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EFFECT OF ACUTE FOAM ROLLER AND PERCUSSION THERAPY ON MUSCLE ARCHITECTURE AND MUSCLE STIFFNESS

Maryam Yektaei[1*], Orkun Akkoç[1], Sergen Devran[2], Imren Kurtdere[1], Özlem Kirandi[1], Bulent Bayraktar[2]
[1]Istanbul University- Cerrahpasa, Department of Movementng and Training Science, Faculty of Sports Science, ISTANBUL
[2]Istanbul University, Department of Sports Medicine, Faculty of Medicine, ISTANBUL

Abstract: The aim of the study is to investigate the effect of the acute application of foam roller and massage gun, which are self-myofascial techniques, on muscle architecture and muscle stiffness. 27 male athletes participated in the study. Within the scope of the study, the athletes were randomly divided into 3 groups as 1st group foam roller (FR), 2nd group massage gun (MG), 3rd group as control group (CG) and muscle architecture and muscle stiffness (MS) were evaluated as a result of acute exercise. Muscle stiffness (MS) muscle thickness (MT), cross-sectional area (CSA), and pennate angles (PA) of the subjects were measured by ultrasound. The measurement results were tested with repeated measures two-way Anova test analysis of variance in the SPSS program, and significance was accepted as $p<0.05$. When the measurement results of MS, PA, and MT were examined, no significant difference was observed in the FR, MG, and CG pre-test and post-test ($p= 0.94$). In the pretest and posttest results of the CSA of the muscle, a decrease was observed in the FR group and an increase in the MG group ($p=0.03$). In conclusion; shows that muscle thickness,pennation angle, and muscle stiffness do not change after acute self-myofascial relaxations and that foam roller and massage gun do not have superiority over each other. The cross-sectional area decreased after the foam roller application and increased after the massage gun.

Key words: Foam roller, massage gun, muscle architecture, elastography, muscle stiffness

AKUT KÖPÜK ROLLER VE VURMA TERAPİSİNİN KAS YAPISI VE KAS SERTLİKLERİ ÜZERİNDEKİ ETKİSİ

Öz: Çalışmanın amacı self myofasyal tekniklerden foam roller ve masaj tabancası akut uygulamasının kas mimarisi ve kas sertliğine etkisini araştırmaktır. Çalışmaya 27 erkek sporcu katılmıştır. Çalışma kapsamında sporcular 1. Grup foam roller, 2. Grup masaj tabancası, 3. Grup ise kontrol grubu olacak şekilde rasgele 3 gruba ayrılmış ve akut egzersiz sonucunda kas mimarisi ve kas sertliği değerlendirilmiştir. Deneklerin kas sertliği, kas kalınlığı, enine kesit alanı (CSA) ve pennat açıları ultrasonda ölçülmüştür. Ölçüm sonuçları SPSS programında tekrarlı ölçümler iki yönlü Anova testi varyans analizi ile test edilmiş, anlamlılık $p<0,05$ kabul edilmiştir. Kas sertliği, pennasyon açısı ve kas kallınığı ölçüm sonuçları incelendiğinde foam roller, masaj tabancası ve kontrol grubu ön-test ve son – test anlamlı fark gözlemlenmemiştir ($P= 0,94$) Kasın enine kesit alanı ön test ve son test sonuçlarında köpük silindir yapan grupta düşüş, masaj tabancası yapan grupta artış gözlemlenmiştir ($P=0,03$). Sonuç olarak; kas kalınlığı, pennasyon açısı ve kas sertliğinin akut self myofasyal gevşemelerden sonra değişmediğini ve köpük silindir ve masaj tabancasının birbirine üstünlüklerinin olmadığını göstermektedir. Enine kesit alanı ise foam roller uygulamasından sonra azalmış, masaj tabancasından sonra artmıştır.

