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Foam Rolling as a Recovery Tool after an Intense Bout of Physical Activity

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Abstract

Purpose

The objective of this study is to understand the effectiveness of foam rolling (FR) as a recovery tool after exercise-induced muscle damage, analyzing thigh girth, muscle soreness, range of motion (ROM), evoked and voluntary contractile properties, vertical jump, perceived pain while FR, and force placed on the foam roller.

Methods

Twenty male subjects (≥3 yr of strength training experience) were randomly assigned into the control (*n* = 10) or FR (*n* = 10) group. All the subjects followed the same testing protocol. The subjects participated in five testing sessions: 1) orientation and one-repetition maximum back squat, 2) pretest measurements, 10 × 10 squat protocol, and POST-0 (posttest 0) measurements, along with measurements at 3) POST-24, 4) POST-48, and 5) POST-72. The only between-group difference was that the FR group performed a 20-min FR exercise protocol at the end of each testing session (POST-0, POST-24, and POST-48).

Results

FR substantially reduced muscle soreness at all time points while substantially improving ROM. FR negatively affected evoked contractile properties with the exception of half relaxation time and electromechanical delay (EMD), with FR substantially improving EMD. Voluntary contractile properties showed no substantial between-group differences for all measurements besides voluntary muscle activation and vertical jump, with FR substantially improving muscle activation at all time points and vertical jump at POST-48. When performing the five FR exercises, measurements of the subjects' force placed on the foam roller and perceived pain while FR ranged between 26 and 46 kg (32%–55% body weight) and 2.5 and 7.5 points, respectively.

Conclusion

The most important findings of the present study were that FR was beneficial in attenuating muscle soreness while improving vertical jump height, muscle activation, and passive and dynamic ROM in comparison with control. FR negatively affected several evoked contractile properties of the muscle, except for half relaxation time and EMD, indicating that FR benefits are primarily accrued through neural responses and connective tissue.

Foam rolling (FR) is commonly used as a recovery tool after a bout of physical activity, with advocates (3,15) claiming that FR corrects muscular imbalances, alleviates muscle soreness, relieves joint stress, improves neuromuscular efficiency, and improves range of motion (ROM). FR has been implemented into several different rehabilitation and training programs to help promote soft tissue extensibility, enhance joint ROM, and promote optimal skeletal muscle functioning (3,15,25). Although FR has been strongly advocated and is commonly used, there have only been three peer-reviewed research articles published to date. Pearcey et al. (31) examined the effects of FR on pressure pain threshold and dynamic performance measures after an intense exercise protocol, concluding that FR is an effective method in reducing delayed onset muscle soreness (DOMS) and associated performance decrements in sprint time, power, and dynamic strength/endurance. MacDonald et al. ([25]) investigated the effects of acute FR before physical activity and demonstrated that FR had no effects on neuromuscular performance, although significantly increasing ROM at 2 and 10 min post-FR by 10% and 8%, respectively. Curran et al. ([15]) determined that a higher density foam roller significantly increased soft tissue pressure and isolated the soft tissue contact area, potentially increasing the effects FR has on improving soft tissue health. Quantifiable scientific evidence to validate the use of foam rollers and understand the effectiveness of FR as a recovery tool from physical activity is rudimentary; thus, it would be prudent to further investigate its effectiveness and mechanisms.

From the recreationally active to the elite athlete, many individuals commonly experience exercise-induced muscle damage (EIMD) resulting in DOMS after an intense bout of physical activity. EIMD is characterized by muscle soreness, muscle swelling, temporary muscle damage, an increase in intramuscular protein and passive muscle tension, and a decrease in muscular strength and ROM ([10,36]). In addition to these responses, EIMD can affect neuromuscular performance by reducing shock attenuation and altering muscle sequencing and recruitment patterns, potentially placing unaccustomed stress on muscle tendons and ligaments ([10]). There are several proposed theories regarding the mechanisms of DOMS, with the bulk of the literature reporting that high mechanical stress placed on the myofibrils, most commonly seen during eccentric exercise, damages the muscle tissue and connective tissue, triggering an acute inflammatory response consisting of edema and inflammatory cell infiltration that leads to a loss of cellular homeostasis, particularly due to high intracellular calcium concentrations ([36]). Sarcomere damage, calcium accumulation, protein degradation, and osmotic pressure all combine to sensitize nociceptors and other pain receptors, causing the sensation of DOMS ([10]). Through the analysis of several review articles, treatments that have shown potential benefits in treating symptoms of EIMD include cryotherapy ([12,20,36]), light exercise ([12,36]), and compression ([10,12]). Although these therapies have shown to be beneficial in treating EIMD symptoms, the contrary has also been demonstrated in the literature ([10,12,20,36]). On top of this, although these methods have shown to be beneficial in treating EIMD symptoms, no one therapy has proven to be beneficial in treating the full array of symptoms often presented by EIMD. Varying results demonstrated in the literature can be attributed to the varying EIMD protocols, along with the heterogeneity among studies assessing a given therapy in relation to the dose, frequency, and intensity of the intervention.

Currently, there is only one published article by Pearcey et al. ([31]) pertaining to the effects of FR on EIMD. Pearcey et al. ([31]) analyzed the effects of FR on functional measures such as sprint speed, agility, broad jump, squat strength, and pain threshold but did not examine the possible underlying mechanisms. With FR commonly being termed as a method of self-myofascial release or self-massage ([25]), massage research may allow us to gain insight into the mechanisms and effects of FR on EIMD. Although massage has not been shown to be an effective method in improving ROM ([36,39]) or muscular strength ([18,36,39]) after EIMD, massage has been shown to be beneficial in treating EIMD by increasing mitochondrial biogenesis ([13]), restoring blood flow ([34]), and improving vertical jump height ([26,38]) while decreasing muscle soreness ([13,18,34,39]), cellular stress ([13]), and inflammation ([13]). Massage has also shown varying results in reducing limb circumference ([36,39]) and creatine kinase levels ([34,36]) while potentially increasing circulating neutrophil counts ([12,34,36]).

