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Research article

The Effects of Foam Rolling at Different Speeds on Mechanical Properties of Quadriceps Femoris

Atilla Çağatay Sezik [1]✉, Özgün Uysal [2], Tuzun Fırat [2], Irem Düzgün [2] and Volga Bayrakcı Tunay [2]
[1] Yuksek Ihtisas University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Ankara, Türkiye; [2] Hacettepe University, Faculty of Physical Therapy and Rehabilitation Ankara, Türkiye

Abstract
Foam rolling have gained popularity among elite athletes, but the effect of the speed parameter of foam rolling has not yet been determined. Our objective was to investigate the impact of different application speeds of foam roller on the mechanical properties of the quadriceps femoris muscle. Eighteen male professional basketball athletes (age 23 ± 4 years, body mass index 24.43 ± 1.59 kg/m²) participated in this study. We used a crossover design to randomize the order of the treatment speeds (30 beats per minute-FAST, 15 beats per minute-SLOW, and a self-determined speed-SELF) with a one-week washout period between each session. We measured dominant quadriceps femoris muscle tone, elasticity, and stiffness using the Myoton device before and after the interventions. We found that the average rate for SELF was 33±10 beats per minute, making SELF the fastest. All application speeds showed similar results in pre-intervention measurements of the mechanical properties of the tissues ($P > 0.05$). However, post hoc analysis revealed that a decrease was evident in SLOW compared to SELF in muscle tone in post-intervention measurements ($P = 0.037$). Also, we noted that comparison of pre- and post-intervention on FAST and SLOW showed a significant reduction in muscle tone ($P = 0.002$, $P = 0.008$). Slower foam rolling prior to training or competition may lead to a delay in the reaction time due to the reduction in tonus, that can increase the injury risks. Alternatively, the significant reduction in tonus may be useful in regulating the increased tonus after training and competition.

Key words: Stiffness, muscle tonus, elastic modulus, basketball.

Introduction

Foam rolling is a self-myofascial massage technique where the targeted myofascia is compressed and rolled using a foam roller. This application enables athletes to perform massage to myofascia without an assistance of a professional. Foam roller applications are becoming more popular among elite athletes and health professionals. Due to cost and availability, many athletes are opting to purchase these devices rather than seeking myofascial release applied by a professional. This method is preferred to accelerate recovery after physical activity and increase muscle flexibility.(Macdonald et al., 2014) Recent studies have shown that the applications performed by athletes with foam roller has positive effects on flexibility and normal joint movement; however, these effects are observed for a short time.(Beardsley and Skarabot, 2015; Bushell et al., 2015; Cheatham et al., 2015; MacDonald et al., 2013; Mohr et al., 2014; Škarabot et al., 2015)

The athletes should be aware of the proper techniques and parameters for applying foam rollers to ensure effectiveness and safety. Despite their growing popularity, the studies on the mechanisms of these applications are not sufficient yet. The insufficiency arises from the use of diverse parameters in studies, leading to varied outcomes in explaining the mechanism. The underlying mechanisms are thought to be the changes in blood circulation, viscoelastic properties of the myofascia, perception of tension, and regaining the mobility of the fascia.(Cheatham et al., 2015; MacDonald et al., 2013; Mohr et al., 2014; Schleip, 2003) Researchers have yet to establish a singular mechanism, forcing them to settle for multiple interrelated explanations.

The studies, which use mathematical models to explain the behavior of hyaluronan, have shown that myofascial techniques applied at different speeds induces deformation and compression of the upper and lower fascial layers.(Chaudhry et al., 2013; Roman et al., 2013) This results in displacement of the hyaluronan liquid layer, leading to varying degrees of elevation of the upper fascial layer.(Roman et al., 2013) When the application is accelerated, the fluid pressure increases, which subsequently reduces the viscosity of hyaluronan.(Chaudhry et al., 2013; Cowman et al., 2015; Pratt, 2021) Although slow-speed applications generate low liquid pressure, the gap between layers gradually increases, resulting in a wider liquid layer. This increased volume of the fluid layer supports the gliding system, allowing the muscles to work more efficiently.(Pratt, 2021; Roman et al., 2013) The varied speeds of application affect the viscosity of hyaluronan, albeit through different mechanisms. The application of a foam roller, employing myofascial massage principles, may show similar results on the fascia,(MacDonald et al., 2013) but modifying the speed of foam roller application could potentially influence the mechanism.

