International Journal of
EXERCISE SCIENCE

Original Research

A Single Bout of Foam Rolling Increases Flexibility of the Hip Adductor Muscles without Compromising Strength

GAVIN CONNOLLY†[1,2], ROGER L. HAMMER‡[1], JOSEPH A. POWELL†[1], and PAUL L. O'CONNOR‡[1]

[1]Herbert H. and Grace A. Dow College of Health Professions, School of Health Sciences, Division of Exercise Science, Central Michigan University, Mt. Pleasant, MI, USA; [2]Department of Nutrition Science, Purdue University, West Lafayette, IN, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(7): 938-949, 2020. Foam rolling (FR) is a method of self-myofascial release (SMR) implemented to reduce tension in underlying soft tissue, leading to increased range of motion (ROM). The hip adductor muscles of the groin are commonly less flexible and often a site for soft tissue injuries. Limited research has been done to determine the most effective flexibility exercises to increase ROM in the groin muscles prior to exercise without comprising strength. The purpose was to determine the effect of an acute bout of FR on passive groin flexibility and strength. Randomized crossover study with 3 X 2 (Condition X Time) repeated measures ANOVA statistical design. 40 volunteers (n = 20 males; n = 20 females) with limited flexibility in groin ROM participated. Following warm-up, maximal voluntary isometric contraction (MVC) and static ROM were measured pre and postintervention. Conditions included 60 seconds of FR, SS, and CON. The Condition X Time interaction was not significant for MVC or ROM. A main effect of time showed a significant increase in ROM from pre to post for FR (1.2°, $p < 0.001$), SS (1.0°, $p < 0.001$), and CON (0.5°, $p = 0.039$). No significant changes in MVC were observed for FR from pre to post ($p > 0.05$), whereas SS and CON both increased ($p < 0.05$). An increase in passive groin ROM after acute bouts of SMR or SS without compromising MVC was observed. This suggests that 60 seconds of FR may be employed before exercise to improve flexibility without strength decrement.

KEY WORDS: Self-myofascial release, groin muscles, range of motion, maximal force output

INTRODUCTION

It is common practice among athletes and recreational exercisers to incorporate stretching procedures as part of a warm-up routine before an exercise session. It is believed that participating in such a warm-up protocol will increase range of motion (ROM) and may aid in decreasing injury risk caused by the ensuing sport or vigorous activity (2, 7, 15, 22, 33). Performance enhancement is also a main objective of stretching in order to improve outcomes in subsequent physical endeavors. This may be achieved through factors like improved joint mobility, movement competency and increased force output. Many variables can affect the outcome of a warmup, therefore it is important to describe the type, technique, duration and intensity of stretching when it is part of a preparticipation routine (30).

Various types of stretching have been employed in warm-up routines and more recently include methods of self-myofascial release (SMR). Foam rolling (FR) is a common SMR technique used and has become popular in both warm-up and recovery protocols across athletics and general fitness (7). It has been shown that the use of FR improves ROM and decreases resistance to stretch without compromising muscle strength (3, 11, 20, 34). The improved ROM through SMR is hypothesized to be due to both neural and mechanical factors that result in reduced muscle tension. Other benefits of FR include reduction in delayed onset muscle soreness (14, 19) and improved endothelial function (25). In the literature, many other positive effects of FR have been proposed, but in many cases are theoretical or have not be proven and are beyond the scope of this paper. Interested readers are directed to a number of review papers that have detailed proposed mechanisms (1, 2, 7, 16, 32).

Current evidence indicates that performing short duration FR acutely prior to an exercise session results in increased ROM without inhibiting a muscle's force production (2, 3, 13, 16, 20). These findings agree with other research regarding static stretching (SS). SS durations of $\leq$ 60 seconds may lead to increased ROM without detrimental effects on strength and power output (4, 5, 8, 17). Whereas, durations exceeding 60 seconds have tended to show significant losses in strength and power output, with decrements in performance appearing as stretch duration increases (4, 5, 17). Practically, the use of short duration SS as a warmup method is well established, yet further research needs to be conducted to provide more appropriate guidelines regarding the use of FR as a part of a warm-up routine.