With several studies showing the benefits of massage when treating EIMD, the purpose of our research was to substantiate if FR was an effective tool to aid in the recovery from an intense bout of physical activity that induces DOMS and identify potential mechanisms. We specifically addressed the effects of FR on muscle soreness, voluntary and evoked contractile properties, vertical jump, and ROM. This investigation also explored the general characteristics of FR relating to force application and perceived pain during five different lower body FR exercises.

METHODS

Subjects

Twenty physically active resistance-trained male subjects volunteered for the study. All the subjects regularly resistance trained three times a week or more (one-repetition maximum (1RM) squat, 129.2 ± 26.7 kg; 1RM as percent body weight, 152.2% ± 24.5%). The subjects were randomly assigned to an experimental "foam rolling" (FR) (*n* = 10; height, 180.9 ± 5.5 cm; weight, 82.4 ± 9.4 kg; age, 25.1 ± 3.6 yr; 1RM squat, 130.0 ± 20.6 kg) or "control" (CON) (*n* = 10; height, 179.4 ± 4.0 cm; weight, 86.9 ± 8.6 kg; age, 24.0 ± 2.8 yr; 1RM squat, 128.4 ± 32.9 kg) group. Written informed consent was obtained from all the subjects. The Memorial University of Newfoundland Human Investigation Committee approved the study.

Experimental Design

All the subjects were required to participate in five testing sessions, all occurring at the same time of day for each participant. The organization of the five testing sessions was 1) orientation and 1RM testing, 2) pretest measurements (PRE), 10 × 10 squat protocol, posttest 0 (POST-0), 3) posttest 24 (POST-24), 4) posttest 48 (POST-48), and 5) posttest 72 (POST-72) h. All testing sessions were separated by 24 h, except sessions 1 and 2, which were separated by at least 96 h, to ensure that the subjects had recovered from the 1RM protocol. (See Figure 1.) The flowchart displays methodology along with the dependent variables assessed each time test measurements were taken.

In session 1, the subjects were provided with a verbal explanation of the study and read and signed an informed consent form. Participants' age, height, weight, and thigh girth (TG) were recorded. The subjects were randomly assigned to one of two test groups, FR or CON.

Once the subjects were assigned to their test group, the subjects' 1RM for a free weight back squat was determined. The 1RM protocol consisted of a general warm-up on a stationary cycle ergometer with the resistance set at 1 kp, cycling at a cadence of 70 rpm for 5 min. The squat protocol required the subjects to perform a full ROM (thighs parallel to floor) plate-loaded barbell back squat. The subjects were instructed to position the plate-loaded barbell above the posterior deltoids at the base of the neck.

Before attempting a 1RM lift, the subjects performed a series of submaximal sets of eight, five, and two repetitions (reps) with increasing loads. The subjects rested for 2 min between submaximal lift trials and for 3 min between each 1RM trial. If the subjects successfully performed a squat with proper form, the weight was increased by approximately 1–10 kg, and the subject would attempt another squat at the new set weight. A failed lift was defined as a squat falling short of full ROM or failure to complete the squat repetition. If a subject failed in two consecutive attempts at a set weight or felt that they had reached their 1RM, the previous successfully lifted weight was considered the subject's 1RM.

Once the subjects' 1RM was determined, all the subjects were familiarized with the EIMD protocol, along with the test measures and instruments used to conduct the experiment. The subjects in the FR group were also oriented with the FR exercise protocol (see FR section), instructed on how to perform the experimental exercise techniques, and given time to ask any questions they had regarding the FR exercise protocol.

In session 2, all the subjects were required to complete an EIMD protocol consisting of 10 sets of 10 reps of back squats, with 2 min of rest between each set. The weight was set at 60% of their 1RM weight. Three subjects from each group failed to complete the EIMD protocol, implementing the 2-min rest period between each set. Adequate rest was given to the subjects, allowing them to complete all 100 reps outlined in the protocol. Two subjects were exempt from the study because they were unable to complete the required 100 reps. Before completing the EIMD protocol, the subjects performed the same previously described 5-min cycle ergometer warm-up, followed by two sets of five reps at 50% of their 1RM. Squats were performed at a tempo of 4-s eccentric movement, 1-s pause at the bottom, 1-s concentric movement, and 1-s pause at the top of the lift to focus on the eccentric phase of the lift for greater EIMD. The tempo was controlled using an interval timer, with the investigator signaling the subject regarding the changes in the lifting phase.

Testing sessions 2–5 had similar sequences. Upon entering the laboratory, the subjects would have their TG measured and perceived pain assessed. The subjects then performed the previously described 5-min stationary cycle ergometer warm-up. The subjects completed the vertical jump trials followed by a randomized allocation of the assessment of their maximal voluntary contractile (MVC) force and quadriceps and hamstrings ROM measurements. Vertical jump was not randomized and was tested before MVC and ROM measurements because it is a bilateral movement, whereas MVC was measured with the subjects' right leg, and ROM was measured with the subjects' left leg. The subjects performed three trials for each test measurement, with the best result being recorded. Session 2 differed slightly because it included the EIMD protocol after the PRE, along with posttest (POST-0) measurements immediately after the EIMD protocol. The subjects in the FR group were required to perform the FR exercise protocol upon completion of the testing protocol at POST-0, POST-24, and POST-48.