Anahtar kelimeler: Köpük silindir, masaj tabancası, kas mimarisi, elastografi, kas sertliği

[*] *Sorumlu Yazar: Maryam Yektaei, E-mail: m.yektaei1@outlook.com*

INTRODUCTION

Skeletal muscle architecture is defined as the regulation of muscle fibers in a muscle according to the strength generation axis (Lieber et al., 2000). Skeletal muscle architecture is one of the most important characteristics determining the strength, power, and movement skill of a muscle. In muscle architecture, distinguishing measurement data can be obtained in several parameters like MS, MT, CSA, PA, and fascicule length.

Differences in a maximum inter-muscle shortening speed are closely related to the differences in muscle fascicule length, (sarcomere number in a series) and PA (Abe et al., 2000; Frontera et al., 2015). MT is measured from one aponeurosis to another aponeurosis. MT is related to muscle size (Nadzalan, 2018). The increase in muscle size which is one of the indications of muscle strengthening affects the muscle structure by increasing PA. In recent studies, MT and CSA of muscle was reported to be a determiner in predicting isometric and isokinetic power during contraction and relaxation (Sekir, 2022).

PA is the angle that muscle fibers build according to connective tissue and tendon. Changes in pennation angle cause alterations in power transmission that muscle fibers transfer to the tendon (Nadzalan, 2018; Ulubaba, 2022). How different alterations like muscle size, fascicule length, and PA in muscle architecture affect athletic characteristics have been studied in the literature. Studies related to PA were particularly focused. While the decrease in PA was associated with the characteristics like power and speed, the increase in PA was associated with strength (Abe et al., 2000; Nadzalan et al., 2018; Wakahara et al., 2012). In addition, there are studies reporting that additional myofascial relaxing workouts decrease PA (García-Sillero., 2021; Trainer et al., 2022) The decrease in PA was associated to a decrease in the injury risk of muscle along with an increase in muscle fascicule length. This can particularly be explained with the adaptation of muscle to eccentric based contractions (Timmins et al., 2016).

Sports injuries, drug use, cramps, structural defects, fatigue, exercise and different type of training methods, relaxation techniques can make alterations in MS (Akkoç et al., 2018; Page et al., 2012). The increase and decrease in MS may affect athletic performance negatively. For this reason, MS should be maintained in one's own normal stiffness range. Injury, spasm, cramp and extreme trainings increase MS. In spite of that, performing stretching and other myofascial relaxation techniques excessively may decrease MS (Akkoç et al., 2018; Morales et al., 2017). In order not to decrease MS relaxation techniques should not be performed for long time. Calıskan and Morales have put the relationship between muscle stiffness and duration forward and reported that MS decrease as relaxation exercise duration (Caliskan et al., 2019; Morales et al., 2017). MS characteristics of lower limb has been shown to affect the performance in several athletic tasks that are dominant in many sports like jump, running, and change of direction (Brazier et al., 2019). However, there is a consensus about an extreme increase or decrease in this stiffness level could affect sportive performance negatively and cause sports injuries (Koulouris et al., 2003; Kurtdere et al., 2021).

Fascia is located in muscle groups and is the general name of a connective tissue layer surrounding structures like blood vessels and nerves or producing muscle sheath (Lieber et al., 2000). Fascia is placed integrally in muscular-skeletal integrally and may play a role in the transmission of power (Benjamin et al., 2009).

Individual myofascial relaxation applications are defined as a general term used for several manual therapy techniques performed by a pressure on muscle and fascia (McKenny et al., 2013). There are different types of applications for relaxing fascia like massage, electric applications, acupuncture, hot applications, stretching and exercise, FR, MG, and vibration application. Additionally, self-myofascial relaxation is a type of a myofascial relaxation carried out by individual by him/herself using a means not by a clinician. Most common tools used for self-myofascial relaxation are FR and (MG) application (Beardsly et al., 2015; García-Sillero., 2021; Okamoto et al., 2014). Myofascial relaxation reduces oedema, and spasm in muscle fibers caused muscle rigidity, stiffness, and ache. As a result of this, it causes an increase in range of motion and flexibility after the healing of soft tissue. Individual myofascial application after massage cause alterations in flexible structure of muscle and it enhances the genesis (biogenesis) of mitochondria, genesis of new blood vessels (angiogenesis) or it enhances blood flow by providing blood recirculation which is significant for muscle (Schroeder et al., 2015).