Hip adductor muscle injuries, more commonly referred to as groin strains, are recognized as a common soft tissue injury occurring across athletics where rapid acceleration and change of direction are required (9, 24, 38, 40). The six muscles of the hip adductor muscle group are the adductor longus, magnus, and brevis, the gracilis, pectineus, and obturator externus. These muscles have various attachment points that are short, medium and long distance from origin to insertion making it a unique challenge in determining their role in specific movement patterns and injuries. Their primary movement is adduction of the thigh in the frontal plane, but this group is also involved in several different lower body joint actions and stabilization in the sagittal and transverse planes as well, such as hip flexion, extension, external and internal rotation (9). To help combat the incidence of soft tissue injuries, preexercise procedures such as FR have been gaining popularity, and are sometimes recommended by athletic performance and sports medicine professionals (2, 22, 27, 32, 33).

Previous SMR research is limited in regard to the hip adductor region. In fact, to our knowledge this is the first FR study that has targeted this area. Since FR has experienced a rapid growth in popularity it is worth investigating if there is any increase in hip adductor ROM or changes in force production when an acute bout of FR is part of a warmup procedure. Therefore, the purpose of this study was to determine if an acute bout of FR administered to the hip adductors significantly increases hip abduction ROM, without any significant negative impact on force output in comparison to SS and control (CON) conditions. We hypothesized that FR would be as effective as SS for increasing joint ROM while not resulting in a subsequent decrease in force output, and that both methods would be more effective than CON at increasing ROM.

METHODS

Participants

Forty individuals (Table 1.) volunteered to participate in this investigation which was part of a comprehensive effort that was divided *a priori* into separate research questions, where subjects experienced multiple stretching interventions and acted as their own control in a randomized crossover model. Two papers have recently been published addressing other specific questions of this larger project (8, 12). Participants were pooled from a sample of university students and staff (ages 18-35 years). To be eligible for the study participants were required to demonstrate limited flexibility in their hip abduction ROM. A screening process was administered to verify limited hip abduction ROM as described by Hammer et al.(12) Only those with verified inability to achieve a predetermined level of passive hip abduction ROM (approximately equivalent to less than 45°) while seated reclined in a Cybex Adductor/Abductor Machine [(model #1181-91 Cybex International Inc., Medway, MA) (CAAM)] were enrolled (see Figure 1). Those with flexibility that exceeded this criteria for passive hip abduction ROM were assumed to be closer to their individual ROM limit and less likely to benefit from these interventions. Exclusion criteria included current or previous groin injury within the last 6 months, self identification as physically inactive (exercise less than twice a week), and a reported current or recent pregnancy (within 6 months). None of the participants had previous experience with FR of the groin muscle region. They were allowed to participate in their regular physical activities, but were instructed not to exercise within 24 hours prior to testing and to refrain from additional stretching of muscles in the groin region for the duration of the study. Because this was part of a larger overall study, eligible participants reported to the laboratory nine times in total (1 familiarization day and 8 testing days), at least 48 hours apart, dressed in non-restrictive shorts and a t-shirt. For this manuscript, focus was placed on only four of the nine days (familiarization, FR, SS, and CON). The schedule of participants and stretches per testing day were selected using a random function generator in Excel® 2010 (Microsoft Corp., Redmond, Washington, USA) to eliminate effects from sequencing. The mean time for each participant to complete all trials was 43 days from start to finish. All participants provided written consent, and the study was approved by the institutional review board. This research was carried out fully in accordance to the ethical standards of the *International Journal of Exercise Science* (23).

Table 1. Participant Characteristics (*n* = 40).

	Males (*n* = 20)	Females (*n* = 20)
Age (yr)	22.5 ± 1.8	23.6 ± 4.2
Height (cm)	181.7 ± 6.1	168.8 ± 6.3
Mass (kg)	88.8 ± 13.1	70.6 ± 10.3
Body Mass Index (BMI)	26.9 ± 3.7	24.8 ± 3.1

Note. Values are mean ± standard deviation (SD).

