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Acute Effect of Foam Roller Practice on Isokinetic Parameters*

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Research Article
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Abstract

We aimed to examine the differences in knee strength, range of motion, and fatigue characteristics during high vs. low-speed isokinetic testing following FR practice on hamstring muscles and changes in the ROM on the knee extension and parameters during isokinetic fatigue testing. In total, 35 participants (20 men, 15 women) were recruited in this study. Of these 35 participants, 20 (12 men, 8 women) randomly underwent FR practice and the other 15 received no treatment (NFR). Pre-to-posttest body composition and high (180 °/sec) and low (60 °/sec) speed neuromuscular performance were performed with 24-h intervals. Follow-up screening showed significant decreases in knee extension and flexion parameters in the NFR group. Posttest percent knee extension and flexion torque deficit during fatigue testing protocol was significantly higher, while knee extension torque and ROM parameters were found significantly lower in the NFR group. FR group showed higher mean absolute torque and ROM values and lower percent knee extension and flexion torque deficit during fatigue resistance testing compared to baseline screenings. Positive significant correlations occurred between the ROM and knee extension (r=0.61) and flexion (r=0.52) peak torque and Hcon:Qcon (r=0.385) parameters during posttest screenings. The results of the current study suggest that the practice of high vs. low-speed isokinetic testing following foam rolling practice on hamstring muscles after strenuous exercise increased ROM without a decrease in peak and mean extension and flexion moments and helps to enhance an accelerated recovery.
Keywords: Foam roller, Recovery, Fatigue, Isokinetic.

Foam Roller Uygulamasının İzokinetik Parametrelere Akut Etkisi

Öz

Bu çalışmada hamstring kaslarına uygulanan FR uygulamasını takiben yüksek ve düşük hızdaki izokinetik testler sırasındaki diz kuvveti, eklem hareket açıklığı ve yorgunluk özelliklerindeki farklılıkları ve ROM'da meydana gelen değişimin yorgunluk testi esnasındaki diz ekstansiyon ve fleksiyon parametreleri üzerindeki etkisini incelemeyi amaçladık. Çalışmada toplam 35 katılımcı (20 erkek ve 15 kadın) yer aldı. Bu katılımcıdan 20'si (12 erkek, 8 kadın) FR grubuna rastgele atanırken diğer 15'i katılımcı uygulamaya tabii tutulmadı (NFR). Ön-test ve son-test vücut kompozisyon ölçümleri ve yüksek (180o/sn) ve düşük (60o/sn) hızdaki nöromüsküler performans ölçümleri 24 saatlik aralıklarla gerçekleştirildi. Son-test ölçümleri, NFR grubunda diz ekstansiyon ve fleksiyon parametrelerinde anlamlı düşüşler gösterdi. Yorgunluk testi protokolü sırasında diz ekstansiyon ve fleksiyon parametrelerinde görülen yüzde kuvvet kaybı NFR grubunda anlamlı olarak yüksek iken diz ekstansiyon ve ROM parametreleri anlamlı olarak daha düşük bulundu. FR grubu, ön test ölçümler ile karşılaştırıldığında son-test izokinetik yorgunluk testinde ortalama mutlak tork ve ROM değerlerinde istatistiksel olarak daha yüksek sonuçlar elde ederken DE ve DF parametrelerinde görülen yüzde tork kaybı istatistiksel olarak daha düşük bulundu. Son test ölçümlerindeki ROM değerleri ile diz ekstansiyon (r=0.61) ve fleksiyon (r=0.52) pik tork ve Hcon:Qcon (r=0.385) parametreleri arasında pozitif yönde anlamlı korelasyonlar oluştu. Mevcut çalışmanın sonuçları, hamstring kaslarına yorucu bir egzersizden sonra uygulanan FR uygulamasının, pik ve ortalama ekstansiyon ve fleksiyon torklarında bir azalmaya sebep olmadan ROM'u arttırdığını ve toparlanma sürecini arttırmaya yardımcı olduğunu göstermiştir.
Keywords: Foam roller, Toparlanma, Yorgunluk, İzokinetik

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INTRODUCTION

The quadriceps and hamstring muscles, which are an important muscle group in the lower extremity, have a great effect on the range of motion as well as the stabilization of the knee and the co-activation of these muscle groups has an essential role during physical activities that constitute walking and running. However, compared to quadriceps muscle groups hamstring muscles have a faster adaptive and shortening mechanism which leads to reduced neuromuscular efficiency and range of motion (ROM), increased energy expenditure, and greater strain on the knee (López-Miñarro, Muyor, Belmonte & Alacid, 2012). In addition to this, musculoskeletal adaptation and repeated actions on a musculotendinous unit may lead to decreased joint ROM and force production, changes in biomechanical patterns, and a considerable risk of overuse injuries (Burkhart, Morgan & Kibler, 2003). Because of the musculoskeletal system's structural characteristics, activity levels during human muscle motion are conditioned to vary significantly depending on the joint angle (Kim et al., 2005). Considering the importance of joint angle in muscle maximum force production, the magnitude of change in joint or muscle length has a significant effect on the maximum force produced by the muscle during muscle contraction of the length member (Yang et al., 2014).