Small fluctuations stretch tissue by applying direct and wide pressure on soft tissue and produce friction between soft tissue and FR. Friction caused by fluctuations cause facia to warm and makes fascia more fluidlike (known for facia’s thixotropic feature) and breaks stringy cohesions between the layers of fascia and regains soft tissue extensibility (McDonald et al., 2013). There are studies related to FR application enhances range of motion without negative effects on performance and reduces delayed onset muscle pain before and after exercise (Cheatham et al., 2015). However, there is very few knowledge related to the effect on muscle architecture in literature. Nowadays the use of MG has become more popular. MG are usually used for alleviating muscle pain, shortening healing period before training or competition, enhancing blood circulation, preventing muscle spasms, and supporting muscle development (Konard et al., 2020). Despite limited research on MG, in a study an increase was observed in range of motion following a MG application throughout 5-min however no change was reported in power outputs. For this reason, in order to optimize an athlete’s flexibility level before he loses muscle performance a MG application was recommended to be included in warm up program (Konard et al., 2020). FR and MG applications are intensively used in recovery, recovery of delayed onset muscle soreness, preparation to warm up, and warm up.

The purpose of using warm up and recovery is to relax fascia, increasing blood flow and preparation to athletic performance. FR applications performed in warm up stage enhance athletic performance (Chen et al., 2021; Wiewelhore et al., 2019). In a study on two separate groups, while first group conducted a warm-up combined with FR, second group conducted a general warm up. As a result, MS was determined to be the same in both groups and there was no extra stiffness in FR group (Morales et al., 2017). This suggests that FR applications have no negative effects on athletic performance reducing MS On the other hand, research on the effects of alterations on muscle architecture and structural characteristics of muscle has become more popular. Different exercise types, exercise duration and exercise type have several effects on muscle architecture. Acute and chronic effects of FR application from self-myofascial relaxation techniques have been researched in literature. However, MG is a novel relaxation technique and is a matter of curiosity whether it has strengths and weakness on other relaxation techniques. The purpose of this study was to examine FR and MG acute application from self-myofascial techniques on muscle architecture and MS.