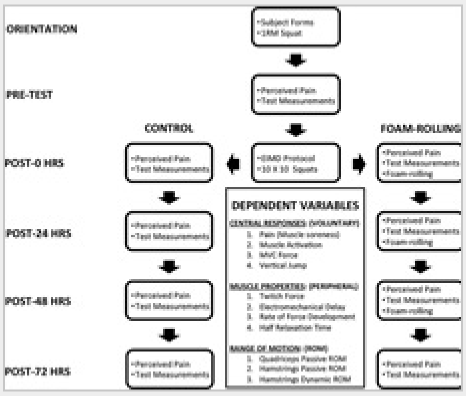

FIGURE 1: Methodology. Flow chart displays methodology, along with the dependent variables assessed each time test measurements were taken.

Independent Variable

FR

The subjects in the FR group performed five different FR exercises, targeting the major muscle groups of the anterior, lateral, posterior, and medial aspect of the thigh, along with the gluteal muscles. A custom-made foam roller that was constructed of a polyvinyl chloride pipe (10.16-cm outer diameter and 0.5-cm thickness) surrounded by neoprene foam (1-cm thickness) was used for all exercises because greater pressure can be placed on the soft tissues of the body when using a high-density foam roller versus a low-density foam roller ([15,25]). The subjects performed each of the five exercises on both the right and left legs for two 60-s bouts each. For exercises targeting the thigh (anterior, lateral, posterior, and medial), the subjects were instructed to place their body weight on the foam roller, starting at the proximal aspect of the thigh and rolling down the thigh, using small undulating movements, gradually working their way toward the knee. Once the foam roller reached the distal aspect of the thigh, the subjects were instructed to return the roller to the starting position in one fluid motion and continue the sequence for the remainder of the 60-s trial. For the fifth exercise, targeting the gluteal muscles, the subjects were instructed to sit on top of the foam roller, placing both of their hands on the floor behind the foam roller. The subjects then crossed their right/left leg over their left/right knee, positioning their body so their right/left gluteal muscles were in contact with the roller, and their body weight was placed on the foam roller. The subjects were instructed to undulate back and forth, with the foam roller running inline with the origin to insertion point of the gluteus maximus muscle. The subjects completed all five exercises on one side of the body and then switched to the other side of the body and repeated all five exercises.

Dependent Variables

TG

TG was defined as the circumference at midthigh. Midthigh was defined as the halfway point between the anterior superior iliac spine and the proximal aspect of the patella. All measurements were taken when the subject was standing erect, with their right thigh muscles relaxed. A line was permanently marked around the circumference of the right thigh on the first day of testing to ensure measurements were reliable between testing sessions.

Muscle soreness

Muscle soreness was measured using the BS-11 Numerical Rating Scale (NRS). The NRS allowed the subjects to express the amount of pain in reference to muscle soreness they perceived. The NRS is an 11-point scale, ranging from 0 to 10, with “0” being defined as “absolutely no muscle soreness” and “10” being defined as “the worst muscle soreness you have ever felt.” Muscle soreness measurements were taken before each testing session. The subjects performed a squat using only body weight (no external resistance), squatting down until their thighs were parallel with the floor. Once the subjects had assumed the squat position with their thighs parallel with the floor, the subjects were then asked to rate their perceived pain on the basis of muscle soreness.

ROM

To assess hamstrings and quadriceps ROM, three measurements were taken at the knee and hip of the left leg. The three measurements included quadriceps passive ROM (QP-ROM), hamstrings passive ROM (HP-ROM), and hamstrings dynamic ROM (HD-ROM). QP-ROM was measured by having the subjects perform a modified kneeling lunge and measuring passive knee flexion angle using a manual goniometer (accurate to 1°), as outlined in a previous study ([25]). All landmark sites were marked with permanent marker and remained marked for all testing sessions to ensure reliability across trials. A decrease in the angle between the posterior aspect of the shank and thigh indicated an increase in quadriceps ROM.

Hamstrings ROM measurements were taken using a custom-made electronic goniometer (Memorial University Technical Services, St. John's, Newfoundland, Canada) and analyzed using a software program (AcqKnowledge 4.1; BioPac Systems Inc., Holliston, MA), measuring changes in ROM at the hip. The subject's left leg was equipped with a knee brace to prevent movement at the knee joint and to isolate the hip. The subjects stood erect and were strapped to a wooden platform harnessed to the wall. Three straps placed around the right ankle, right thigh, and across the chest harnessed the subject to the wooden platform. HP-ROM was assessed by having the investigator passively flex the subject's right hip until the subject reached a point of maximum discomfort. HP-ROM measurements have been reported to have a high intraclass correlation coefficient reliability (r = 0.96) ([30]). HD-ROM was assessed with the same harnessing and knee brace on the custom-made electronic goniometer by having the subjects contract their hip flexors and kick up as high and as fast as possible.

Evoked contractile properties

Peak twitch force (TF) was evoked with electrodes connected to a high-voltage stimulator (Stimulator Model DS7AH; Digitimer, Welwyn Garden City, Hertfordshire, UK) as outlined in a previous study ([32]). Stimulating electrodes were placed over the inguinal triangle (proximal) and directly above the patella (distal) of the right leg. To determine the peak TF, voltage was sequentially increased (100–300 V) until a maximum TF was achieved. The amperage (1 A) and duration (50 μs) were kept constant throughout. Once peak twitch was achieved, the voltage used to achieve the peak TF was maintained throughout the testing session.