There are several methods for reducing exercise-related impairments and improving exercise performance, such as using a foam roller, which relies on increased compression on tissues to induce vasodilation and increase blood circulation, which can also improve fascia hydration and elasticity (Dommerholt, Finnegan, Hooks & Grieve, 2016; Dupuy, Douzi, Theurot, Bosquet & Dugué, 2018; Kim, Park, Goo & Choi, 2014; Rodríguez-Fuentes et al., 2016). It is used during movement by applying pressure with a person's body weight on a foam roller, thereby affecting soft tissue (Cheatham, Kolber, Cain & Lee, 2015). It is especially beneficial for relaxing myofascia after intense exercise and aids in increasing range of motion, improving neuromuscular function, reducing muscle, myofascial pain, and convulsions, and regulating muscle imbalance (Wiewelhove et al., 2019). It has been reported that foam roller helps to stimulate the mechanical receptors and the heat generated during the practice of foam roller increases the viscosity of the muscles and myofascial ingredient, letting for a raised ROM (Lim, Park & Kim, 2019). The practice of foam roller to the hamstring muscles have been shown to have an immediate effect to increase ROM as opposed to other interventions (Madoni, 2018; Su, Chang, Wu, Guo & Chu, 2017). Despite it is well documented that foam roller practice has a significant acute impact on neuromuscular performance there is limited information with regards to angle specific changes in muscle strength following foam roller practice. However, previous research has also shown that the assessment of changes in torque parameters considering the full range of motion of the limb during muscle recruitment rather than evaluation of the peak torque at a specific angle allows also to determine the area under the torque curve. Evaluation of the muscular strength characteristics and their interaction to the changes in torque parameters thus has been shown as a more precise indicator of muscular performance since the peak torque is the highest instantaneous value it gives at one point of the joint along the angle of motion, this causes the joint to be thought of as producing the same force at every angle when the entire motion is looked at (Erdoğan, Umutlu & Acar, 2019). However, from a biomechanical standpoint, changes in the joint angle of a lever arm length, and the length of the muscle, leads to changes in the joint angle during maximal isokinetic testing (Baltzopoulos & Brodie, 1989). In this regard, changes in muscle length as a result of joint angle change cause an alter in force formed in the muscles, which impacts muscle activity (Kim et al., 2005). Therefore, it is essential to examine the muscular performance considering the joint angles in the relevant joints of the human body since it may provide the optimum mechanical advantage during isokinetic testing. Due to this affair between muscular strength and joint angle, it is essential to examine the muscular performance of the knee joint considering the changes in knee range of motion and its relation to neuromuscular performance. With this regard, since the early compensation of muscular strength discrepancies plays a vital role to prevent a potential injury risk and helps to improve exercise performance and accelerate recovery, we aimed to examine if there were any differences in top muscular strength, mean muscular strength, and fatigue characteristics at the knee joint during high-speed vs. low-speed isokinetic testing between control and foam roller conditions. Also, to test the acute effects of foam rolling practice following a fatigue test protocol on the hamstring muscles we aimed to determine the interactions between the changes in top muscular strength and mean muscular strength, and fatigue characteristics between control and foam roller conditions and its relation to the changes in the knee-joint posture during isokinetic testing.

Even though foam roller practice has been shown to have a significant acute impact on neuromuscular performance, there is little information on angle-specific changes in muscle strength following foam roller practice. This study is important in this sense, as it is considered to fill these gaps in the literature. The FR treatment, we hypothesized, would increase ROM due to changes in fascicle length (FL) from the hamstring muscle.

METHODS

Participants

35 participants recruited in the study (age: 22.06±2.70 years, height: 173.29±9.10 cm, weight: 68.46±11.21 kg, BMI: 22.65±2.02 kg/m^2). Participants were randomly assigned to one of two groups: foam roller treatment (FR, n=20; age: 21.65±2.88 years, height: 174.1±9.49 cm, weight: 69.35±12.26) or no treatment (NFR, n=15; age: 22.6±2.41 years, height: 172.2±8.75 cm, weight: 67.27±9.93). Before taking part in the study, all participants provided written informed consent that was approved by the Institutional Review Board in accordance with the Helsinki Declaration's ethical standards (Protocol number: 501, Date of approval: 07/08/2020). The research was conducted with the participants who met the inclusion criteria. The research included healthy, physically active (e.g., at least three times per week; but they are not professionally involved in a particular sport) male and female participants aged 19 to 32 years old who were not suffering from any acute or chronic disease that would limit their ability to participate in the study. However, refusal to provide informed assent, failure to comply with pre-test deficiencies, and evidence of altered training/fitness were all grounds for exclusion from the study.

Ethics

We declare that the experiments described in this study were carried out in compliance with the Declaration of Helsinki's ethical standards and that all participants completed an informed consent form. Furthermore, Mersin University Science and Engineering Sciences Ethics Committee acquired an ethics committee authorization letter dated April 13, 2021, and numbered 5 for the associated project.

Procedures

A randomized controlled trial with a parallel-group design was used in the current study. Both groups (FR/NFR) came to the physiological performance laboratory once, on different days.FR group received a foam roller practice on their hamstring muscles following isokinetic testing to investigate the effects of the foam roller practice after a strenuous exercise on ROM-related strength characteristics, and also fatigue-resistance of the extension, and flexion parameters during isokinetic fatigue testing. Whereas the NFR group received no treatment before or after isokinetic testing sessions. A 24-hours interval were provided between each session.

The Evaluation of Body Composition: Bioelectrical impedance analysis (Tanita 418-MA Japan) was used to obtain body weight, percent fat mass and lean body mass of participants, before all testing sessions for both groups, and the mean data used for analysis. Height was measured through a stadiometer in the standing position (Holtain Ltd. U.K.). BMI was calculated from body weight and height (kg/m^2). Before participating in the study, all participants were mandated to maintain their normal food intake, hydration, and physical activity.