Protocol

The procedures in our lab for warmup and preintervention MVC and ROM measurements were described previously by Hammer et al.(12). In brief, on a separate day each participant was familiarized with all warmup, testing and stretching procedures. A standardized warmup was performed using an upright cycle (750U, True Fitness Technology, St. Louis, MO). Hip abduction ROM and hip adduction MVC were measured while subjects were seated on the CAAM (see Figure 1). A soft half bolster that was 7.62 cm in depth was placed in the lordotic curve for lumbar support. Subjects were secured in place with an 8 cm wide x 213 cm long belt that was fastened around the waist to prevent arching of the back or movement of the pelvis during MVC testing. MVC's were recorded on an electronic dynamometer (model microFET2 Hoggan Health Industries, Inc., West Jordan, Utah) (see Figure 2). For MVC determination, participants were instructed, by script, to squeeze the pads together as hard as possible, without additional verbal encouragement. The dynamometer was placed in between the foot cradles to record peak bilateral adductor force (see Figure 2). This method was chosen as it is similar to the adductor squeeze test described by Nevin and Delahunt (24). This procedure was repeated a second time following a 30-second rest interval. Following the MVC participants were re-fitted and aligned for preROM measurements and the load that caused movement into end hip abduction ROM was determined on the CAAM (Figure 1). The weight stack was initially loaded equal to 30% of each participant's body mass (BM) to test for appropriate passive stretch force and adjusted up or down (± ~10 % of participants BM) to cause hip abduction and allow a sufficient stretch of the groin muscles. For this study, an optimal stretch was considered to be rated by the subject as a 7 out of 10 on a stretch sensation scale (SSS) as previously described by Hammer et al.(12). This determined baseline load was then subsequently used consistently for each ROM measurement, thus ensuring no subjective bias on the part of the researcher by applying force differentially, or inconsistently, in favor of one stretching method over another. A load that caused a stretch that exceeded the point of discomfort and elicited pain or wincing was deemed to be in excess of a tolerable stretching sensation for the purposes of this study. Once subjects had gradually allowed their hips to be passively moved bilaterally into hip abduction and settled into position, they relaxed, abdominally breathed slowly and allowed the load to statically stretch them passively for 30 seconds into their final position. A ROM displacement recording was then quickly determined by reading the gap distance of displacement of the weight stack from 0 millimeter starting position, the subject then rested in the seated position for 30 seconds while unloaded, and was remeasured.

On any given testing day following a 5-minute warm-up on a cycle ergometer (heart rate of 130-150 bpm; rating of perceived exertion of 12-14 on the Borg scale) and preintervention measures of ROM and MVC, subjects performed one of two interventions, FR or SS, or CON and were then remeasured. On subsequent testing days the other conditions were performed in randomized crossover order. Hip abduction angle was measured as just described for ROM with the exception being that as soon as the subject was passively abducted into a stretched position of a 7 on the SSS a measurement was quickly taken (about 5 sec) and the subject was returned to resting position. We have described in a prior paper (12) how a calibration coefficient was developed between the linear excursion of the CAAM pulley strap and the CAAM leg cradles and how hip ROM was determined. The change in linear distance of the pulley strap (measured in mm using an affixed measuring tape) had a correlation of *r* = 0.998 with simultaneous goniometric determination of the leg cradle during abduction from 0 to 90°. Each millimeter change in strap movement (weight stack displacement) equaled a 0.19° change in leg cradle hip abduction angle. Repeat ROM measurements within-day were shown to have a Pearson Correlation of *r* = 0.960. Simultaneous interrater ROM comparison had a correlation of *r* = 0.995. Between-day variability was found to be *r* = 0.763.

The FR technique was based on recommendations in line with Lukas (18) and Paolini (27). All FR procedures were completed using a 15.24 cm diameter x 30.48 cm length foam roller (Ultrafit semi-firm foam roller, Gopher Sport, Owatonna, Minnesota) along with a yoga mat to brace the forearms upon (see Figure 3). Subjects were instructed to FR the entire length of the hip adductor muscle group unilaterally while in the prone position propped on forearms with the opposite leg acting as a stabilizer (see Figure 3). As much body weight pressure as needed was applied to elicit a sensation level of 7 out of 10 on the SSS, which was a similar intensity as instructions given by Halperin et al.(11). The participants foam rolled proximally (from the groin) to distally (to the knee) in small undulating movements (approximately one per second) for 30 seconds followed by a fluid motion to return to the starting position and repeated for another 30 seconds for a total of 60 seconds. Participants then followed the same protocol on the opposite leg. The SS intervention was performed in the CAAM for 60 seconds as per the description above. For CON the subjects rested while standing for 60 seconds. After the interventions or CON post ROMs and post MVCs were recorded in the same manner as the pre ROMs and MVCs. The greater value in each of the two trials pre and post was used for analysis. In order not to introduce bias into their effort, subjects were not made aware of their results after any trial.