An evoked twitch was administered 2 s before the subject's MVC, allowing peak TF, electromechanical delay (EMD), rate of force development (RFD), and half relaxation time (½RT) to be analyzed. An evoked twitch was also administered 2 s post-MVC to analyze potentiated twitch characteristics. EMD was defined as the period between the onset of muscle stimulation and the onset of TF production (>1% of the twitch amplitude from baseline) ([2]). RFD was measured over a 50-ms window, beginning at the onset of TF development, defined as the force deviating >1% of the twitch amplitude from baseline force measurements ([2]). ½RT was defined as the time required for the TF to decrease from peak TF to 50% of peak TF ([37]). Potentiated TF (PTF) was defined as the peak force produced from an evoked twitch elicited 2 s after the MVC.

Voluntary contractile properties

MVC force was assessed via an isometric knee extension (knee angle, 90°) of the right leg. MVC force protocol followed methods outlined in a previous study ([32]). Button and Behm ([7]) reported that MVC demonstrated excellent day-to-day reliability ($r = 0.99$). Before attempting an MVC, the subjects performed two submaximal contractions. The subjects performed three 3- to 5-s MVC, separated by 2 min each, with all forces detected by the strain gauge, amplified (BioPac Systems Inc. DA 150 and analog-to-digital converter MP150WSW), and displayed on a computer monitor. Data were sampled at 2000 Hz and analyzed using a software program (AcqKnowledge 4.1, BioPac Systems Inc.). To ensure that the subjects were performing to their maximal effort, the subjects had to perform two MVC with no >5% variance in force outputs between trials ([7]). Verbal encouragement was given to all the subjects during the MVC to provide motivation.

Voluntary muscle activation (VA) was assessed using the interpolated twitch technique (ITT). ITT was used to measure muscle activation and the CNS's ability to fully activate the contracting muscle ([5]). The voltage used to elicit the peak TF was used during the MVC to provide an interpolated or superimposed twitch. ITT methods administrated were similar to previous studies ([4,7,32]). ITT was performed using two evoked twitches: 1) an interpolated twitch once the subjects reached their maximal force output, determined via visual inspection (once the subjects'

MVC force output plateaued) and 2) a potentiated twitch approximately 2 s post-MVC. An interpolated twitch ratio was calculated comparing the amplitude of the interpolated twitch with the potentiated twitch to estimate the extent of activation during a voluntary contraction ([1 − (interpolated doublet force / potentiated doublet force)] × 100 = % of muscle activation) ([4]).

Integrated EMG (iEMG) activity was used as a measure of peripheral muscle activation. Surface EMG recording electrodes (Meditrace 133 ECG Conductive Adhesive Electrodes; Tyco Healthcare Group LP, Mansfield, MA) were placed on the right leg, over the muscle belly of the rectus femoris. Electrodes were placed at half the distance between the anterior superior iliac spine of the pelvis and the patella. A ground electrode was secured on the fibular head. Thorough skin preparation for all electrodes was administered ([32]). EMG activity was sampled at 2000 Hz, with a Blackman −92 dB band pass filter between 10 and 500 Hz, was amplified (bipolar differential amplifier, input impedance = 2 MΩ, common mode ejection ratio >110 dB minimum (50/60 Hz), gain × 1000, noise >5 μV), and was analog-to-digitally converted (12 bit) and stored on a personal computer for analysis. iEMG was measured for a 1-s period during the subject's peak MVC force (0.5-s premaximum and postmaximum force output).

Vertical jump

Vertical jump testing followed the vertical jump protocol outlined in *The Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA)* manual ([14]). One modification was made to the protocol. Instead of pausing at the bottom of the squat, the subjects were instructed to perform a countermovement jump (CMJ). The subjects were given the same instructions before performing each CMJ for the entirety of the study. Depth and speed of the countermovement were not controlled to allow the movement to be as natural as possible. Permanent marker was placed on the tip of the subject's middle finger. The difference between the subject's standing reach height and CMJ height was recorded as the subject's vertical jump height. Visual inspection of the marking as it lined up with the measuring tape was recorded to the nearest 0.1 cm.

Foam Roller

Perceived pain while FR (FR-pain) was measured while the subjects performed the FR exercise protocol using the NRS. The NRS 11-point scale ranged from 0 to 10, with “0” being defined as “absolutely no pain” and “10” being defined as “the worst pain you have ever felt.” At 30 s into each 60-s FR trial, the subjects rated their perceived pain for each of the five FR exercises.

Force placed on the foam roller (FR-force) was measured using a force plate (Biomechanics Force Platform model BP400600HF; Advanced Mechanical Technology, Inc., Watertown, MA). The force plate contains four load cells that measure the three orthogonal force and moment components along the *X*, *Y*, and *Z* axes, producing a total of six outputs (Fx, Fy, Fz, Mx, My, and Mz). The subjects foam rolled over the force plate, with the force plate being the only point of contact for the roller. The subjects were instructed to perform the FR exercise protocol, keeping the foam roller on the force plate while keeping all body parts off the force plate. Force was analyzed using the force measurements recorded in the Fz-plane during each 60-s trial and collected at a sampling rate of 60 Hz.

Statistical Analysis

To avoid the shortcomings in relation to the clinical significance of the present research base on null hypothesis significance testing, magnitude-based inferences and precision of estimation were used ([21]). Magnitude-based inferences on the interaction effects in the mean changes between the intervention trials (CON and FR) were determined. The interaction effect of time and FR was calculated from the mean difference between PRE and each time point (PRE to POST-24, 48, and 72) for CON and FR. The two differences were then subtracted to estimate the effect of FR at each time point.

Qualitative descriptors of standardized effects were assessed using these criteria: trivial, <0.2; small, 0.2–0.5; moderate, 0.5–0.8; and large, >0.8 ([11]). Precision of estimates is indicated with mean difference ± 95% confidence limits, which defines the range representing the uncertainty in the true value of the (unknown) population mean.