The Evaluation of Neuromuscular Components: Upon completion of assignments for similar group the screening period of neuromuscular performance, a warm-up that include a running protocol was applied to all participants at a submaximal level (10 km/h) on the treadmill for 10 minutes both before baseline and follow-up isokinetic testing sessions. After this warm-up session, participants were seated in the upright position with the hips flexed at an angle of 90° and the hips and thighs were stabilized through pelvic and thigh straps to determine isokinetic knee extension and flexion peak torques. All participants performed trials over a series of 10 submaximal repetitions (about 50 % maximum voluntary contraction), both during flexion and extension at 180°/s before the test session for familiarization. Following this session, they performed 5 maximal bilateral knee extension (con) and flexion (con) repetitions at an angular velocity of 60°/s to determine isokinetic peak torque strength (30-sec rest between sets). All measurements were made only on the dominant feet of the participants. The hamstrings-to-quadriceps ratios (Hcon/Qcon) were also calculated from the obtained data by dividing hamstrings peak torque by the quadriceps peak torque within the same limb ($FR_{H/QPRE}$: %53; $FR_{H/QPOST}$: %60; $NFR_{H/QPRE}$:%51; $NFR_{H/QPOST}$: %55.). In the literature, H/Q force ratio of less than 60% has been associated with lower extremity injuries (Kim, 2011). The ROM for the contractions was performed from full extension (0 degrees) to full flexion and was recorded during each set for all repetitions to determine the ROM-related knee extension and flexion peak torque changes during 3 sets of isokinetic testing. Following 3 sets of reciprocal isokinetic knee extension and flexion, once both limbs had been tested, each participant was given a brief period of volitional recovery (about five minutes) and then asked to perform 50 maximal repetitions at 180°/sec to determine fatigue resistance. During this protocol, all participants were instructed to complete tasks as quickly as possible but not at full effort. The average of the peak torques for repetitions 1–5 and 46–50 was recorded for both KE and KF separately, and the percent decline from the former to the latter repetitions was calculated using the equation as follows (Kawabata et al., 2000).

(Maximum torque of the first 5 knee bends – maximum torque of the last 5 knee bends) / maximum torque of the first 5 knee bends × 100

Foam Rolling Practice: After the isokinetic test, during the form roller method, the dominant leg to be massaged was extended straight to the ground, while the other leg was kept in a bent position. Under the supervision of an expert trainer, the following protocol was applied to the foam roller group (FR). The foam roller application was applied only to the hamstring muscle group. Volunteers were asked to go back and forth on the foam roller between the two endpoints of the hamstring muscle group by applying pressure with their own body weight. Accordingly, 10 sets of FR applications were performed, with 1 minute of each set, 1 minute of passive rest between sets, and each rounding for 1-2 seconds (Bradbury-Squires et al., 2015). 30×15 cm GRID foam roller was used (Adamczyk, Gryko & Boguszewski, 2020).

Statistical Analysis

The sample size was calculated using the G Power (3.1.9.2) program. To test the normality of distribution Shapiro Wilk-W test analysis was used. Baseline mean of isokinetic strength parameters and SDs of FM and NFR groups (174.74±54.69 vs 187.73±33.26 Nm) were used to calculate minimum sample size for each group. Based on a power calculation using G*Power 3.1.9.2, a lower limit of 8 participants per group was estimated to be adequate to show a meaningful effect (with a power of 0.83, an error probability of 0.05, and an effect size of 1.8735). The results obtained for the subgroups before and after treatment (groups vs. pre/post-treatment) were measured with two-way mixed ANOVA with repeated measures. The Wilcoxon test for paired and two independent sample t-test for non-paired data was used to analyze the results obtained for all groups before and after treatment to compare the results over time. Correlations were assessed using the Pearson product-torque correlation coefficient to test the interactions between the baseline and post-test joint angle and muscular strength parameters both in the FR and NFR conditions. All results were presented as the mean±SD. For all comparisons, the level of statistical significance was set at $p<0.05$ and $p<0.001$. For graphical expression, GraphPad Prism 6 software was used.

RESULTS

Between-Group Comparisons of Neuromuscular Components

The results of the independent sample t-test analysis revealed no statistically significant difference between NFR and FR group in knee extension and flexion parameters during baseline measurements (p>0.05). However, follow-up screening showed that knee extension parameters significantly decreased in the NFR group during the second (p<0.01) and third set (p<0.001). Similarly, knee flexion parameters during follow-up measurements were also found significantly lower in the NFR group compared to the FR group (p<0.05).

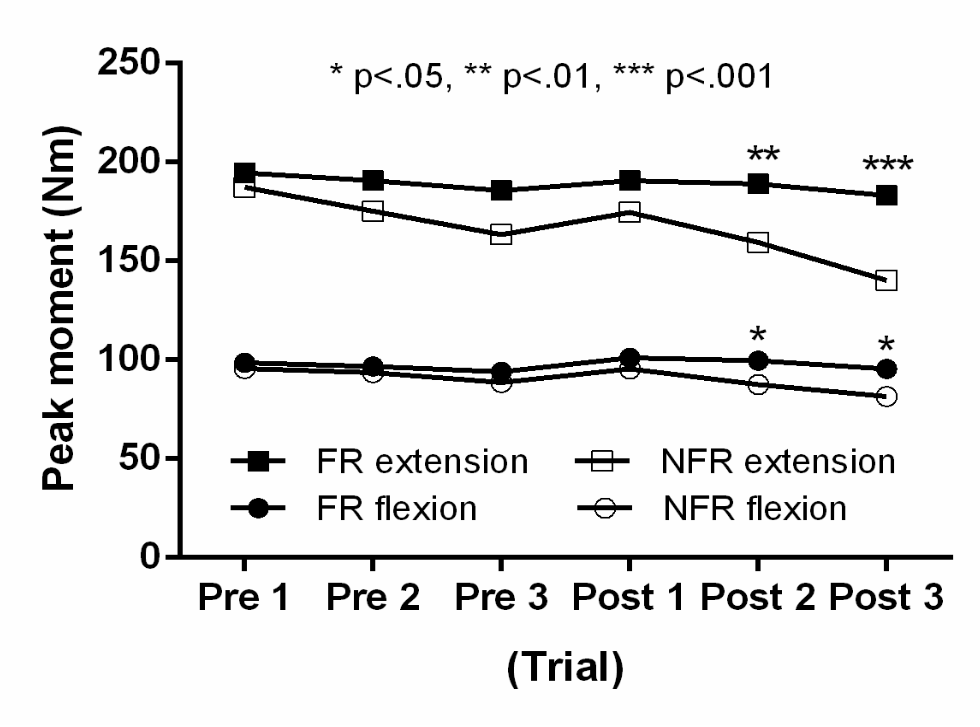

Figure 1. The comparison of baseline and posttest peak torque parameters during isokinetic testing between the FR and NFR conditions

Within-Group Comparisons of Neuromuscular Components between Baseline and Follow-Up Screenings during Isokinetic Fatigue Test Protocol

Paired sample t-test results showed that mean absolute torque values of the NFR group were significantly higher in percent knee extension torque deficit between the repetitions of 1-5 and 46-50 (p<0.05). Percent knee flexion torque deficit between the repetitions of 45-50 during fatigue resistance testing protocol was also significantly higher in favor of follow-up measurements (p<0.05).

