mathrm{M\Omega}$, common mode ejection ratio >110 dB min [50/60 Hz], gain $\times 1{,}000$; noise $>5\ \mu\mathrm{V}$) and was analog to digitally converted (12 bit) and stored on a personal computer for analysis. The EMG was measured for a 1-second period between the 2 superimposed doublets, to allow generation of peak forces during the MVC (Figure 3).

Tetanic stimulation involved 100-Hz stimulation for 300 milliseconds using the same voltage, amperage, and pulse duration as the doublet twitch administered during the ITT. Tetanic forces were elicited via the surface electrodes 2 minutes after the ITT, while the subject was told to relax. Subjects' average tetanic force was 80% of their MVC force. Tetanic force was not much higher than this because of the

TABLE 1. Raw data presented as mean and *SD*.*†

	Precondition		Postcondition (2 min)		Postcondition (10 min)		Total	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Control								
ROM (°)	71.27	10.02	72.81	11.24	74.36	11.34	72.82	10.89
ROM (Δ)	0.00	0.00	0.91	3.44	1.50	3.30	1.2	3.37
Force (N)	704.00	123.10	677.40	103.60	646.30	96.57	656.64	96.99
Muscle inactivation (%)	8.62	3.18	10.55	4.69	10.20	3.46	9.79	3.80
EMG ($\mathrm{mV \cdot s^{-1}}$)	0.18	0.11	0.19	0.10	0.18	0.11	0.18	0.10
Tetanus (N)	571.50	131.70	557.00	131.90	547.00	140.70	558.50	134.77
RFD ($\mathrm{N \cdot s^{-1}}$)	498.10	202.10	504.90	124.30	481.50	128.10	494.83	151.50
Twitch force (N)	150.90	35.60	137.80	32.40	134.90	31.10	135.89	30.59
1/2 Relaxation time (ms)	0.07	0.02	0.07	0.02	0.08	0.03	0.05	0.01
Foam roller								
ROM (°)	77.55	10.17	88.18†	8.54	86.36†	8.91	84.03‡	10.11
ROM (Δ)	0.00	0.00	10.6†	6.70	8.8†	5.50	9.2‡	6.1
Force (N)	727.50	101.30	692.80	98.48	683.9†	86.97	683.89	86.97
Muscle inactivation (%)	8.30	3.41	9.25	5.22	9.15	4.00	8.90	4.16
EMG ($\mathrm{mV \cdot s^{-1}}$)	0.25	0.17	0.24	0.14	0.25	0.17	0.25	0.15
Tetanus (N)	567.90	125.60	541.30	123.40	532.30	124.50	547.17	124.50
RFD ($\mathrm{N \cdot s^{-1}}$)	566.30	99.70	496.20	171.30	517.30	89.10	526.60	120.03
Twitch force (N)	151.20	38.10	140.60	33.50	134.30	31.20	136.41	31.09
1/2 Relaxation time (ms)	0.07	0.02	0.07	0.02	0.06	0.02	0.05	0.01

*ROM = range of motion; EMG = electromyography; RFD = rate of force development.
†Represents a significant ($\rho < 0.001$) difference between foam rolling and control at 2 and 10 minutes.
‡Represents a significant ($\rho < 0.001$) main effect between foam rolling and control.

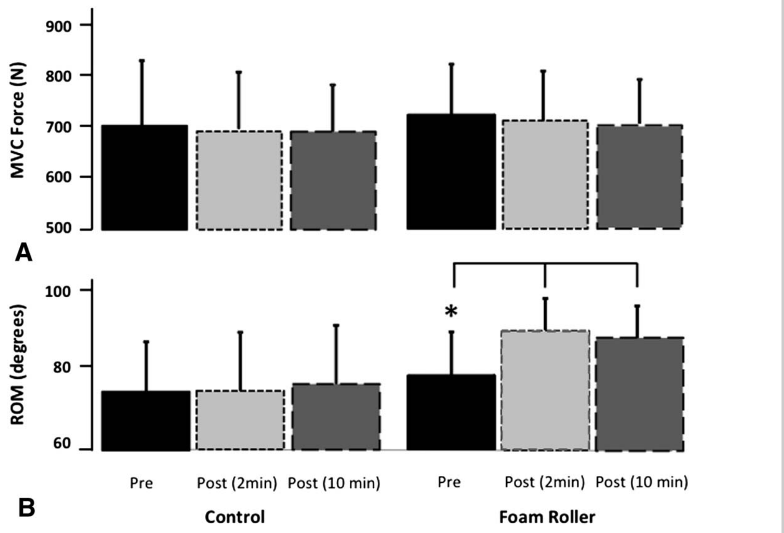

Figure 5. Knee extension force and knee joint ROM during the control and foam rolling conditions. A) Force was not affected by the control or foam rolling conditions. Forces were similar for each condition and at all time points. B) Knee joint ROM did not change in the control condition but significantly increased after foam rolling. * Represents a statistical significance at $p < 0.001$. All data are presented as mean ± 1*SD*.

pain tolerance of the subjects. Tetanic force was used to measure the mechanical integrity of the muscle to produce force as it bypasses the central nervous system. Peak tetanic force was measured.