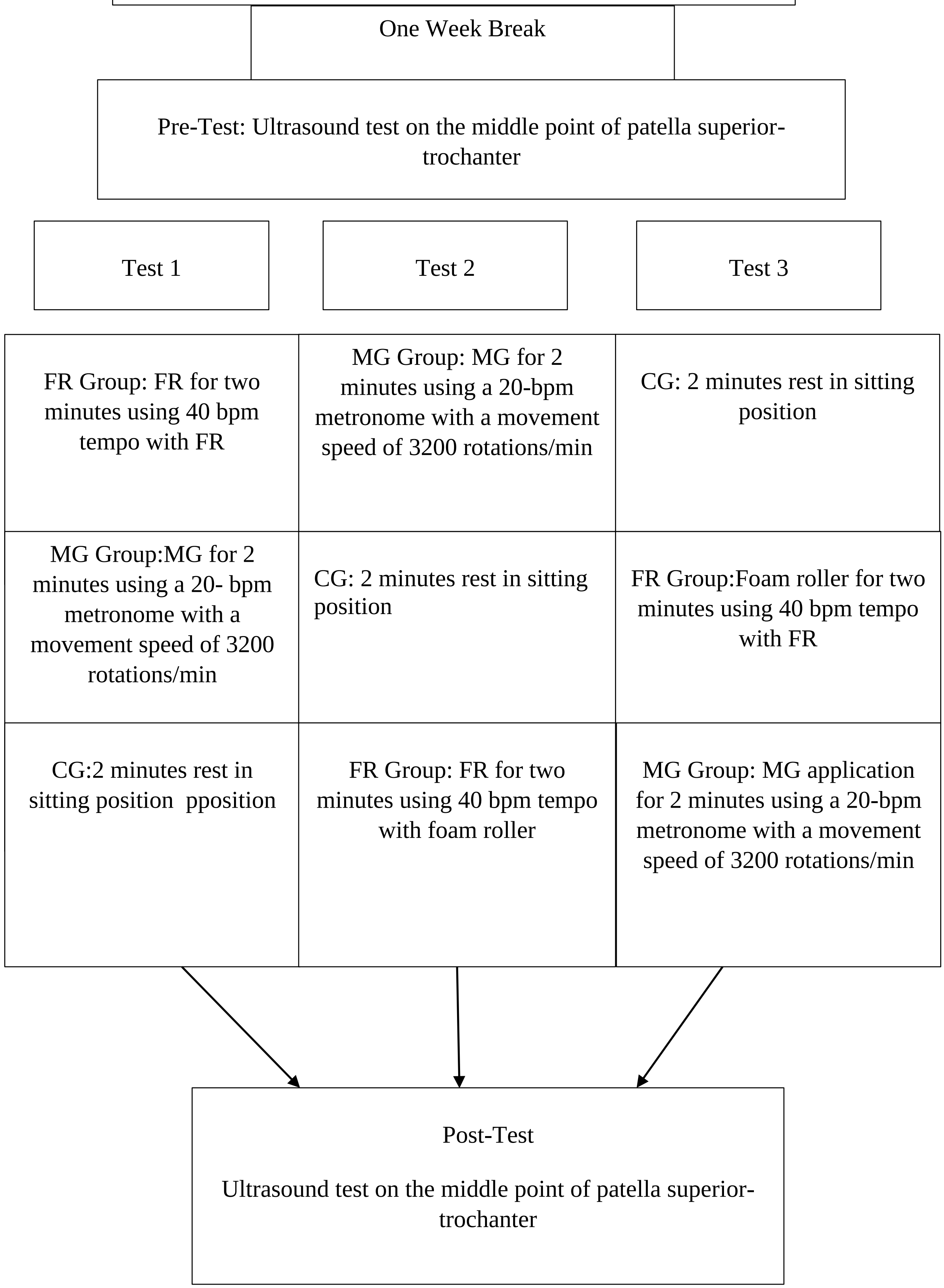
METHODS

Twenty-seven male (20,32±2,39) sports science faculty students participated in this study. Participants consisted of individuals who had no lower limb injury in the past six months. Subjects with medical history, chronic drug use, rheumatic, systemic and/or connective tissue disorders were not included in the study. All the participants were informed of the experimental procedure and any potential ethical implications, and all the participants provided written informed consent. The study was approved by the Istanbul University-Cerrahpasa Ethical Committee and was performed in accordance with the principles of the Declaration of Helsinki seventh revision. (Approval No: E-59491012-604. 01.02-46366).

Study Design

The study was conducted as cross over design. MG, FR and CG took place in research. Participants were divided into three groups randomly as CG (n=9), MG (n=9), and FR (n=9). The research was conducted as 1 day throughout 3 weeks. For example, participant X included in FR group first week, MG second week, and CG third week. In this way each participant was included in each separate group and by which application they had better results was determined. Participants did not perform any physical activity in the last 48 hours before the ecercises. In order not to experience temporal differences in the data of athletes' sessions were carried out on Saturdays between 09:00 AM and 11:00 AM. A week before the start of the study, a familiarization study was carried out in the application area in order to explain the study process and method to the participants. The test began with anthropometric measurements (height, weight) then location was marked on rectus femoris muscle of participants where ultrasound and application will be performed. The marked location indicates the ultrasound test location. This location is the middle point of patella superior-trochanter major. The pre-test was conducted after this application. Pre-test and post-test application was conducted on rectus femoris dominant leg. Pre-test results were recorded in log sheets. Ultrasound application was conducted by a practitioner who had 5 years of experience. Right after pre-test application MG application was conducted to a group for 2-min and other group was conducted FR for 2-min. For those who were included in CG no application was conducted and they were asked to wait sitting for 2-min. The study was completed by measuring the muscle CSA, MS, MT, PA with ultrasound by performing the post-test application immediately after the myofascial release applications. The study design is shown in Figure 1.

Figure 1. The study design



Demographics
Average ages, heights and weights of participants were as 20.32±2.39, 177±5.12 cm and 78±4.28 kg respectively.