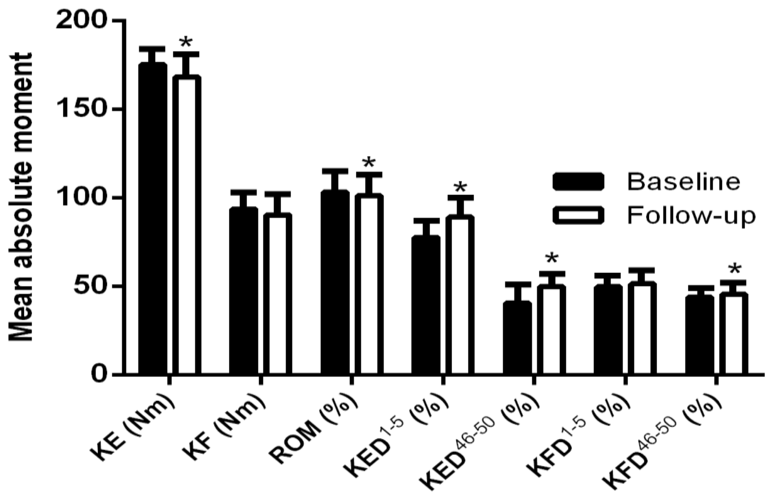

Figure 2(a). Comparison of baseline and follow-up mean neuromuscular components of isokinetic testing between the NFR conditions

However, knee extension mean torque and ROM parameters were found significantly lower in the NFR group compared to baseline measurements ($p<0.05$). On the other hand, paired sample t-test results revealed that mean absolute torque and ROM values of the FR group were significantly higher compared to baseline measurements ($p<0.05$). However, percent knee extension torque deficit between the repetitions of 1-5 and 46-50 and percent knee flexion torque deficit between the repetitions of 45-50 during fatigue resistance testing protocol was significantly lower in favor of follow-up measurements ($p<0.05$).

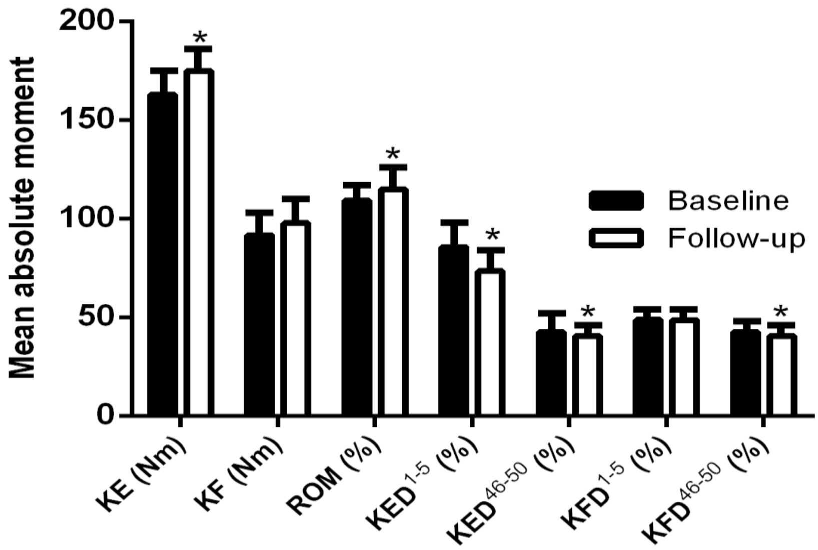

Figure 2(b). Comparison of baseline and follow-up mean neuromuscular components of isokinetic testing between the FR conditions

The Associations Between the Range of Motion and Neuromuscular Components

The result of the Pearson torques correlations coefficient revealed that there was no statistically significant correlation between ROM and baseline knee extension (r=0.30, p=0.283) and flexion (r=0.50, p=0.057) peak torque parameters during baseline screenings in the NFR group. The ROM and knee extension (r=0.36, p=0.186) and flexion (r=0.41, p=0.125) peak torque parameters were also not correlated during follow-up screenings in the NFR group.

(a) **(b)**

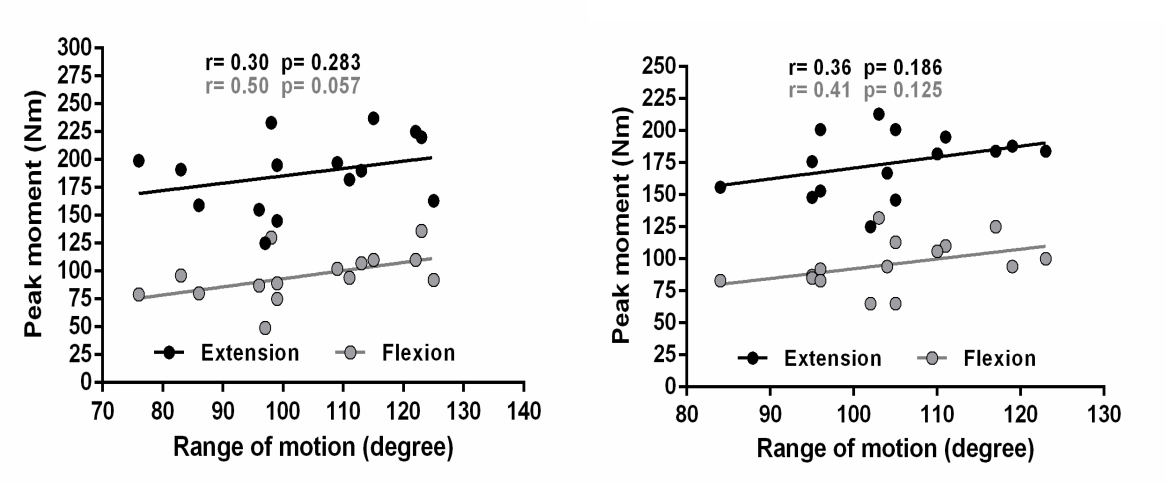

Figure 3. The associations between the (a) baseline and (b) posttest peak extension and flexion torques and range of motion parameters in FR conditions.