We were interested in practical differences between groups and time, so we based the smallest worthwhile change on a small effect size (>0.2). The likelihood that the observed effect size was larger than the smallest worthwhile change (i.e., was clinically meaningful) was calculated on the basis of previous methods. Chances of clinically meaningful difference were interpreted qualitatively as follows: <1%, almost certainly not; <5%, very unlikely; <25%, unlikely; 25%–75%, possible; >75%, likely; >95%, very likely; and >99%, almost certain ([21]). Therefore, results are expressed by the percent change from PRE (%Δ), percent likelihood that the observed between-group difference was greater than a small effect size (% likelihood), and the effect size. Results with a >75% likelihood were considered to be substantial.

RESULTS

Fatigue: EIMD

The prescribed EIMD protocol induced substantial changes in all the dependent variables except HP-ROM (−1%, unclear, trivial (%Δ, % likelihood, effect size)) and HD-ROM (0%, unclear, trivial). The DOMS protocol induced a substantial increase in TG (2%, >99%, small), along with several performance decrements in the dependent variables measured: QP-ROM (−7%, 76%, small), TF (−40%, >99%, large), RFD (−39%, >99%, large), PTF (−41%, >99%, large), vertical jump (−13%, >99%, large), MVC force (−24%, >99%, large), muscle activation (−9%, >99%, large), and iEMG (−14%, 96%, small). EMD (−6%, 95%, moderate) and ½RT (−22%, >99%, moderate) were the only two dependent measures to show improvements immediately after the DOMS protocol (Fig. 2).

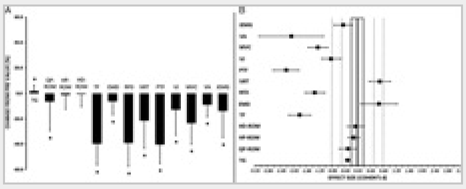

FIGURE 2: Changes induced by EIMD protocol. A, 1/2RT, half-relaxation time; EMD, electromechanical delay; iEMG, integrated electromyography; HDR, hamstrings dynamic ROM; HPR, hamstrings passive ROM; MVC, maximal voluntary contractile force; PTF, potentiated twitch force; QPR, quadriceps passive ROM; RFD, rate of force development; TF, twitch force; TG, thigh girth; VA, voluntary muscle activation; VJ, vertical jump. They-axis displays %Δ from PRE. The x-axis displays the dependent variables. Asterisks (*) indicate conditions with substantial change (>75% likelihood that the difference exceeds the smallest worthwhile difference). B, Graph plots standardize effect size differences between CON and FR groups. Plots represent the magnitude of difference between the two groups. Error bars indicate 95% confidence limits of the mean difference between groups. The shaded area of the graph indicates the region in which the difference between groups is trivial (i.e., between −0.20 and 0.20 standardized effect sizes.

TG

TG, with PRE of FR, 58.3 ± 2.7 cm, and CON, 59.1 ± 4.2 cm, showed no substantial between-group differences at POST-24 (FR, 1%; CON, 1%; 0.03 ± 0.31 cm; FR, %Δ; CON, %Δ; mean difference ± 95% CI), POST-48 (FR, 3%; CON, 3%; 0.03 ± 0.65 cm), and POST-72 (FR, −1%; CON, −2%; 0.03 ± 0.51 cm), with all time points showing "unclear" results regarding whether FR is beneficial or detrimental due to trivial effect sizes (POST-24, −0.09 ± 0.96; POST-48, −0.04 ± 0.96; POST-72, −0.06 ± 0.97; *d* ± 95% CI).

Muscle soreness

Muscle soreness, recorded before each testing session, with PRE of FR, 0.7 ± 1.0 points, and CON, 0.7 ± 1.1 points, showed substantial between-group differences at POST-24 (FR, 543%; CON, 714% (%Δ)), with FR (85% (% likelihood)) having a substantial effect in reducing muscle soreness, demonstrating a "moderate" effect size, POST-48 (FR, 414%; CON, 807%), and POST-72 (FR, 243%; CON, 607%), with FR (48 h, 98%; 72 h, 97%) having a substantial effect in reducing muscle soreness, demonstrating a "large" effect size, based on NRS measurements (Fig. 3).

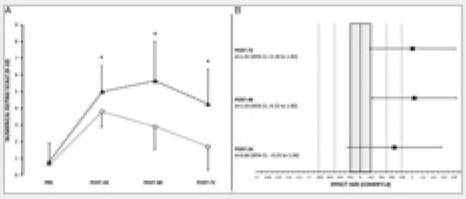

FIGURE 3: Muscle soreness. A, They-axis displays muscle soreness on the basis of the NRS. The x-axis displays PRE and posttest measurements for the four different time points. Asterisks (*) indicate conditions with substantial change (>75% likelihood). B, Please see Figure 2B for description.

ROM

QP-ROM PRE was 59.0° ± 12.8° for FR and 64.7° ± 14.6° for CON. QP-ROM showed no substantial between-group differences at POST-24 (FR, 8%; CON, 5%) but showed substantial differences at POST-48 (FR, 11%; CON, 0%) and POST-72 (FR, 13%; CON, 4%), with FR increasing QP-ROM, demonstrating a “moderate” effect size (Table 1).

TABLE 1: Range of motion.

HP-ROM PRE was 111.2° ± 6.9° for FR and 103.8° ± 14.8° for CON. HP-ROM showed no substantial between-group differences at POST-24 (FR, −1%; CON, −3%) and POST-48 (FR, 0%; CON, 0%) but showed substantial differences at POST-72 (FR, 3%; CON, 0%), with FR increasing HP-ROM, demonstrating a “moderate” effect size (Table 1).