Devices
Myofascial Relaxation Applications
Applications were conducted on the middle point of patella superior-trochanter major. For locating the place where ultrasound and myofascial application on rectus femoris muscle of participants up and down sides were marked with a measuring tape and myofascial relaxations were applied in that range.

Foam Roller
A 38 cm foam roller Nyambaplates roll was used for foam roller application. Participants proned out for application and the foam roller was placed under the leg (right leg). Foam rollers were applied on the rectus femoris in the leg extension and the other leg (left leg) flexion. Foam roller application was applied to the marked area according to the midpoint of the rectus femoris for 2-min at a tempo of 40 bpm.

Massage gun Application
For massage gun application Diesel Phoenix Massage Tool (1DIMSPHNX) was used. During the application, the participants were held on a stretcher, knees extended, and supine position. The massage gun was applied to the marked area according to the midpoint of the rectus femoris for 2-min. The massage gun was used in third gear with blue lights on and the warning frequency was as 3200 turns/min. The rate of motion was adjusted by using a 20-bpm metronome.

Ultrasound Tests
After the probe is placed longitudinally on tendon, ROI boxes in rectangular shape (with a length of 1.5 cm and thickness of 1.0 cm) were placed from the midline (the point where the image is more clear) of the muscle. Then measurement was performed in kPa by placing a 0.4 cm circular ROI inside of these boxes after waiting for five seconds. A third and fourth measurements were taken in the presence of 20% difference between previous and next measurements (Taş et al., 2017). For PA, MT, and CSA evaluations that are related to muscle architecture, measurement was performed from the midpoint (middle of sias-patellar tendon) of rectus femoris (the point where the image is more clear). For MT, the distance between the up and down fascia of rectus femoris was recorded in the longitudinal section. Similarly, the angle that fascicules formed at a point where sub-fascia of muscle for PA was, recorded. Transverse plane was used inside of the muscle CSA, and fascia surrounding the muscle where the muscle can be seen clearly in image was tracked for MT, the distance between up and down fascia of the rectus femoris was recorded in the longitudinal section. Similarly, the angle that fascicules formed at a point where sub-fascia of muscle for PA was recorded (Blazevich et al., 2005). Transverse plane was used inside of the muscle CSA, and fascia surrounding the muscle where the muscle (Seymour et al., 2009). ultrasound measurements were performed with the Toshiba Aplio 500 (Toshiba Medical Systems Corporation, Otawara, Japan). A 10 MHz (5-14 MHz) lineer prob was used for these measurements. All the measurements were performed at room temperature (23 °C) with Aqua-Sonic 100 ultrasound gel (Parker Laboratories Inc, Fairfield, New Jersey). The rectus femoris measurements of all individuals were performed on the ultrasound examination table, in the neutral

and supine position, with the knee in full extension. Before starting the ultrasound measurements, the athletes rested on the ultrasound examination table in a neutral position for 5-min. During the measurement, the probe was held softly on the skin so that the pressure-related values did not change, and a large amount of ultrasound gel was used. After all the measurements were performed twice, next examination started. The averages of these measurements were taken during the statistical analysis. After starting the measurements with elastography MT, MA and CSA area were evaluated respectively. Shear wave (Toshibe Medical Systems Corporation) was used to evaluate the mechanical properties of rectus femoris.

Statistical analysis

Statistics results were obtained using an IBM SPSS 28 package. Descriptive statistics were given as average and standard deviation for quantitative variables, number and percent for qualitative variables. Shapiro-Wilk test was used in the evaluation of suitability to normal distribution. Repeated Measures two-way Anova test was used for the examination of alterations in FR, MG, CG pre-post measurements. Anova was used for subgroups evaluation and correction of significant results was evaluated with Bonferroni. The significance value was taken as ($p<0,05$).