Figure 1


Figure 2


Figure 3

Figure 1. Measuring hip abduction ROM in the CAAM (left).
Figure 2. Measuring of the bilateral MVC of the hip adductor muscles (center).
Figure 3. Foam rolling of the hip adductor muscles (right).

Statistical Analysis

A randomized crossover design using a 3 X 2 factorial repeated measurements analysis of variance (ANOVA) was performed to test for the interaction between the stretching interventions for ROM and MVC. Statistical analyses were performed via SigmaPlot 13.0 (Systat Software, San Jose, CA). The independent variables were condition (FR, SS, and CON) and time (pretreatment and posttreatment). The dependent variables were change in ROM and maximal voluntary isometric contraction (MVC) from preintervention to postintervention. Sex as a between-subjects factor was also measured. The 2 factors included Condition (FR, SS and CON) and Time (pre vs. post-stretching intervention). Assumptions of ANOVA were examined and

ROM scores were found to be non-normally distributed. As such, the variables were transformed by using a two-step transformation technique according to Templeton (36). The newly transformed data identified normality for ROM values. A p-value of < 0.05 was used for statistical significance. If a difference was found, post-hoc analyses were performed using the Bonferroni pairwise comparison method. Minimum detectable change (MDC) for ROM and MVC was calculated as SEM*√2*1.96. In crossover design studies it is important to verify whether long-term day-to-day increases in flexibility occurred which could potentially confound interpretation of the results. Thus, pre-intervention ROM on the first and last days of data collection were analyzed by a paired t-Test.

RESULTS

Descriptive statistics (mean ± SD) for change in hip adductor ROM and MVC from pre to postintervention are shown in Table 2. No significant differences were observed between conditions preintervention ($p > 0.05$). ROM from pre to postintervention significantly increased for all conditions (FR: $p < 0.001$); SS: $p < 0.001$); CON: $p = 0.039$). No significant differences were observed in MVC between conditions pre or postintervention ($p > 0.05$). There were significant increases in MVC from pre to postintervention for SS ($p = 0.034$) and CON ($p = 0.007$), whereas no significant change over time was observed for FR ($p = 0.537$). MDC at 95% confidence interval for ROM and MVC was 0.6° and 0.9 kg respectively.

The paired t-Test did not reveal a significant difference ($p > 0.05$) between first session pretest ROM and final session pretest ROM, indicating that there were not significant increases in hip abduction ROM over the testing period. This indicates no carry-over effect of the stretching across time. The ANOVAs for ROM and MVC revealed no significant ($p > 0.05$) interaction between sex and stretching interventions, thus sexes were combined for each variable.

Table 2. Summary of Flexibility and Strength Changes.

	Foam Rolling (FR)	Static Stretching (SS)	Control (CON)
ROM (degrees[°])			
Pre-test mean (SD)	54.6 ± 4.1	53.8 ± 4.9	53.7 ± 4.8
Post-test mean (SD)	55.8 ± 4.3	54.8 ± 4.8	54.3 ± 48
Mean gain (SD)	1.2 ± 1.5*	1.0 ± 1.9*	0.6 ± 1.4*
MVC (kg)			
Pre-test mean (SD)	23.1 ± 7.1	23.5 ± 7.0	23.1 ± 7.0
Post-test mean (SD)	23.3 ± 7.3	24.3 ± 7.4	24.1 ± 7.2
Mean gain (SD)	0.2 ± 2.1	0.8 ± 2.2*	1.0 ± 2.5*

Note. Values are mean ± SD. *Indicates significant increases from pre to postintervention, $p < 0.05$.