Similarly, baseline range of motion in FR group was not correlated with knee extension (r=0.08, p=0.749) and flexion (r=0.11, p=0.637) peak torque parameters. However, positive significant correlations occurred between the ROM and knee extension (r=0.61, p=0.004) and flexion (r=0.52, p=0.002) peak torque parameters following the practice of foam roller on hamstring muscle during the recovery period after isokinetic testing.

(c) **(d)**

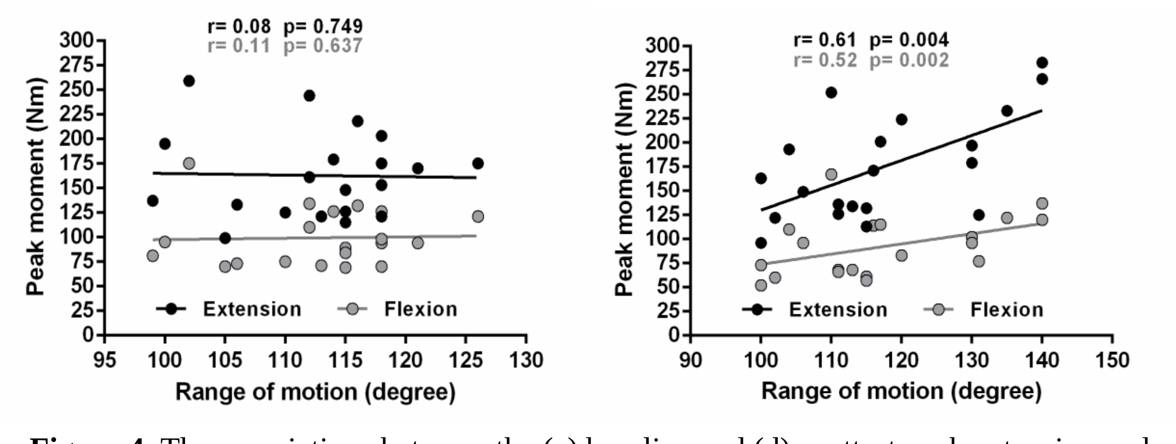

Figure 4. The associations between the (c) baseline and (d) posttest peak extension and flexion torques and range of motion parameters in NFR conditions.

Contrary, range of motion was not correlated with the percent extension (r=0.208, p=0.230) and flexion (r=0.209, p=0.149) torque decrease during baseline screenings. Follow-up measurements also revealed no statistically significant correlation between the percent extension (r=0.104, p=0.552) and flexion (r=0.099, p=0.571) torque decrease.

(a) **(b)**

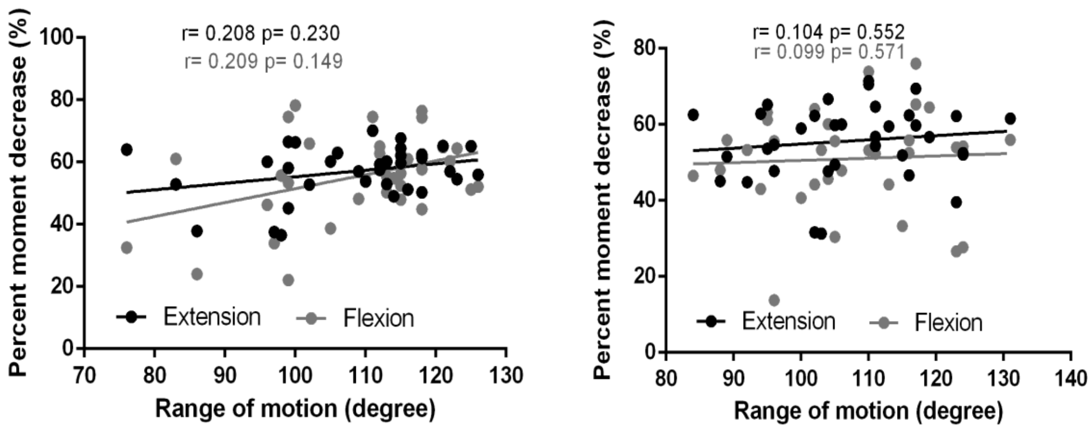

Figure 5. The associations between the baseline (a) and posttest (b) percent extension and flexion torque decrease and range of motion parameters in FR and NFR conditions.

Additionally, pretest screening revealed no statistically significant correlation between Hcon:Qcon and ROM parameters (r=0.322, p=0.059) whereas, the aforementioned components were found positively significantly correlated during posttest screenings (r=0.385, p=0.023).

(c) **(d)**

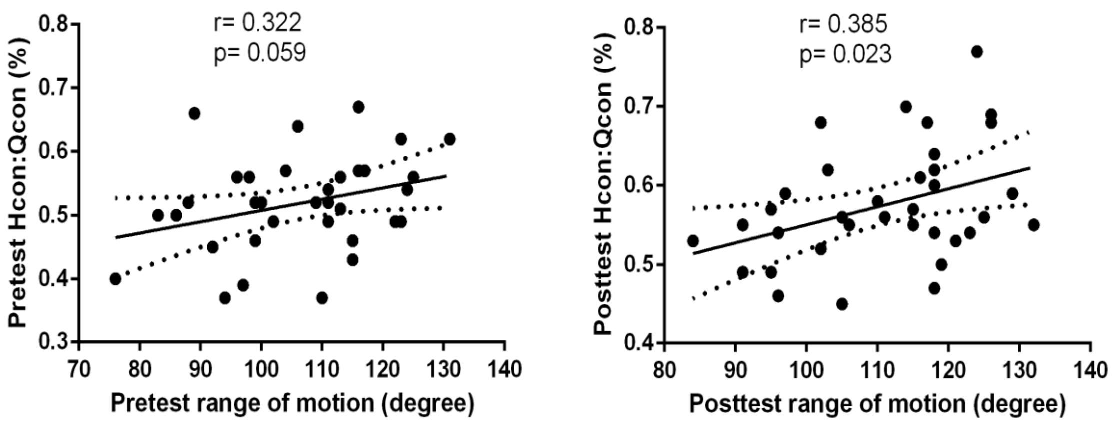

Figure 6. The associations between the baseline (c) and posttest (d) Hcon:Qcon ratio and range of motion parameters in FR and NFR conditions.