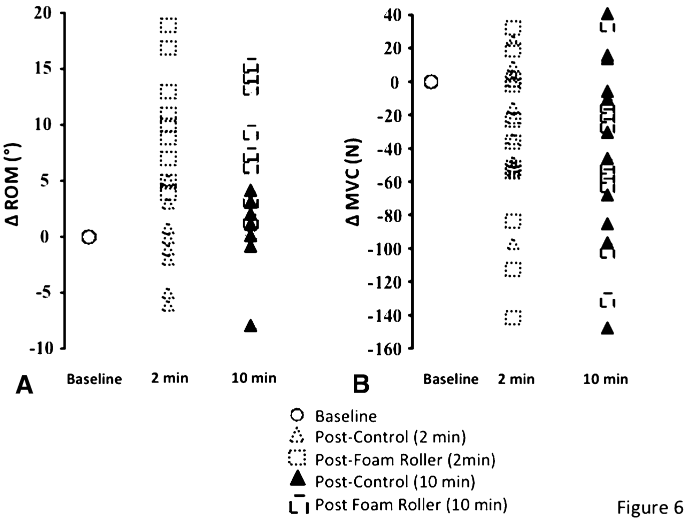

Figure 6. Each data point represents the Δ change in A) range of motion (ROM, °) and B) force (newtons) for each subject at 2 and 10 minutes postbaseline. Overall, subjects' ROM significantly increased at 2 and 10 minutes postfoam rolling but not postcontrol. There was no difference between subjects' force after the foam rolling and control conditions.

Range of Motion. To assess knee joint ROM, the subjects were asked to perform a modified kneeling lunge, with their torso in an upright and erect position, placing their left knee in line with their left ankle and aligning their lower left leg perpendicular to the floor (Figure 4). They were instructed to position themselves so that the right hip was stretched to the point of discomfort. The angle, to which the right hip was stretched, was measured and this hip angle was used for all subsequent ROM measurements during each experimental condition. This process was repeated in all experimental conditions. After the hip angle measurement, initial knee angle was recorded using a goniometer with measurements taken using the following landmarks; the lateral malleolus, the lateral epicondyle, and the center of the vastus lateralis. The subjects were then asked to maintain the stretch at the hip and were restrained by investigators across the chest to avoid any further hip flexion. After proper positioning, the subjects were told to contract the abdominal muscles to ensure maintenance of their trunk posture. The subject's right knee was then passively flexed by investigators until the participant reached a point of discomfort. The change in the angle at the knee was the ROM measurement.

Statistical Analyses

A 2-way analysis of variance (ANOVA) with repeated measures (time) was performed on all dependent variables recorded in the precondition and postcondition tests (SPSS). The 2 factors (2 × 3) included condition (control and foam roller) and time (precondition and postcondition tests at 2 and 10 minutes). The *F*-ratios were considered statistically

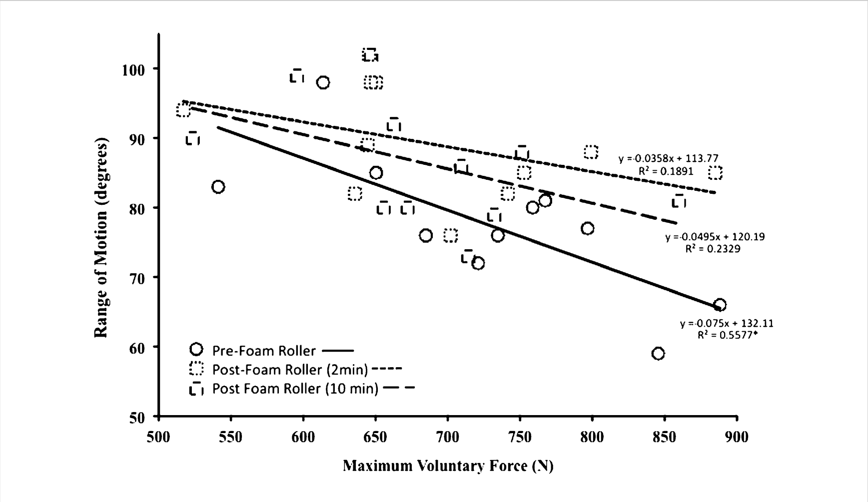

Figure 7. Correlation between subjects' range of motion (ROM) and force. After foam rolling, there was no longer a significant correlation between ROM and force. Each data point represents force and ROM of 1 participant. * Represents a significant ($\rho < 0.01$) negative correlation between subjects' quadriceps force and knee joint ROM before the foam rolling condition.