RESULTS

Table 1. Demographic features of the participants

Demographic information	Mean±Std
Age	20.32±2.39
Height	177±512
Weight	78±4.28

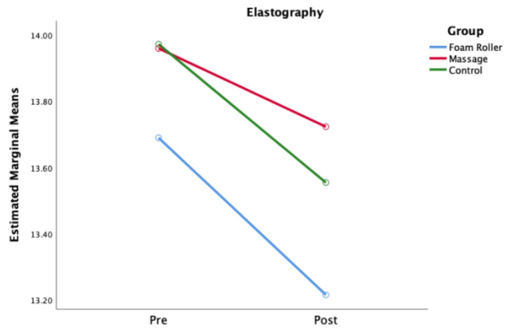
When the muscle stiffness measurement results were examined, foam roller pre-test was 13,71±1,97, post-test was 13,22±2,06, massage gun pre-test was 13,96±2,94, post-test was 13,72±2,08, control group pre-test was 13,97±2,60, post-test was 13,55±2,25. No significant difference was observed in the muscle stiffness pre-test and post-test results. When the pennation angle measurement results were examined, foam roller pre-test was 11.02±1.69, post-test was 11.20±2.10, massage gun pre-test was 10.54±1.81, post-test was 10.80±1.57, control group pre-test was 11.53±1.78, post-test was 11.13±1.99. No significant difference was observed in the pennation angle pre-test and post-test results. When the cross-section area measurement results were examined, foam roller pre-test was 11.48±1.54, post-test was 10.92±1.61, massage gun pre-test was 10.39±1.15, post-test was 10.58±1.09, In the control group, pre-test was 11.09±3.23 and post-test was 11.35±1.56. In cross section area pre-test and post-test results, a decrease was observed in foam roller group and an increase in massage gun group. When Muscle Thickness measurement results were examined, foam roller pre-test was 24.18±2.98, post-test 23.48±3.09, massage gun pre-test 24.17±3.94, post-test 25.25±6.49, control group pre-test 24.18±2.94, post-test 24.09±2.84. No significant difference was observed in muscle thickness pre-test and post-test results. In addition, there was no found significant difference in all groups ($p>0,05$). The results obtained, elastografi pre-test was ($p=0,91$), post-test was ($p=0,67$), PA pre-test was ($p=0,12$), post-test was ($p=0,7$), CSA pre-test was ($p=0,38$), post-test was ($p=0,32$), MT pre-test was ($p=0,99$), post-test was ($p=0,34$).

Table 2. Anova results (evaluation of the difference between groups)

Tests	Test Groups	N	Mean	Std. Dev.	95% Confidence Interval		F	p
					The Lowest	The Highest		
Elastography Before	Foam Roller	27	13.71	1.97	12.93	14.49	0.09	0.91
	Massage Gun	27	13.96	2.94	12.8	15.12		
	Control Group	27	13.97	2.6	12.95	15		
Elastography After	Foam Roller	27	13.22	2.06	12.4	14.03	0.40	0.67
	Massage Gun	27	13.72	2.08	12.9	14.55		
	Control Group	27	13.55	2.25	12.66	14.45		
PA Before	Foam Roller	27	11.02	1.69	10.35	11.69	2.14	0.12
	Massage Gun	27	10.54	1.81	9.82	11.25		
	Control Group	27	11.53	1.78	10.82	12.24		
PA After	Foam Roller	27	11.2	2.1	10.37	12.03	0.35	0.70
	Massage Gun	27	10.8	1.57	10.18	11.42		
	Control Group	27	11.13	1.99	10.34	11.92		
CSA Before	Foam Roller	19	11.48	1.54	10.74	12.22	0.99	0.38
	Massage Gun	15	10.39	1.15	9.75	11.03		
	Control Group	20	11.09	3.23	9.58	12.6		
CSA After	Foam Roller	19	10.92	1.61	10.15	11.7	1.18	0.32
	Massage Gun	15	10.58	1.09	9.98	11.18		
	Control Group	19	11.35	1.56	10.6	12.1		
MT Before	Foam Roller	27	24.18	2.98	23	25.36	0.00	0.99
	Massage Gun	27	24.17	3.94	22.61	25.73		
	Control Group	27	24.18	2.94	23.01	25.34		
MT After	Foam Roller	27	23.48	3.09	22.26	24.7	1.09	0.34
	Massage Gun	27	25.25	6.49	22.68	27.82		
	Control Group	27	24.09	2.84	22.97	25.21		