DISCUSSION

The primary goal of this study was to compare the differences in average and maximum muscular strength, and fatigue characteristics at the knee joint during high vs. low-speed isokinetic testing between control and foam roller conditions. Also, to test the acute effects of foam rolling practice following a fatigue test protocol on the hamstring muscles we aimed to determine the interactions between the changes in average and maximum muscular strength, and fatigue characteristics between control and foam roller conditions and its relation to the changes in the knee-joint posture during isokinetic testing. The main findings in this study were: (1) using a foam roller on hamstring muscles after high-intensity isokinetic testing appears to have short-term impacts on increasing joint ROM without negatively impacting muscle activity, (2) using a foam roller after strenuous exercise may help to reduce decreases in peak and mean knee extension and flexion knee torques, (3) despite the relationship between the ROM and peak and mean torques of extensor and flexor muscles, the changes in the ROM does not affect extension and flexion percent torque decrease during fatiguing testing.

The results of the current study revealed no statistically significant differences between NFR and FR group in knee extension and flexion parameters during baseline measurements. However, follow-up screening showed that knee extension parameters significantly decreased in the NFR group during the second and third set. Similarly, knee flexion parameters during follow-up measurements were also found significantly lower in the NFR group compared to the FR group. Within-group comparisons also showed that mean absolute torque values of the NFR group were significantly higher in percent knee extension torque deficit between the repetitions of 1-5 and 46-50. Percent knee flexion torque deficit between the repetitions of 46-50 during fatigue resistance testing protocol was also significantly higher in favor of follow-up measurements. Similar to the results of the current study, another study reported that hamstrings ROM increased in the FR condition and decreased in the control condition. Contrary to our findings, they also found that peak torque in the concentric hamstrings and standard H: Q ratios reduced after both conditions, with fewer declines after FR (Madoni, 2018).

The current study's findings were similar to previous studies that experienced an increase in ROM as a consequence of a foam roller protocol applied to the hamstring muscle (Arazi, Asadi & Hoseini, 2012; Behara & Jacobson, 2017; Junker & Stöggl, 2015; Madoni, 2018; Stecco & Schleip, 2016). Similar to our findings, another study examined a group of muscles which was the flexibility of the quadriceps and overall improvement in ROM after a bout of foam roller intervention whereas they found that the rise in ROM did not reduce strength generation, while another study reported a gain in flexibility without a reduction in performance following the same intervention (MacDonald et al., 2013; Macgregor, Fairweather, Bennett & Hunter, 2018; Madoni, 2018; Su, Chang, Wu, Guo & Chu, 2017; Sullivan, Silvey, Button & Behm, 2013). Considering the responses to the given intervention, the increase in the ROM may be related to various factors such as thixotropic properties and the degree to which the nerve root is activated. Previous research also confirmed that increased arterial blood flow induced by the practice of foam roller may enhance physiological mechanisms during physical exercise (Boguszewski, Falkowska, Adamczyk & Białoszewski, 2017; Peacock et al., 2015).

When evaluating the power of the lower extremity, the data with regards to the hamstrings-to-quadriceps ratio can offer essential information in the evaluation of neuromuscular performance. In addition to the significant differences between FR and NFR conditions, the hamstrings-to-quadriceps ratio was found to increase after FR conditions from pre- to post-test. In contrast to our findings, another study found that standard H: Q ratios reduced from pre- to post-test after each of the conditions. They asserted that this decrease might have resulted from a decrease in the muscle activation which may lead to a decrement in the muscle peak torque and subsequent change in ratios (Holcomb, Rubley, Lee & Guadagnoli, 2007). The desired level of H/Q force ratio (>60%) is related to the strength of the hamstring muscle rather than the quadriceps muscle. During this study, the application is aimed at the hamstring muscle; may have increased the recovery in the hamstring and may have caused the decrease in strength to be lower than the quadriceps.Taking the association between a decreased H:Q ratio and increased risk of injury of the hamstring muscles into consideration, the practice of FR on hamstring muscles following a strenuous exercise may help to reduce the risk of injury and increase muscle activation and force production during exercise.

In addition to its effect on force production, it may also be speculated that the use of foam rolling after exercise plays a vital role during recovery. Due to its positive effects, the use of foam rolling after workouts have been shown to enhance recovery between training sessions (Cheatham, Kolber, Cain & Lee, 2015; Healey, Hatfield, Blanpied, Dorfman & Riebe, 2014; Rey, Padrón-Cabo, Costa & Barcala-Furelos, 2019). Positive circulatory response after foam rolling has also been shown since foam roller interventions help to raise arterial blood flow, enhance vascular endothelial function, and reduce arterial stiffness (Hotfiel et al., 2017; Moraska et al., 2018). It has also been suggested that this practice may help to prevent muscle fatigue by improving arterial perfusion as a consequence of enhanced blood flow in the arteries, which may also contribute to physiological adaptive responses such as continuous improvements, ROM, and recovery (Junker & Stöggl, 2019). In this regard, foam rolling after training could be beneficial and practical strategy for accelerated recovery after exercise during training or competitions that contains a short duration of rest. Still, an interesting finding within the current study was that despite the significant correlations between posttest ROM and knee extension and flexion peak torques percent extension and flexion torque decrease were not correlated with ROM parameters during isokinetic fatiguing testing. Based on these findings, it is possible to conclude that ROM may be a less important factor during isokinetic fatiguing testing because resistance is higher throughout the whole of ROM and exertion is also maximal, resulting in similar power outputs (Schoenfeld & Grgic, 2020).