significant at the $p \leq 0.05$ levels. A Tukey Post Hoc test was performed to test for significant differences between interactions. Person product correlations were also performed to determine relationships between dependent variables. Correlations were considered statistically significant at the $p \leq 0.05$ level. Descriptive statistics in text and where applicable in figures include mean ± *SD*.

RESULTS

Neuromuscular Performance of the Quadriceps

A 2-way ANOVA test revealed that there were no significant differences in any neuromuscular performance measurements (muscle force, RFD, and muscle activation) between the control and foam roller conditions (see Table 1 for details). Specifically, there were no force deficits seen following foam rolling (Figure 5A). The MVC forces were reliably ($\rho < 0.001$, $r = 0.85$) performed within and between the control and foam rolling conditions. Furthermore, the coefficient of variation for MVC force within the control and foam rolling conditions was 5%. Thus, the subjects were able to produce similar forces during both conditions and at all time points.

Knee Joint Range of Motion

A 2-way ANOVA repeated measures test revealed that there was a significant main effect for the foam roller condition on knee joint ROM. Overall, subjects' ROM during the control condition was significantly ($\rho < 0.001$) lower, a mean difference of approximately 7–10° in comparison to the foam roller condition. The 2-way ANOVA repeated measures test also revealed a significant ($\rho < 0.001$) interaction effect of condition × time. A post hoc analysis revealed that compared with prefoam rolling ROM, ROM significantly increased 12.7 and 10.3% at 2 and 10 minutes, respectively, postfoam rolling. The control ROM increased but not significantly by 2.2 and 4.2% at 2 and 10 minutes, respectively, postcontrol condition (Figure 5B). The ROM was significantly ($\rho < 0.001$) higher after the foam rolling condition compared with the control condition at 2 and 10 minutes.

Delta change in ROM and FORCE is as follows: At 2 minutes postfoam rolling, all-subjects increased their ROM by at least 4° to a maximum of almost 20° (Figure 6A). Even at 10 minutes postfoam rolling, subjects' ROM was still greater than their precondition ROM (range 3–17°). After the control condition, subjects' ROM showed little change, and in some cases, there was a slight but not significant decrease in ROM. Subjects' change of force was similar 2 and 10 minutes postfoam rolling and control conditions (Figure 6B).

Correlation Between Quadriceps Force and Knee Joint ROM After Foam Rolling

There was a significant ($\rho < 0.01$) negative correlation between dependent variables; subjects' quadriceps force and knee joint ROM pretest for foam rolling and control conditions. After foam rolling, subjects' quadriceps force and knee joint ROM no longer correlated at 2 and 10 minutes (Figure 7, for clarity only the foam rolling correlations are shown), whereas after the control condition, the significant ($\rho < 0.05$) negative correlation between quadriceps force and knee joint ROM remained at 2 and 10 minutes.

DISCUSSION

Self-myofascial release via a foam roller is a form of massage implemented and promoted by therapists (physical, occupation, athletic) along with functional movement and sport professionals. Foam rolling is used as a warm-up, recovery, and maintenance technique that targets soft-tissue to improve joint ROM and optimize muscular function. This study examined SMR as part of a warm-up protocol to potentially acutely enhance muscular performance. To our knowledge, this is the first peer-reviewed study to analyze the practical and theoretical use of foam rolling. The most important findings presented are as follows: (a) There was a significant increase in knee joint ROM at 2 minutes postfoam rolling (12.7%) and 10 minutes postfoam rolling

(10.3%) of the quadriceps muscles, (b) there was no significant changes in voluntary or evoked muscle properties after foam rolling, and (c) after foam rolling, the negative correlation between ROM and force production no longer existed. Our results strongly show that an acute bout of foam rolling greatly improves joint ROM with no concomitant detrimental effects on neuromuscular force production.