HD-ROM, with PRE of FR, 105.5° ± 6.2°, and CON, 98.0° ± 11.3°, showed substantial between-group differences at POST-24 (FR, 0%; CON, −4%), with FR increasing HD-ROM, demonstrating a “moderate” effect size, but showed no substantial differences at POST-48 (FR, 0%; CON, −3%) and POST-72 (FR, 1%; CON, −1%) (Table 1).

Evoked contractile properties

TF, with PRE of FR, 153.4 ± 34.8 N, and CON, 135.7 ± 27.8 N, showed substantial between-group differences at POST-24 (FR, −14%; CON, −5.%), POST-48 (FR, −9%; CON, 8%), and POST-72 (FR, −10%; CON, −3%), with FR reducing TF, demonstrating “moderate,” “large,” and “moderate” effect sizes, respectively (Table 2).

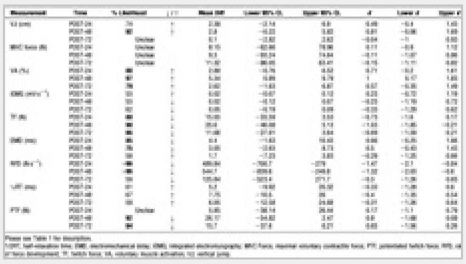

TABLE 2: Contractile properties.

EMD PRE was 46.1 ± 4.7 ms for FR and 46.4 ± 4.4 ms for CON. EMD showed substantial between-group differences at POST-24 (FR, −2%; CON, 7%) and POST-48 (FR, −1%; CON, 6%), with FR shortening EMD duration, demonstrating a “moderate” effect size, but showed no substantial differences at POST-72 (FR, 2%; CON, −2%) (Table 2).

RFD, with PRE of FR, 1852.6 ± 478.8 N·s^{-1}, and CON, 1488.5 ± 460.5 N·s^{-1}, showed substantial between-group differences at POST-24 (FR, −23%; CON, 5%) and POST-48 (FR, −17%; CON, 15%), with FR reducing RFD, demonstrating a “large” effect size, but showed no substantial differences at POST-72 (FR, −10%; CON, −4%) (Table 2).

½RT PRE was 68.4 ± 21.0 ms for FR and 64.6 ± 20.8 ms for CON. ½RT showed no substantial between-group differences at POST-24 (FR, 9%; CON, 1%), POST-48 (FR, 7%; CON, −5%), and POST-72 (FR, 6%; CON, −3%) (Table 2).

Voluntary contractile properties

MVC force, with PRE of FR, 761.4 ± 126.3 N, and CON, 621.9 ± 100.9 N, showed no substantial between-group differences at POST-24 (FR, −9%; CON, −12%), POST-48 (FR, −6%; CON, −6%), and POST-72 (FR, −7%; CON, −6%), demonstrating a “trivial” effect size at all time points (Table 2).

VA PRE was 93.3% ± 4.2% for and 91.9% ± 4.0% for CON. VA showed substantial between-group differences at POST-24 (FR, 0%; CON, −4%), POST-48 (FR, 1%; CON, −5%), and POST-72 (FR, 1%; CON, −2%), with FR increasing VA, demonstrating “moderate,” “large,” and “moderate” effect sizes, respectively.

iEMG, with PRE of FR, 0.43 ± 0.11 mV, and CON, 0.42 ± 0.16 mV, showed no substantial between-group differences for POST-24 (FR, −2%; CON, −7%), POST-48 (FR, −4%; CON, 0%), and POST-72 (FR, −9%; CON, −2%) (Table 2).

Vertical jump

Vertical jump height PRE was 51.7 ± 7.9 cm for FR and 46.5 ± 7.0 cm for CON. Vertical jump height approached substantial between-group differences at POST-24 (FR, 0%; CON, −6%), with FR increasing vertical jump height, demonstrating a “small” effect size, and showed substantial between-group differences for POST-48 (FR, 1%; CON, −5%), with FR increasing vertical jump height, demonstrating a “large” effect size, but showed no substantial differences at POST-72 (FR, 0%; CON, 0%).

FR force

FR-force averaged between 28–46 kg or 35%–55% of the subjects’ body weight at POST-0, 26–44 kg or 32%–53% of the subjects’ body weight at POST-24, and 26–44 kg or 32%–53% of the subjects’ body weight at POST-48 (Tables 3–4).

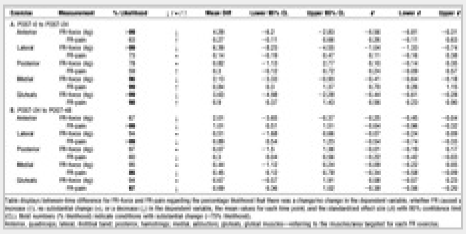

TABLE 3: FR properties.

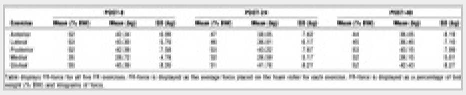

TABLE 4: FR-force.

FR-force showed substantial time differences between POST-0 and POST-24 for the anterior (−10%, moderate (%Δ, effect size)), lateral (−15%, large), medial (−7%, small), and gluteal (−8%, moderate) FR exercises, with no substantial differences for the posterior (2%, trivial) exercise (Table 3A).

FR-force showed no substantial between-time differences between POST-24 and POST-48 for the anterior (−6%, small), lateral (−1%, trivial), posterior (0%, trivial), medial (−2%, trivial), and gluteal (2%, trivial) FR exercises (Table 3B).