The current study, however, has some limitations. Our study groups consisted of few participants, while the practice of FR was restricted to a single foam rolling method and foam roller type. Also, only male participants recruited in the current study. In addition to that, some of the other confounding factors were the frequency and roller density of the practice, and the pressure implied on muscle tissue. Future research should be conducted to account for these confounding factors, in order to clarify several of the conflicting results in the published studies.

CONCLUSION

In conclusion, the results of the current study suggest that the practice of FR on hamstring muscles did not lead to knee joint angle-specific decreases in peak and mean extension and flexion torques. The practice of FR protocol for the hamstrings muscles seems to enhance an accelerated recovery compared to the control group. The results suggest that FR practice does not result in an attenuated muscular performance, knee joint angle-specific decreases in neuromuscular performance, a deficit in peak torques, or H:Q ratios and may be used as a treatment for post-exercise recovery.

Conflict of Interest: There is no personal or financial conflict of interest within the scope of the study.

Statement of Contribution of Researchers: Research Design-NEA, IY, Statistical analysis-GU, IY, NEA; Preparation of the article, GU, NEA; Data Collection- Performed by NEA, GA, DSSU, EG, MP.

Information on Ethics Committee Permission

Name of Board: Mersin University Science and Engineering Sciences Ethics Committee

Date: 13.04.2021

Issue/Decision Number: 5

REFERENCES

Adamczyk, J. G., Gryko, K., & Boguszewski, D. (2020). Does the type of foam roller influence the recovery rate, thermal response and DOMS prevention? *PloS One*, *15*(6), e0235195, 1-14. https://doi.org/10.1371/journal.pone.0235195

Arazi, H., Asadi, A., & Hoseini, K. (2012). Comparison of two different warm-ups (static-stretching and massage): Effects on flexibility and explosive power. *Acta Kinesiologica*, *6*(1), 55-59.

Baltzopoulos, V., & Brodie, D. A. (1989). Isokinetic dynamometry. *Sports Medicine*, *8*(2), 101-116.

Behara, B., & Jacobson, B. H. (2017). Acute effects of deep tissue foam rolling and dynamic stretching on muscular strength, power, and flexibility in division I linemen. *The Journal of Strength & Conditioning Research*, *31*(4), 888-892. https://doi.org/10.1519/JSC.0000000000001051

Boguszewski, D., Falkowska, M., Adamczyk, J. G., & Białoszewski, D. (2017). Influence of foam rolling on the functional limitations of the musculoskeletal system in healthy women. *Biomedical Human Kinetics*, *9*(1), 75-81. https://doi.org/10.1515/bhk-2017-0012

Bradbury-Squires, D. J., Noftall, J. C., Sullivan, K. M., Behm, D. G., Power, K. E., & Button, D. C. (2015). Roller-massager application to the quadriceps and knee-joint range of motion and neuromuscular efficiency during a lunge. *Journal of Athletic Training*, *50*(2), 133-140. https://doi.org/10.4085/1062-6050-49.5.03

Burkhart, S. S., Morgan, C. D., & Kibler, W. B. (2003). The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *19*(4), 404-420. https://doi.org/10.1053/jars.2003.50128

Cheatham, S. W., Kolber, M. J., Cain, M., & Lee, M. (2015). The effects of self-myofascial release using a foam roll or roller massager on joint range of motion, muscle recovery, and performance: a systematic review. *International Journal of Sports Physical Therapy*, *10*(6), 827-838.

Dommerholt, J., Finnegan, M., Hooks, T., & Grieve, R. (2016). A critical overview of the current myofascial pain literature–September 2016. *Journal of Bodywork and Movement Therapies*, *20*(4), 879-892. https://doi.org/10.1016/j.jbmt.2016.09.010

Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugué, B. (2018). An evidence-based approach for choosing post-exercise recovery techniques to reduce markers of muscle damage, soreness, fatigue, and inflammation: A systematic review with meta-analysis. *Frontiers in Physiology*, 9(403), 1-15. https://doi.org/10.3389/fphys.2018.00403

Erdoğan, A. T., Umutlu, G., & Acar, N. E. (2019). Evaluation of shoulder strength characteristics in overhead sports and range of motion related changes during isokinetic testing. *Isokinetics and Exercise Science*, *27*(2), 153-161. https://doi.org/10.3233/IES-183221

Healey, K. C., Hatfield, D. L., Blanpied, P., Dorfman, L. R., & Riebe, D. (2014). The effects of myofascial release with foam rolling on performance. *The Journal of Strength & Conditioning Research*, *28*(1), 61-68. https://doi.org/10.1519/JSC.0b013e3182956569

Holcomb, W. R., Rubley, M. D., Lee, H. J., & Guadagnoli, M. A. (2007). Effect of hamstring-emphasized resistance training on hamstring: quadriceps strength ratios. *Journal of Strength and Conditioning Research*, *21*(1), 41-47. https://doi.org/10.1519/00124278-200702000-00008

Hotfiel, T., Swoboda, B., Krinner, S., Grim, C., Engelhardt, M., Uder, M., & Heiss, R. U. (2017). Acute effects of lateral thigh foam rolling on arterial tissue perfusion determined by spectral doppler and power doppler ultrasound. *Journal of Strength and Conditioning Research*, *31*(4), 893-900. https://doi.org/10.1519/JSC.0000000000001641

Junker, D. H., & Stöggl, T. L. (2015). The foam roll as a tool to improve hamstring flexibility. *The Journal of Strength & Conditioning Research*, *29*(12), 3480-3485. https://doi.org/10.1519/JSC.0000000000001007

Junker, D., & Stöggl, T. (2019). The training effects of foam rolling on core strength endurance, balance, muscle performance and range of motion: a randomized controlled trial. *Journal of Sports Science & Medicine*, *18*(2), 229–238.