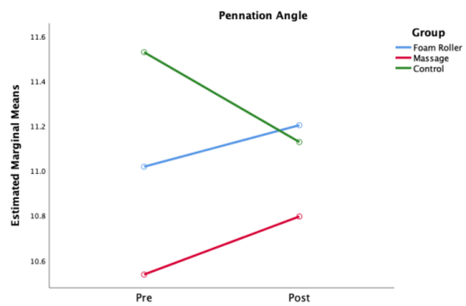
PA: Pennation Angle, CSA: Cross Sectional Area, MT: Muscle Thickness

A decrease was observed in MS values of all groups, but this was not significant (Graph1).



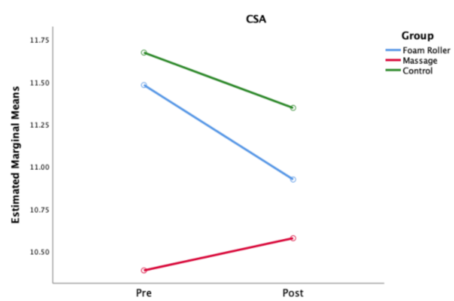
Graph1. Muscle stiffness (MS)

A decrease in PA in CG and an increase in FR and MG groups, however it has no statistical significance (Graph2).



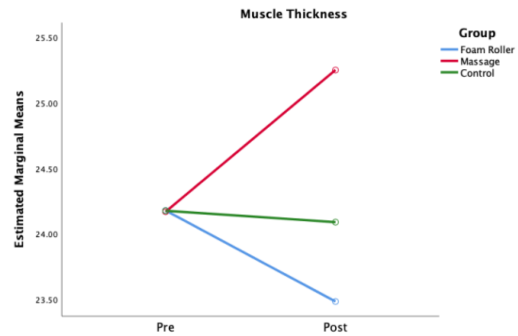
Graph 2. Pennation angle (PA)

While a decrease was observed in FR and CG in CSA, and an increase was observed in MG group, this result was not statistically significant (Graph3).



Graph 3. Cross-sectional area (CSA)

It was observed that muscle thickness increased after massage gun and decreased after foam roller (Graph4).



Graph 4. Muscle thickness (MT)

DISCUSSION

The aim of the study is to investigate the effect of the acute application of foam roller and massage gun, which are self-myofascial techniques, on muscle architecture and muscle stiffness. Our measurement results of MS, PA, and MT were examined, no significant difference was observed in the FR, MG, and CG pre-test and post-test. In the pretest and post-test results of the CSA of the muscle, a decrease was observed in the FR group and an increase in the MG group.

A Primary School class of 30 years five children, attended the university on 10 occasions during the spring term for approximately 50 min (during curriculum time) to receive rugby coaching sessions. The effects of FR and massage on the range of motion, MS, myofascial soreness and sportive performance were examined in recent studies (García-Sillero., 2021; Konard et al., 2020; Macgregor et al., 2018). furthermore, effect of muscle architecture on acute and chronic athletic performance were studied (Morales et al., 2017; Nadzalan et al., 2018). As new imaging techniques such as ultrasound, magnetic resonance, shear wave elastography emerged with technological developments; measurements of muscle architecture properties such as PA, MT, and CSA have become easier (Lieber et al., 2000). Alterations in muscle architecture have been known to alter athletic properties (Mangine et al., 2014; Nadzalan et al.,2018). On the other hand, it was reported that self-myofascial applications had acute and chronic effects on athletic properties (Trainer et al., 2022), and self-myofascial relaxation techniques were reported have effects on muscle architecture (Torrente et al., 2022).

MT: MT is one of the most effective property from muscle architecture properties in strength and power production. MT adjust acutely and chronically with exercise. The cause of acute thickness enhancement is the replacement of the liquids in a cell. Also, the duration, type and velocity of exercise can be effective in the alteration of MT. It was determined that there was an increase in MT following acute strength and power workouts (Gaspari et al., 2021), Contrary to this, MT is expected to increase after relaxations such as FR and self-myofascial application (Freiwald et al., 2016). A FR study on nine trained men who did resistance exercises and compared 3-min FR application to 1-min FR application. As a result of 3-min FR application an increase observed in vastus lateralis MT, and they recommended 3-min and longer FR applications for an increase in MT (Brigatto et al., 2021).