Clinicians believe that the rolling speed should be determined by individual preference to achieve the best results.(Cheatham, 2019; Wilke et al., 2020) Athletes may also prefer to use the foam roller at a self-determined speed, however; no study has investigated this aspect. Although previous studies did not compare different speeds, they utilized various constant speeds during foam roller application, ranging from 1 second to 2 seconds(Bradbury-Squires et al., 2015; Mohr et al., 2014; Pearcey et al., 2015) for the distance between the origin and insertion of the muscle. Only one study has examined the effects of foam rolling at different application speeds on tissue mechanical

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properties that found tissue stiffness is decreased regardless of the speed.(Wilke et al., 2019) There was no observable difference in physically active adults based on the speed of the application. Consensus on the speed of the application has not been reached yet.(Beardsley and Skarabot, 2015; Cheatham et al., 2015; Škarabot et al., 2015) However, a review advises to use 2-4 seconds (15-30 beats per minute) rolling speeds to archive immediate increase in range of motion.(Behm et al., 2020) They also advised to use 1-3 sets, 30-120 seconds total duration per set. The application of different speeds may produce different results in professional athletes.(Charcharis et al., 2019)

Although the effects of the foam roller have been demonstrated in various ways, there is insufficient evidence regarding the outcomes of its use under different conditions. Using the foam roller prior to training or competition may lead to a delay in the desired reaction time due to the reduction in tonus, which can increase the risk of joint and ligament injuries in athletes. Instead, using the foam roller after the training or competition may be useful in regulating the increased tonus. But, at which speed do these effects of foam roller occur, which speed should be preferred before, and which speed should be preferred after training or competition are not established yet. In this study, our aim was to examine the effects of foam roller application at different speeds on the mechanical properties of quadriceps femoris muscle in professional athletes. Accordingly, our hypothesis was that the application of foam roller at different speeds would alter the mechanical properties of the quadriceps femoris muscle.

Methods

Study design

This study was a three-arm crossover study design with the sequence of treatments randomized for each participant after a one-week washout period between each session. All participants performed these speeds of application: slow foam rolling (15 beats per minute-SLOW), fast foam rolling (30 beats per minute-FAST), and a self-determined foam rolling in which participants decided which speed was most effective for them (SELF). This study was registered on ClinicalTrials.gov with registration number NCT04210947.

Participants

We conducted this study at the facilities of two professional basketball teams competing in the major basketball leagues. We recruited our participants from these professional sports clubs, collecting demographic information (age, height, body weight), weekly training hours, age at which they started basketball, and dominant extremity. Eighteen male professional basketball athletes who actively continue basketball training were included. All athletes had prior experience with the foam roller and included foam roller as a regular part of their training routine for at least a year. Athletes who had any acute pain or signs of inflammation, known chronic systemic disease, lower extremity injuries in the last six months, or lower extremity surgeries were excluded. All participants signed informed consent and our institutional ethical committee approved the study (GO 18/539), which was conducted according to the Declaration of Helsinki.

Procedures

We used a hard, cylindrical foam roller with a smooth surface (Blackroll Pro, Gray, 30 cm x 15 cm, Germany) for all interventions. Prior to the study, participants had a session to try five repetitions in accordance with speed, becoming familiar with the application and time. Participants applied foam roller to their quadriceps femoris muscle on dominant leg, in prone position, rolling between anterior superior iliac spine and patella. They crossed their legs while on application to increase the compression on the soft tissue, thus contacting the ground on three points (two forearms and one leg via the foam roller)(MacDonald et al., 2013) (Figure 1). Participants completed two sets of fifteen repetitions (from origin to insertion counting as one) with thirty-second rest.(Behm et al., 2020; Cheatham et al., 2015) Application speed was determined and tracked by using a metronome (smartphone application, "Pro Metronome", EUMLab, Berlin, Germany). All participants randomly performed each speed, separated by a one-week wash-out period.(Wilke et al., 2019) We used "http://randomization.com" to determine the sequence of treatment order.

Figure 1. Application of the foam roller.