DISCUSSION

The main objective of this study was to determine change in hip adductor ROM following an acute warm-up which included a FR intervention compared to SS as a stretching standard and CON. Pre and postintervention MVCs were also recorded to determine if there was a negative effect of either intervention on subsequent force output. In brief, we found that an acute 60-second bout of either FR or SS increased ROM without compromising MVC. We accept our hypothesis that FR was as effective as SS at increasing flexibility. An increase in ROM following FR of similar durations has also been shown by others in various lower extremity muscles, not including the hip adductors (2, 3, 7, 15, 20, 33, 34). It is important to note that FR and SS were not statistically more effective than CON in our study. However, the increases in ROM for FR surpassed the MDC by approximately twofold, which was similar to SS, whereas, the change in CON did not. Changes in flexibility were small. A minimal clinically important difference for hip abduction ROM has not yet been established to know if this degree of change is sufficient alone to benefit physical performance. The present study carefully controlled for intensity and stretch force applied to the limbs as we have reported previously (8, 12), making the endpoint measurement of ROM objectively precise with high resolution. This may be one reason why only minimal change in flexibility was seen as potential tester subjective bias was eliminated.

Our findings also demonstrate that acute bouts of FR and SS significantly increased hip abduction ROM without compromising force output, which is also in support of our hypothesis. The mean change in MVC from pre to post for FR was in an upward direction, but insignificant. The SS and CON interventions significantly increased MVC from pre to post intervention. These changes, although significant, were relatively small and approximately the same as MDC. It is unknown whether these changes would lead to clinical improvements in strength using other performance criteria. Our main stated purpose in this regard was to determine if FR had a deleterious effect on strength. Our present findings indicate that FR does not have a negative impact on strength.

There is a growing body of research on the topic of SMR in general, but to our knowledge this is the first study to investigate the effects of FR on the hip adductor muscle group. However, although controversial, there is no direct evidence demonstrating that there is an actual myofascial release that occurs (2). Although potential mechanisms were not directly examined in this study it is thought that FR may stimulate a number of physiological changes that may enhance a muscles' pliability and ROM. It has been suggested that FR provides a stimulus that may lead to H-reflex inhibition with resulting increased flexibility (35). FR may also work via an increase in autogenic inhibition (15). This process of relaxation is proposed to occur in the same muscle that is experiencing a directed increase in pressure via the foam roll which would stimulate the Golgi tendon organ and reflexively decrease muscle tension (18). Another potential explanation for the increase in ROM following FR is a change in the thixotropic property of the fascia surrounding the muscle (22, 27). Fascia is comprised of colloidal substances, and when fascia is left undisturbed it thickens and becomes more viscous, taking on a more solid like state, whereas when it is disturbed by heat and mechanical stress, it softens and takes on a more gel-like state (32). Abnormal crosslinks or adhesions due to repeated stress of the soft-tissue or inactivity may also reduce joint ROM. It is proposed that shear forces by SMR may mechanically reduce these restrictions and restore the thixotropic properties of the fascia, increasing soft-tissue compliance and hydration allowing for freer movement (1, 27, 32). FR pressure causes deformation of the neuromuscular tissue which may also desensitize the area leading to increased stretch tolerance, often given as a reason for temporary ROM increases from other stretching methods (14, 19). FR is also associated with increased arterial distensibility. Friction from the pressure on the foam roll has been shown to increase nitric oxide production, thereby reducing arterial stiffness and improving endothelial function, meaning increased blood flow along with a potentially raised surface temperature of a muscle (25). Thus, localized heat production may be another mechanism which contributes to actual increased musculotendinous length leading to the improvements in flexibility. In regards to this however, Murray et al.(22) has shown that 60 seconds of FR does not increase surface temperature of the underlying muscle. Perhaps longer periods of FR would increase muscle temperatures but when using FR as part of a warm up procedure, durations longer than 60 seconds per area may be considered impractical.