Foam rolling for 2 minutes increased knee joint ROM by approximately 11 and 9° at 2 and 10 minutes, respectively, postfoam rolling. One potential theory to explain the increase in ROM after foam rolling is a change in the thixotropic property (fluid-like form) of the fascia encasing the muscle (27). Fascia is made of colloidal substances, and when it is disturbed, via heat and mechanical stress, it softens and takes on a more gel-like state, but when left undisturbed, it thickens and becomes more viscous, taking on a more solid state (30). Repeated stress placed on the soft-tissue of the body due to overuse or inactivity may cause abnormal crosslinks and scar tissue to form in the fascia. Subsequently, these abnormal crosslinks and scar tissue may inhibit proper biomechanics and reduce joint ROM. The SMR may mechanically shear out these crosslinks and breakdown scar tissue, remobilizing the fascia back to its gel-like state (33). Once the fascia is in a more gel-like state, soft-tissue compliance increases allowing for greater ROM (5). Two important factors to increase soft-tissue compliance are the duration and force of mechanical stress application. Twomey and Taylor (37) demonstrated that long-term mechanical stress application was required to induce a gel-like state. Threlkeld (36) calculated that mechanical stress application forces of 24–115 kg was high enough to cause such changes. In this study, mechanical stress application was only applied for 2 minutes but at very high forces (average body mass 86.3 ± 7.4 kg). Perhaps the high force mechanical stress application (i.e., a combination of body mass and high-pressure foam rolling) performed in this study was enough to induce a gel-like state in the fascia leading to increased soft-tissue compliance and subsequently greater knee joint ROM. In addition to a change in the thixotropic properties of the fascia, foam rolling involves vigorous soft-tissue to roller contact, which places constant pressure on the soft-tissue. Vigorous pressure placed on the soft-tissue may overload the cutaneous receptors, possibly dulling the sensation of the stretch endpoint and increasing stretch tolerance (20), therefore increasing joint ROM.

The increase in ROM after foam rolling was similar to that found after other forms of soft-tissue manipulation. Massage of the of the plantar flexors (20) and hamstrings musculotendinous junction (9) significantly increases ankle and hamstring ROM, respectively. Crossman et al. (14) showed an increase in the ROM at the hip joint following massage of the hamstrings. Arabaci (2) showed that Swedish massage significantly increased sit and reach flexibility. However, Wiktorsson-Moller et al. (38) demonstrated that massage improved ROM but that static stretching resulted in significantly greater hip, knee, and ankle ROM than that obtained by massage, warming up, or warming up and massage combined. Currently, there is no research directly comparing SMR via foam rolling and static stretching-induced changes to ROM. Based on the current SMR study and previous static stretching studies (6–8,16,29), ROM appears to increase by a similar percentage after SMR and static stretching. McKechnie et al. (20) showed a 9–14% (5 minutes post) increase in ROM poststatic stretching, which was similar to the percentage increase in the ROM after foam rolling in this study.

Foam rolling for two, 1-minute bouts did not impede voluntary muscle activation, force or evoked contractile properties. Currently, there are no other studies demonstrating the effects of foam rolling on muscle force. Wiktorsson-Moller et al. (38) found that massage induced a decrease in quadriceps isometric force and hamstrings isokinetic force, which was contradictory to the results found in the present study. A key difference between this study and Wiktorsson-Moller et al. (38) was massage time (2 vs. 7–15 minutes, respectively) and massage type (foam rolling vs. a massage therapist, respectively). Others have found that short-duration massage increases joint ROM while maintaining muscular power (20).

Based on studies demonstrating the effects of massage on EMG and spinal cord excitability, it was surprising to find no change in muscle force. Arroyo-Morales et al. (3) demonstrated a significant decrease of vastus medialis EMG during 40 minutes of massage on the quadriceps. Thus, a transient loss in muscle strength may be seen after massage, although this was not tested. In this study, myofascial release was for 2 minutes as opposed to 40 minutes. No changes in EMG levels were seen after the short-duration SMR implemented in this study. Perhaps there is an EMG vs. massage-time relationship. Shorter massage times may cause no change in EMG and subsequent force production (20). Several studies (17,23,34) have found that massage decreases spinal motoneuron excitability along with a depression in H-reflex amplitude after a short bout of massage. The H-reflex size was dependent on the massage pressure. A deeper massage induced greater inhibition of the spinal motoneuron. The H-reflex depression was not dependent on mechanical stimulation of cutaneous mechanoreceptors but may have been so because of the involvement of deep mechanoreceptors (17,23,34). Unfortunately, we were unable to determine the amount of pressure between the quadriceps muscle and foam roller and nor was H-reflex measured. Each subject placed most or all of their body mass on the foam roller during rolling, which should be comparable or greater in intensity than that of a deep massage. In the previous studies, the H-reflex was recorded during the massage itself. Perhaps in those studies, if muscle force and activation were measured directly after the massage, there may have been decreases. In this study, activation and force were tested 2 and 10 minutes postfoam rolling. The 2-minute rest period may have allowed for a reduction in deep mechanoreceptor activation, leading to a restoration of the H-reflex, allowing for normal force production.