In the SLOW application, participants performed the distance from origin to insertion in four seconds (15 beats per minute). In the FAST application, participants completed the same distance in two seconds (30 beats per minute).(Behm et al., 2020; Cheatham et al., 2015) In the SELF application, the rhythm of the foam roller was left to the participants' decision (average rate: 33 ± 10 beats per minute). We recorded the application videos using a smartphone camera that was positioned on a tripod and placed alongside the participant to capture the moment in which the participant reached the origin or insertion, and then the rate was decided visually using a video editing software. Participants followed the rhythm with the help of a metronome in SLOW and FAST applications. The researcher counted all repetitions verbally in SLOW and FAST applications. However, in SELF application, only the first, seventh, fourteenth, and fifteenth repetitions were said to participants in order to prevent researcher's effect on participants' speed decisions.

Outcomes

Myoton (Myoton 3, Myoton AS, Tallinn, Estonia) is used to measure muscle tonus, elasticity, and stiffness. We took measurements before and five minutes after intervention. Before the test, participants were in a supine position for five minutes. Measurements were taken from the muscle belly of the rectus femoris, from the 2/3 proximal region between the anterior superior iliac spine and the superior pole of the patella.(Macdonald et al., 2014) The device probe was placed in a vertical orientation on the skin, directly over the designated muscle point for assessment (Figure 2). The device applies a brief mechanical pulse, inducing a temporary deformation. The muscle reacts to the mechanical stimulus by producing damped oscillations, which are captured by an acceleration transducer at the testing end. Sandbags were used to keep hips at the same rotational angle for measurement. The intraclass correlation coefficients (ICC) for rectus femoris(Mullix et al., 2012) measurement were determined to range from 0.72 to 0.87. We repeated the application ten times and took the average values.(Mullix et al., 2012; Uysal et al., 2021) Any set of parameters (muscle tone, elasticity, stiffness) with a coefficient of variation (CV) greater than 3% was excluded and the test was repeated.

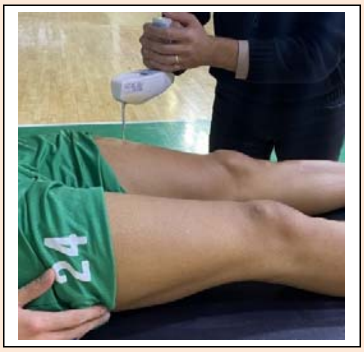

Figure 2. Measurement of the Myoton.

The device measures the response of three biomechanical tissue parameters: muscle tone(Hz), elasticity (D [log]), and stiffness(N/m). Muscle tone is defined as the passive tension of a muscle when it is relaxed or in a non-contraction state, which is derived from the intrinsic visco-elastic properties of the muscle. The frequency of oscillation reflects muscle tone, and demonstrates deformation that occurs on the tissue.(Masi and Hannon, 2008) If there is greater deformation, there will be more frequent oscillation, thus resulting in a more tense muscle tone. In a relaxed muscle, oscillation frequency values typically range from 11 to 16 Hz, and the values increase with contraction.(Chuang et al., 2012) Muscle elasticity is defined as the ability of tissue to recover its original shape after a mechanical stimulus. Reduction of oscillations indicates the muscle's elasticity; however, an increase in reduction of oscillations indicates a decrease in muscle elasticity, resulting in the dissipation of mechanical energy.(Chuang et al., 2012) Generally, the values of the reduction of oscillation range from 1.0 to 1.2. Muscle stiffness is the muscle's ability to maintain its original shape against external forces.(Masi and Hannon, 2008) A higher value indicates that more force is required to alter the tissue's shape. Furthermore, higher stiffness increases the energy expenditure of movement. Muscle contraction increases stiffness, while the resting value remains between 150 and 300 N/m.(Masi and Hannon, 2008)

Statistical analysis

We performed the statistical analyses using the Statistical Package for Social Sciences (SPSS) 21.0 software (SPSS INC., Chicago, IL, USA). We examined variables visually using methods such as histograms and probability plots, and analytically using the Shapiro-Wilk test to assess normality. We presented descriptive data as median and interquartile range (25-75). Due to the non-normal distribution of the data, we applied the Friedman test for comparisons of speeds (comparison of FAST, SLOW and SELF applications). We conducted pairwise comparisons (post hoc analyses) when considered necessary and evaluated results using Bonferroni correction. We used the Wilcoxon test for pre- and post-intervention comparisons. We used type-1 error level of 5% for statistical significance.