FR pain

FR-pain ranged between 2.5 and 7.5 points at POST-0, 3 and 7.5 points at POST-24, and 2.5 and 6.5 points at POST-48 on the NRS for the five different FR exercises (Table 3).

FR-pain showed substantial time differences between POST-0 and POST-24 for the medial (19%, moderate) and gluteal (24%, moderate) FR exercises, with no substantial differences for the anterior (5%, small), lateral (2%, trivial), and posterior (11%, small) exercises (Table 3A).

FR-pain showed substantial time differences between POST-24 and POST-48 for the anterior (−16%, moderate), lateral (−12%, moderate), medial (−8%, small), and gluteal (−15%, small) FR exercises, with no substantial differences for the posterior (10%, small) exercises (Table 3B).

DISCUSSION

The study by Pearcey et al. ([31]) is the only research article to analyze the effects of FR on recovery from EIMD resulting in DOMS. No research to date has examined the potential physiological mechanisms regarding the recovery benefits seen with FR that have been outlined in previous literature ([31]). The most important findings of the present study were that FR was beneficial in improving dynamic movement, percent muscle activation, and both passive and dynamic ROM in comparison with the CON group while attenuating muscle soreness, although no benefits were seen at the muscular level when it was isolated.

EIMD protocol

Similar to previous EIMD-related studies ([19,33]), substantial muscular fatigue and damage were inflicted by the EIMD protocol, resulting in a substantial increase in TG, along with substantial decrements in QP-ROM, TF, RFD, PTF, vertical jump height, MVC force, muscle activation, and iEMG. Only two muscle properties showed improvements immediately postexercise, with a reduction in the duration of EMD and ½RT.

Muscle soreness: DOMS

In the FR group, muscle soreness peaked at POST-24, whereas the CON group peaked at POST-48. Results are parallel to the findings in a study by Smith et al. ([34]) comparing a massage intervention group with a CON group. The massage group reported peak muscle soreness at POST-24, whereas the CON group peaked at POST-48. In the present study, substantially higher muscle soreness readings were recorded at all time points for the CON group, showing the effectiveness of FR in reducing muscle soreness. Reductions in muscle soreness readings can be further supported by the force plate data collected from the FR exercise protocol (Table 4) at POST-24 and POST-48. Although the FR group showed no substantial changes in FR-force between POST-24 (26–44 kg) and POST-48 (26–44 kg) for all five foam roller exercises, substantial decreases in FR-pain (POST-24, 3–7.5 points, and POST-48, 2.5–6.5 points) were seen while performing four out of the five exercises. This finding further supports that muscle soreness peaked at POST-24 for the FR group and then began to return to baseline levels. The improved recovery rate in muscle soreness in the FR group signifies that FR is an effective tool to treat DOMS.

DOMS has been attributed to both muscle ([8,12,29,35]) and connective ([17,23,28,35]) tissue damage. Although DOMS is associated with muscle cell damage, it is unlikely that DOMS is the direct result of muscle cell damage ([35]) because muscle enzyme efflux and myofibrillar damage are not correlated with the actual sensation of muscle soreness ([10,23]). It has been postulated that DOMS may be the result of connective tissue damage more so than muscle damage. Connolly et al. ([12]) stated that pain and stiffness may be more related to the inflammatory response ([13]), as a result of cells and fluid moving into the interstitial spaces rather than the actual muscle damage incurred. This can be supported by Mills et al. ([28]) who demonstrated the presence of muscle damage without the presence of muscle soreness, as well as the presence of muscle soreness without muscle damage. Jones et al. ([23]) suggested that changes in connective tissue properties are the main cause of DOMS, with the myotendinous junction being the predominant area of soreness ([24]). Previous studies have reported connective tissue breakdown after eccentric exercise ([1,24]), with damaged connective tissue stimulating mechanically sensitive receptors, giving rise to pain when stretched or pressed ([23]). This finding suggests that the benefits of FR may be more predominant for the treatment of connective tissue rather than muscle tissue damage.

Evoked contractile properties

The evidence that FR has a greater effect on connective tissue rather than muscle can be further strengthened by the greater decrement in evoked contractile properties with FR versus CON. Decrements in TF, PTF, and RFD in the FR group may be a result of increased muscle damage from the FR protocol. Callaghan ([8]) showed that after a vigorous massage protocol, an increase in lactate dehydrogenase and creatine kinase was reported, both being markers of muscle damage. Zainuddin et al. ([39]) and Crane et al. ([13]) both showed that massage was effective in alleviating DOMS, although Zainuddin et al. ([39]) found that massage had no effect on muscle function. The present findings suggest that although FR may be beneficial in treating connective tissue damage, minor damage to muscle tissue may incur. Whether this is beneficial for the repair process occurring in the muscle or only causing more damage to the muscle is unknown ([10]).

The only evoked contractile property to benefit from the FR protocol in comparison with the CON group was EMD, being substantially shorter at POST-24 (9%) and POST-48 (7%) when compared with CON. EMD has been shown to be influenced by several factors, including series elastic components, ability of the action potential to propagate, and excitation–contraction coupling ([22]). Zhou et al. ([40]) considered EMD to reflect the elastic properties of the muscle, with the major portion of the EMD representing the time required to stretch the series elastic components of the muscle ([9]). After EIMD, elongation of EMD is believed to be due to mechanical stress placed on the muscle and increased passive tension on noncontractile structures in the myofibers ([29]), resulting in connective tissue damage. On the basis of these findings, with FR improving the recovery of EMD to baseline measurements after EIMD, potentially by restoring the passive noncontractile structures (series of elastic components) in the muscle, it is likely that FR provides a more clinically significant recovery effect upon connective tissue versus muscle tissue after EIMD.