Although static stretching increases ROM, it is being eliminated from the traditional preevent warm-up because prolonged static stretching impairs neuromuscular performance (6–8,29). Decreased neuromuscular performance (6–8,29) after static stretching may be attributed to the potential static stretching-induced sarcomere damage. Thus, static stretching may cause tremendous stress during muscle lengthening, potentially damaging the sarcomere (24) and subsequently reducing muscle force. However, recent research demonstrating the effects of acute (25) and chronic (26) static stretching on muscle-tendon unit (MTU) stiffness has shown that decreased MTU stiffness after static stretching was not because of changes in fascicle length but rather a combination of muscle stiffness and changes to the surrounding connective tissue (i.e., fascia). Although a decrease in MTU stiffness may lead to decreased force (19), it is unknown how static stretched-induced changes in connective tissue affects muscle force. The physiological mechanism by which SMR enhances ROM is very different than static stretching. Instead of placing pressure on the origin and insertion points of the muscle, which leads to increase sarcomeres in series, SMR may enhance the thixotropic nature of the fascia enveloping the muscle (see above for more details). Foam rolling is thought to enhance soft-tissue pliability, which allows increased joint ROM (5) and potentially without causing any damage to the crossbridges and sarcomeres of the muscle and subsequently not impacting muscle force production. However, it remains unknown whether foam rolling causes damage to the muscle fibers of the involved muscle.

The present results, illustrating that foam rolling diminished the significant negative correlation between ROM and MVC force production are interesting. Before foam rolling, the subjects who had the least ROM produced the greatest amount of force and vice versa. In accordance with the correlation coefficient, ROM could explain 31% of the factors related to force before foam rolling, which decreased to 5.4 and 3.5% at 2 and 10 minutes postfoam rolling, respectively. Similar to foam rolling, the pretest control ROM could explain 28% of the factors related to force however, unlike foam rolling, the correlation coefficient at 2 and 10 minutes postcontrol remained >22%. The relationship between ROM and force production could have implications in sporting and rehabilitation settings. In clinical rehabilitation settings, individuals who have joint mobility injuries generally receive therapy to increase mobility while still maintaining stability within a given joint, as was seen with the functional movement screen (18). A technique that can enhance ROM without inhibiting force production could be of value in treating joint mobility injuries. This study showed a 10.6 ± 6.7° (2 minutes post) and an 8.8 ± 5.5° (10 minutes post) increase in the ROM post SMR via foam rolling without a subsequent loss in force output, making SMR via foam rolling an applicable technique to enhance the ROM before a muscular performance event.

One potential limitation in the study was the difficulty to find a knee joint ROM test for knee flexion. Part of the difficulty was that most individuals can flex their knee until their heel touches the buttocks. Thus, to assess knee joint ROM, each participant was asked to conform a kneeling lunge position so that the right hip was stretched to the point of discomfort followed by the participant's right knee being passively flexed to the point of discomfort. Even using this standardized technique, 4 of the 11 subjects minimally increased ROM because their heel touched the buttocks. Thus, the ROM mean values reported here were probably an underestimation of the overall effect foam rolling has on the flexibility of the quadriceps.

Based upon this initial investigation, future research may endeavor to examine a postfoam rolling time line to determine how long ROM remains enhanced beyond 10 minutes. Furthermore, the foam rolling duration in this study was only 2 minutes. It would be interesting to determine the effects of longer durations of foam rolling on ROM and muscle performance. In future studies that test knee joint ROM for the quadriceps, it may be optimal to recruit participants who are inflexible. This may reduce the number of participants who are able to touch their heel off the buttocks in the ROM test employed here.

PRACTICAL APPLICATIONS

In conclusion, the data presented in this study suggest that an acute bout (only 2 minutes) of slow undulating foam rolling of the quadriceps on a high-pressure foam roller significantly increases quadriceps ROM. In fact, foam rolling for only 2 minutes enhances quadriceps muscle ROM to a similar degree as previously reported in other static stretching studies. More importantly, acute foam rolling had no significant impact on quadriceps muscle force or activation. Although the results apply to static ROM and isometric force production, which may or may not have application to dynamic movements, the results give supporting evidence to the potential benefits of employing a foam rolling program to increase joint ROM before a physical activity that requires substantial force production.

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