Kawabata, Y., Senda, M., Oka, T., Yagata, Y., Takahara, Y., Nagashima, H., & Inoue, H. (2000). Measurement of fatigue in knee flexor and extensor muscles. *Acta Medica Okayama*, *54*(2), 85-90. https://doi.org/10.18926/AMO/32290

Kim, D., & Hong, J. (2011). Hamstring to quadriceps strength ratio and non-contact leg injuries: A prospective study during one season. *Isokinetics and Exercise Science*, *19*(1),1-6. https://doi.org/10.3233/IES-2011-0406

Kim, J. J., Lee, M. H., Kim, Y. J., Chae, W. S., Han, Y. S., & Kwon, S. O. (2005). Comparison of the maximum EMG levels recorded in maximum effort isometric contractions at five different knee flexion angles. *Korean Journal of Sport Biomechanics*, *15*(1), 197-206. https://doi.org/10.5103/KJSB.2005.15.1.197

Kim, K., Park, S., Goo, B. O., & Choi, S. C. (2014). Effect of self-myofascial release on reduction of physical stress: A pilot study. *Journal of Physical Therapy Science*, *26*(11), 1779-1781. https://doi.org/10.1589/jpts.26.1779

Lim, J. H., Park, C. B., & Kim, B. G. (2019). The effects of vibration foam roller applied to hamstring on the quadriceps electromyography activity and hamstring flexibility. *Journal of Exercise Rehabilitation*, *15*(4), 560-565. https://doi.org/10.12965/jer.1938238.119

López-Miñarro, P. A., Muyor, J. M., Belmonte, F., & Alacid, F. (2012). Acute effects of hamstring stretching on sagittal spinal curvatures and pelvic tilt. *Journal of Human Kinetics*, *31*, 69-78. https://doi.org/10.2478/v10078-012-0007-7

MacDonald, G. Z., Penney, M. D., Mullaley, M. E., Cuconato, A. L., Drake, C. D., Behm, D. G., & Button, D. C. (2013). An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *The Journal of Strength & Conditioning Research*, *27*(3), 812-821. https://doi.org/10.1519/JSC.0b013e31825c2bc1

Macgregor, L. J., Fairweather, M. M., Bennett, R. M., & Hunter, A. M. (2018). The effect of foam rolling for three consecutive days on muscular efficiency and range of motion. *Sports Medicine-Open*, *4*(1), 1-9. https://doi.org/10.1186/s40798-018-0141-4

Madoni, S. N. (2018). Effects of foam rolling on range of motion, peak torque, muscle activation, and the hamstrings-to-quadriceps strength ratios. *Journal of Strength and Conditioning Research*, *32*(7), 1821–1830. https://doi.org/10.1519/JSC.0000000000002468

Moraska, A. F., Hickner, R. C., Rzasa-Lynn, R., Shah, J. P., Hebert, J. R., & Kohrt, W. M. (2018). Increase in lactate without change in nutritive blood flow or glucose at active trigger points following massage: A randomized clinical trial. *Archives of Physical Medicine and Rehabilitation*, *99*(11), 2151-2159. https://doi.org/10.1016/j.apmr.2018.06.030

Peacock, C. A., Krein, D. D., Antonio, J., Sanders, G. J., Silver, T. A., & Colas, M. (2015). Comparing acute bouts of sagittal plane progression foam rolling vs. frontal plane progression foam rolling. *The Journal of Strength & Conditioning Research*, *29*(8), 2310-2315. https://doi.org/10.1519/JSC.0000000000000867

Rey, E., Padrón-Cabo, A., Costa, P. B., & Barcala-Furelos, R. (2019). Effects of foam rolling as a recovery tool in professional soccer players. *The Journal of Strength & Conditioning Research*, *33*(8), 2194-2201. https://doi.org/10.1519/JSC.0000000000002277

Rodríguez-Fuentes, I., De Toro, F. J., Rodríguez-Fuentes, G., de Oliveira, I. M., Meijide-Faílde, R., & Fuentes-Boquete, I. M. (2016). Myofascial release therapy in the treatment of occupational mechanical neck pain: A randomized parallel group study. *American Journal of Physical Medicine & Rehabilitation*, *95*(7), 507-515. https://doi.org/10.1097/PHM.0000000000000425

Schoenfeld, B. J., & Grgic, J. (2020). Effects of range of motion on muscle development during resistance training interventions: A systematic review. *SAGE Open Medicine*, *8*, 1-8. https://doi.org/10.1177/2050312120901559

Stecco, C., & Schleip, R. (2016). A fascia and the fascial system. *Journal of Bodywork and Movement Therapies*, *20*(1), 139-140. https://doi.org/10.1016/j.jbmt.2015.11.012

Su, H., Chang, N. J., Wu, W. L., Guo, L. Y., & Chu, I. H. (2017). Acute effects of foam rolling, static stretching, and dynamic stretching during warm-ups on muscular flexibility and strength in young adults. *Journal of Sport Rehabilitation*, *26*(6), 469-477. https://doi.org/10.1123/jsr.2016-0102

Sullivan, K. M., Silvey, D. B., Button, D. C., & Behm, D. G. (2013). Roller-massager application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. *International Journal of Sports Physical Therapy*, *8*(3), 228-236.

Wiewelhove, T., Döweling, A., Schneider, C., Hottenrott, L., Meyer, T., Kellmann, M., ... & Ferrauti, A. (2019). A meta-analysis of the effects of foam rolling on performance and recovery. *Frontiers in Physiology*, *10*(376), 1-15. https://doi.org/10.3389/fphys.2019.00376

Yang, J., Lee, J., Lee, B., Kim, S., Shin, D., Lee, Y., ... & Choi, S. (2014). The effects of elbow joint angle changes on elbow flexor and extensor muscle strength and activation. *Journal of Physical Therapy Science*, *26*(7), 1079-1082. https://doi.org/10.1589/jpts.26.1079