Voluntary contractile properties

Although FR did not help in treating EIMD at the muscular level, the FR group showed no decrements in voluntary properties in comparison with the CON group and showed substantially greater muscle activation in comparison with the CON group from POST-24 to POST-72. The most substantial between-group difference in muscle activation was seen at POST-48, occurring when muscle soreness was also at its most substantial between-group difference of any of the three posttest time points. This being said, the FR group may have been able to maintain muscle activation where decrements were seen in the CON group, potentially because of a substantial reduction in DOMS and less neural inhibition as a result of healthier connective tissue, allowing for appropriate afferent feedback from mechanical and sensory receptors located within the connective tissue enveloping the muscle ([12,19]) because of a substantial reduction in DOMS. To our knowledge, there is no information on the effects of massage on muscle activation, although the decrements seen in the CON group were similar to previous EIMD studies ([19,33]).

There were no substantial iEMG between-group differences. This may seem perplexing because muscle activation showed substantial between-group differences. This finding may be the result of large interindividual variations in EMG levels when analyzing sore muscles ([6]). McGlynn et al. ([27]) showed that EMG SD increased by 25-fold from PRE to POST-72. Along with the previously noted findings, Abraham ([1]) demonstrated no changes in EMG readings using bipolar electrodes, with Devries ([16]) claiming that bipolar electrodes may not be sensitive enough to detect changes in EMG. Although not evident with iEMG measures, the improved muscle activation may be the result of decreased neural inhibition ([12,19]) associated with less pain, due to a decrease in inflammation ([13]).

MVC force showed no substantial between-group differences, with both groups showing deficits (6%–12%) at all time points and not recovering to PRE by POST-72. MVC force deficits are similar to those reported in a previous EIMD study ([39]). It is interesting to note that there were no substantial between-group differences in MVC force even though the FR group showed substantial decrements in TF, demonstrating greater damage within the muscle ([19]). Although muscle fibers produced less force (as seen through TF measurement) in the FR group, most likely a result of greater individual muscle fibers damage ([29]), the subjects' ability to activate a greater number of muscle fibers (as seen through VA measurements) may have acted to counterbalance the decrement in force production per fiber ([33]).

ROM

FR was beneficial in improving both passive and dynamic ROM in comparison with the CON group. FR increased passive ROM (QP-ROM and HP-ROM) and maintained dynamic ROM (HD-ROM) in relation to PRE (Table 1). EIMD research ([23,33]) attributes a loss in ROM to the shortening of noncontractile elements. Previously published research from our laboratory demonstrates that the application of FR increases

ROM ([25]). Improved ROM was attributed to FR acting in a similar fashion to myofascial release techniques, potentially reducing muscle soreness, decreasing inflammation, and/or reducing adhesions between layers of fascia ([3,15]). Muscular manipulation has been shown to promote active blood flow and move interstitial fluid back into circulation, reducing inflammation and muscle soreness ([8,13]).

Vertical jump height

Vertical jump performance incorporates all three of the major properties analyzed in the present study (muscle, CNS, and ROM). Similar to the findings by Pearcey et al. ([31]), the FR group showed substantial benefits in comparison with the CON group when assessing dynamic performance at POST-24 and POST-48. Research by Willems et al. ([38]) and Mancinelli et al. ([26]) supports these findings, with massage shown to improve vertical jump height at 48 h postexercise by 3% and 4.5%, respectively. Farr et al. ([18]) contradicts the present findings, showing decrements in vertical jump height at POST-24 in the massage group, although there were no differences between the massage and CON limb. It must be noted that vertical jump tests in the research by Willems et al. ([38]) and Farr et al. ([18]) consisted of one-legged vertical jumps, with the contralateral leg acting as the CON. Because evoked contractile properties are not improved by FR, FR likely acts by reducing neural inhibition ([12,33]) due to accelerated recovery of the connective tissue as a result of decreased inflammation and increased mitochondria biogenesis ([13]), decreasing nociceptor activation ([17]), allowing for better communication from afferent receptors in the connective tissue ([33]). Better communication with afferent receptors may possibly allow for the maintenance of natural muscle sequencing and recruitment patterns ([33]) maintaining vertical jump height.

CONCLUSION

From the present findings, it is speculated that FR provides recovery benefits primarily through the treatment of connective tissue. Because the present evidence is indirect, further research should be conducted.

The FR group displayed substantially less pain at all time points in comparison with the CON group. Because connective tissue (i.e., myotendinous junction) is the major site of EIMD disruption and pain ([17,23,24,35]), FR can be considered to be beneficial in the recovery of connective tissue. Research by Crane et al. ([13]) supports this finding, reporting that massage decreased pain and inflammation, potentially by promoting blood flow to areas of low blood flow, such as the muscle–tendon interface. The FR group recorded substantially less muscle soreness while having substantially greater decrements in evoked contractile properties, ruling out improved muscle recovery as the determining factor. The reduction in pain with FR may have been an influential factor for the maintenance of muscle activation (i.e., less neural inhibition) (12,33). When analyzing dynamic movements (vertical jump height and HD-ROM) or EMD, all heavily involving the series elastic components, FR proved to be beneficial. When comparing isometric (MVC Force) versus dynamic contraction (vertical jump height) results in the FR group, the greatest benefits from FR were displayed in the dynamic movement. It must be emphasized that most of the benefits seen with FR after EIMD are the result of FR maintaining rather than improving PRE (VA, EMD, HD-ROM, and vertical jump height), where the CON group incurred substantial decrements.

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The authors declare no conflicts of interest.

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