The small increase of 1.2° in flexibility due to FR in our study was similar to SS, where a 1.0° increase in hip abduction ROM was observed. This is in line with previous findings by Rubini et al.(31) of a 1.4° (2.8° bilateral) increase in hip abduction following SS. These small changes are similar to the findings from our previously published papers, which showed small, but significant increases in hip abduction flexibility from 1.0-1.7° from stretching interventions that included a modified lunge stretch, a manual joint mobilization procedure and an active 3-dimensional stretch (12) as well as active vs. passive SS (8). Statistically, only the 3-dimensional stretch (1.7°) exceeded control (0.6°) ($p = 0.031$) but was not different than the other stretching methods (12). Although the increases in ROM for the FR and SS interventions in the present study were found to be significant, these values are lower than those previously reported for other muscle groups of the lower extremities (6, 20, 21, 34). In contrast, others have shown that acute short-duration FR does not increase flexibility in the quadriceps, hip flexors (22), or the hamstrings (29). The challenge to positively impact ROM in groin muscles may be due to a number of anatomical factors inherent to this area, such as capsular, bony, muscular and/or ligamentous limitations (10, 37). Individual variations in femoral neck angle may account for differences in the potential for improvements in flexibility measured in the frontal plane as a joint with a bony or capsular end range limit may be more difficult to see increases in (10).

The slight increase in ROM seen in the CON intervention may have been due to the brief stretching stimulus experienced during measurements, which included two preintervention and two postintervention passive static stretch recordings for ~5 seconds each trial. Thus, the test may have been an intervention itself. A possible explanation for the increased ROM observed in all conditions may also be partially related to a reduction in passive resistance or increased tolerance to stretching (10, 39).

Our results demonstrate that FR does not inhibit force output when a strength test was performed after an acute FR session. This is congruent with previous findings using FR on lower body musculature for similar durations which did not result in decrements in isometric force and performance measures (3, 11, 13, 20, 34). Our results compare closely to a similar study by

Macdonald et al.(20) which reported that an acute bout of FR increased knee joint ROM, without a subsequent decrease in knee extensor muscle activation. Similarly, Behara and Jacobson(3) investigated the acute effects of FR on muscular strength, power, and flexibility in Division 1 football lineman. The authors found no significant differences for peak or average knee extension isometric torque, while hip flexibility in the sagittal plane was improved similarly following FR or dynamic stretching. Finally Su et al.(34) showed that FR was more effective than static and dynamic stretching and increased ROM in the quadriceps and hamstrings without hampering muscle strength. Taken together, these findings would suggest that acute bouts of short-duration FR of the lower body musculature do not result in decreases in measures of strength. The findings from the present study suggest that FR and SS may be incorporated as part of a warmup procedure to increase hip adductor ROM without any decrements on force output prior to athletic or recreational exercise performance.

Future research regarding the hip adductor muscle group may consider combining FR with other warm-up methods, such as SS or dynamic stretching. Mohr et al.(21) found that a 3-week training intervention which combined FR and SS resulted in a greater increase in hip-flexion ROM than performing either intervention individually. Combining stretching methods acutely could form the hypotheses of future studies to see if similar outcomes are reproduced. In fact, Roylance et al.(29) demonstrated that an acute treatment of FR significantly increased ROM of the hamstrings when combined with either postural alignment exercises or SS, but not when performed alone. Combining FR with other methods as demonstrated by Mohr et al.(21) and Roylance et al.(29) as well as perhaps combining FR with 3-dimensional dynamic stretching could be investigated (12).

While the findings of this study provide insight on the effects of FR and SS on ROM and force output on the adductor muscle group and can inform future research it has a few limitations. Only participants who were defined as having limited hip abduction ROM were included which may reduce the generalizability of the findings. Although a significant increase in ROM without decrement in MVC for FR was observed, it is unknown whether these changes are clinically or functionally relevant. The adductor muscles remain as an understudied, yet highly important grouping of muscles due to their relatively high injury rate in sport and their roles in several joint actions that take place in all three planes of movement. Another limitation is that we only measured ROM and MVC in this muscle group in the frontal plane and thus did not emphasize other roles of the groin muscles in also controlling hip movements in the sagittal and transverse planes. Measurements in this study also took place while subjects were seated and reclined in the CAAM machine where all movements were closely controlled and monitored, whereas measuring mobility or force output while upright and standing in a 3-dimensional setup, such as by modifying the Star Excursion or Y Balance tests, may better exhibit the unique functional qualities of the adductors while integrated with other muscle groups during exercise and sport (26, 28).