CSA: An increase in the CSA of skeletal muscle fibers is termed fiber hypertrophy and is generally regarded as the primary adaptation in long-term strength training (Jones et al., 1989). Muscle strength is proportional to muscle CSA (McDonagh et al., 1984). When discussing the CSA of a muscle, it should also be noted that the CSA consists of several parts that make up the total muscle CSA, including non-contractile tissue such as blood vessels. The volume of sarcomeres (i.e contractile proteins) is often associated with CSA. Common adaptations based on activity levels such as changes in intravascular and interstitial volume, changes in mitochondrial density and muscle glycogen density also contribute to muscle CSA (Jones et al., 2008). When myofascial release studies using FR and MG are examined in the literature, these studies are mostly related to joint range of motion (McDonald et al., 2013; Trainer et al., 2022). delayed onset muscle soreness (DOMS) (García-Sillero et al., 2021), and MS (Morales et al., 2017), and there is little data on the CSA of the muscle. In the current study, it was seen that FR application decreased CSA and MG increased CSA. The fact that FR application reduced CSA is compatible with the literature, and the increase in the MG is thought provoking. The increase in CSA of the MG suggests a possible muscular activity. More studies are needed to understand the effect of the MG on CSA. Exercise, various training, and relaxation methods alter MS (Akkoç et al., 2018; Page et al., 2012).

MS: The volume and severity of the method are as important as the method applied in alterations in muscle MS (Kurtdere et al., 2021). They emphasized that MS was affected by the duration of the application from this result. García-Sillero et al. (2021), in their acute studies in which they compared the effects of foam roller (FR), manual therapy (massage), MG application and mechanical vibration recovery techniques on muscle tissue through the tensiomyography method, percussion intervention was similar to manual therapy and probably more effective than mechanical vibration or FR application (cost-time relationship) and it showed the potential to restore muscle compliance and reduce stiffness(García-Sillero et al., 2021). In the current study, MS did not alter in both groups. The reason why it did not change may depend on the duration of therapy applied.

PA: alterations in PA as a result of myofascial studies are still being investigated. In a study of Torrente et al. with a total of twenty-five young, athletic male volunteers, they performed a one minute foam roller application for each leg along the full length of both thighs, three times a week, on three separate days for seven weeks and they used ultrasound to determine first and last vastus medialis oblic and vastus lateralis PA. It was reported that a significant decrease in PA was observed in vastus medialis and vastus lateralis muscles after seven weeks of foam roller application. It was reported that balance should be maintained in the PA of the vastus medialis oblique and vastus lateralis muscles in order to maintain the normal movement pattern of the knee. They reported that in case of a loss of PA balance between these two muscles, patellofemoral pain emerges, and an alteration between two muscles could be possible with either increasing muscle fiber angle through targeted exercises or decreasing the angle through stretching exercises (Torrente et al., 2022). Several of these variables were not fully exploredin the included studies or There is a lack of information in the literature on this subject and it has not been researched. To obtain better quality research, in future studies, we endorse applying these applications on different muscle groups, using different type of massage gun and foam roller, or performing the application for different periods of time.

CONCLUSION

This study found that self-myofascial relaxations do not change MS, MT and PA. FR and MG applications were not superior to each other in PA, MT and MS. In addition, FR application decreased CSA and MG increased CSA. The decrease in CSA with FR application is compatible with the literature, and it is surprising that the MG increases CSA. Future studies may examine how MG can increase MT and CSA through which physiological and cellular alterations. In this study, we investigated the acute effects of MG and FR on rectus femoris muscle architecture and MS for 2-min, but no significant differences were found. However, it is still unclear that using of a MG device can effect on muscle architecture in a longer period of time. Subsequently, future research should investigate how long the acute changes in muscle architecture and MS last for after a single application of a MG device. Future research should also focus on the long-term effects of repeated MG use over a period of consecutive days.

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