In conclusion, from a practical standpoint, the results of this study can be used by coaches, trainers, athletes and recreational exercisers to inform appropriate warm-up practices and recommendations. These findings suggest that FR and SS of the hip adductors for periods of 60 seconds may be employed prior to athletic or exercise performance to increase flexibility without any negative consequences on force output.

ACKNOWLEDGEMENTS

The authors wish to thank Brandon Fjerstad, Taylor Lange and Dr. Adam Hammer for assistance with data collection, and Drs. Peter Loubert, Karen Lomond, Naveen Sharma and Adam Hammer for help with procedure design, data interpretation and statistical analyses.

REFERENCES

1. Barnes MF. The basic science of myofascial release: Morphologic change in connective tissue. J of Bodyw Mov Thera 1(4): 231-238, 1997.

2. Beardsley C, Skarabot J. Effects of self-myofascial release: A systematic review. J Bodyw Mov Ther 19(4): 747-758, 2015.

3. Behara B, Jacobson BH. Acute effects of deep tissue foam rolling and dynamic stretching on muscular strength, power, and flexibility in division I linemen. J Strength Cond Res 31(4): 888-892, 2017.

4. Behm DG, Blazevich AJ, Kay AD, McHugh M. Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: A systematic review. Appl Physiol Nutr Metab 41(1): 1-11, 2016.

5. Behm DG, Chaouachi A. A review of the acute effects of static and dynamic stretching on performance. Eur J Appl Physiol 111(11): 2633-2651, 2011.

6. Bradbury-Squires DJ, Noftall JC, Sullivan KM, Behm DG, Power KE, Button DC. Roller-massager application to the quadriceps and knee-joint range of motion and neuromuscular efficiency during a lunge. J Athl Train 50(2): 133-140, 2015.

7. DeBruyne DM, Dewhurst MM, Fischer KM, Wojtanowski MS, Durall C. Self-mobilization using a foam roller versus a roller massager: Which is more effective for increasing hamstrings flexibility? J Sport Rehabil 26(1): 94-100, 2017.

8. Fjerstad BM, Hammer RL, Hammer AM, Connolly G, Lomond KV, O'Connor P. Comparison of two static stretching procedures on hip adductor flexibility and strength. Int J Exerc Sci 11(6): 1074-1085, 2018.

9. Floyd RT, Thompson CW. Manual of structural kinesiology. Boston: McGraw-Hill; 2004.

10. Gajdosik RL. Passive extensibility of skeletal muscle: Review of the literature with clinical implications. Clin Biomech 16(2): 87-101, 2001.

11. Halperin I, Aboodarda SJ, Button DC, Andersen LL, Behm DG. Roller massager improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. Int J Sports Phys Ther 9(1): 92-102, 2014.

12. Hammer AM, Hammer RL, Lomond KV, O'Connor P. Acute changes of hip joint range of motion using selected clinical stretching procedures: A randomized crossover study. Musculoskelet Sci Pract 32: 70-77, 2017.

13. Healey KC, Hatfield DL, Blanpied P, Dorfman LR, Riebe D. The effects of myofascial release with foam rolling on performance. J Strength Cond Res 28(1): 61-68, 2014.

14. Jay K, Sundstrup E, Sondergaard SD, Behm D, Brandt M, Saervoll CA, Jakobsen MD, Andersen LL. Specific and cross over effects of massage for muscle soreness: Randomized controlled trial. Int J Sports Phys Ther 9(1): 82-91, 2014.

15. Junker DH, Stoggl TL. The foam roll as a tool to improve hamstring flexibility. J Strength Cond Res 29(12): 3480-3485, 2015.

16. Kalichman L, Ben David C. Effect of self-myofascial release on myofascial pain, muscle flexibility, and strength: A narrative review. J Bodyw Mov Ther 21(2): 446-451, 2017.

17. Kay AD, Blazevich AJ. Effect of acute static stretch on maximal muscle performance: A systematic review. Med Sci Sports Exerc 44(1): 154-164, 2012.

18. Lukas C. Faszienbehandlung mit der blackroll [treatment of fascia with the blackroll]. Norderstedt: Bod. Kandern, Germany: Narayana Verlag; 2012.

19. MacDonald GZ, Button DC, Drinkwater EJ, Behm DG. Foam rolling as a recovery tool after an intense bout of physical activity. Med Sci Sports Exerc 46(1): 131-142, 2014.

20. MacDonald GZ, Penney MD, Mullaley ME, Cuconato AL, Drake CD, Behm DG, 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.

21. Mohr AR, Long BC, Goad CL. Effect of foam rolling and static stretching on passive hip-flexion range of motion. J Sport Rehabil 23(4): 296-299, 2014.

22. Murray AM, Jones TW, Horobeanu C, Turner AP, Sproule J. Sixty seconds of foam rolling does not affect functional flexibility or change muscle temperature in adolescent athletes. Int J Sports Phys Ther 11(5): 765-776, 2016.

23. Navalta JW, Stone, W.J., Lyons, S. Ethical issues relating to scientific discovery in exercise science. International Journal of Exercise Science 12(1): 1-8, 2019.

24. Nevin F, Delahunt E. Adductor squeeze test values and hip joint range of motion in gaelic football athletes with longstanding groin pain. J Sci Med Sport 17(2): 155-159, 2014.

25. Okamoto T, Masuhara M, Ikuta K. Acute effects of self-myofascial release using a foam roller on arterial function. J Strength Cond Res 28(1): 69-73, 2014.

26. Overmoyer GV, Reiser RF, 2nd. Relationships between lower-extremity flexibility, asymmetries, and the y balance test. J Strength Cond Res 29(5): 1240-1247, 2015.

27. Paolini J. Review of myofascial release as an effective massage therapy technique. Int J Athl Ther Train 14: 30-34, 2009.

28. Plisky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. The reliability of an instrumented device for measuring components of the star excursion balance test. N Am J Sports Phys Ther 4(2): 92-99, 2009.

29. Roylance DS, George JD, Hammer AM, Rencher N, Gellingham GW, Hager RL, and Myrer WJ. Evaluating acute changes in joint range-of-motion using self-myofascial release, postural alignment exercises, and static stretches. Int J Exerc Sci 6(4): 310-319, 2013.

30. Rubini EC, Costa AL, Gomes PS. The effects of stretching on strength performance. Sports Med 37(3): 213-224, 2007.

31. Rubini EC, Souza AC, Mello ML, Bacurau RF, Cabral LF, Farinatti PT. Immediate effect of static and proprioceptive neuromuscular facilitation stretching on hip adductor flexibility in female ballet dancers. J Dance Med Sci 15(4): 177-181, 2011.

32. Schleip R, Muller DG. Training principles for fascial connective tissues: Scientific foundation and suggested practical applications. J Bodyw Mov Ther 17(1): 103-115, 2013.

33. Skarabot J, Beardsley C, Stirn I. Comparing the effects of self-myofascial release with static stretching on ankle range-of-motion in adolescent athletes. Int J Sports Phys Ther 10(2): 203-212, 2015.

34. Su H, Chang NJ, Wu WL, Guo LY, Chu IH. Acute effects of foam rolling, static stretching, and dynamic stretching during warm-ups on muscular flexibility and strength in young adults. J Sport Rehabil 26(6): 469-477, 2017.

35. Sullivan KM, Silvey DB, Button DC, Behm DG. Roller-massager application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. Int J Sports Phys Ther 8(3): 228-236, 2013.

36. Templeton GF. A two-step approach for transforming continuous variables to normal: Implications and recommendations for is research. Commun Assoc Inf Syst 28: 41-58, 2011.

37. Thompson F. Manual of structural kinesiology. Boston: McGraw-Hill; 2003.

38. Waldén M, Hägglund M, Ekstrand J. The epidemiology of groin injury in senior football: A systematic review of prospective studies. Br J Sports Med 49(12): 792-797, 2015.

39. Weppler CH, Magnusson SP. Increasing muscle extensibility: A matter of increasing length or modifying sensation? Phys Ther 90(3): 438-449, 2010.

40. Werner J, Hägglund M, Waldén M, Ekstrand J. UEFA injury study: A prospective study of hip and groin injuries in professional football over seven consecutive seasons. Br J Sports Med 43(13): 1036-1040, 2009.