Results

Eighteen male professional basketball athletes (age 23 ± 4 years, body mass index 24.43 ± 1.59 kg/m², basketball experience 12 ± 4 years, weekly training hours 14 ± 5 h/week) participated in our study. We gave descriptive data and pre- and post-intervention comparisons of each speed on the muscle mechanical properties in Table 1.

Muscle tone was significantly decreased on FAST (*P* = 0.002), and SLOW (*P* = 0.008) applications in comparison of pre- and post-intervention measurement. Elasticity and stiffness were displayed similar results (*P* > 0.05).

Table 1. Pre- and post-intervention comparisons of each speed. Data are median (IQR, interquartile range).

	Speed	Pre	Post	*P* Value
		Median (IQR)	Median (IQR)	
Muscle tone (Hz)	FAST	15.60 (15.22 - 16.15)	15.12 (14.47 - 15.40)	**0.002***
	SLOW	15.39 (14.84 - 16.16)	15.11 (14.45 - 15.49)	**0.008***
	SELF	15.66 (15.03 - 16.20)	15.46 (15.00 - 16.00)	0.133
	P value	0.48	**0.04#**	
Elasticity	FAST	1.84 (1.53 - 2.09)	1.81 (1.52 - 2.05)	0.309
	SLOW	1.69 (1.44 - 1.94)	1.73 (1.57 - 2.05)	0.145
	SELF	1.72 (1.55 - 1.96)	1.79 (1.55 - 2.02)	0.845
	P value	0.31	0.91	
Stiffness (N/m)	FAST	263.6 (244.5 - 274.3)	263.7 (236.0 - 277.6)	0.571
	SLOW	246.8 (202.6 - 279.5)	250.1 (209.5 - 285.2)	0.276
	SELF	271.4 (218.8 - 288.9)	251.0 (227.0 - 282.1)	0.184
	P value	0.21	0.67	

FAST, 30 beats per minute; SLOW, 15 beats per minute; SELF, Self-determined by participant; Hz, Hertz; N/m, Newton/meter; Pre, Pre-intervention; Post, Post-intervention. * indicates a difference (*P* < .05) between pre-post. # indicates a difference (*P* < .05) between SELF and FAST, between SELF and SLOW.

Muscle tone was significantly decreased on FAST ($P = 0.002$), and SLOW ($P = 0.008$) applications in comparison of pre- and post-intervention measurement. Elasticity and stiffness were displayed similar results ($P > 0.05$).

Comparison between the different speeds on elasticity and stiffness were displayed similar results ($P > 0.05$) (Table 1). However, post hoc pairwise comparisons revealed that a significant reduction on SLOW compared to SELF applications on muscle tone between post-intervention measurements ($P = 0.037$).

Discussion

The results of our study indicate that there is distinguishable impact on the muscle tonus when foam rollers are applied at different speeds in comparison to one another. Interestingly, the SELF application had a faster average speed than the FAST, resulting in the SELF being the fastest overall. The SLOW application showed more significant decreases in muscle tonus compared to the SELF application, which was found to be faster than the FAST application. Nevertheless, by analyzing the effects of foam roller application within the group at these three different speeds, we observed a noteworthy reduction in muscle tone in FAST and SLOW applications. Contrary to our hypothesis, faster applications have no superiority against slower applications and using foam roller at or slower than 30 beats per minute may lead to a significant reduction in muscle tone.

We observed a notable superiority among the different application speeds in terms of their influence on the mechanical properties of the tissue, especially when used at or slower than 30 beats per minute (FAST and SLOW applications). This study reveals that the use of foam rollers at SLOW and FAST has a noticeable effect on muscle tone. This outcome may be linked to the slow-adaptive mechanoreceptors, present in connective tissue and stimulated with deep pressure.(Behm and Wilke, 2019; Schleip, 2003) Foam rolling involves the activation of intrafascial mechanoreceptors, might leading to a modified proprioceptive signal to the central nervous system. This modified signal subsequently regulates the tonus of the tissue.(Beardsley and Skarabot, 2015; Schleip, 2003) As these receptors become activated, motor neuron activity decreases, leading to a reduction in tonus.

The only prior study regarding foam roller application speed did not show any differences in stiffness values, however, they found all application speeds were more effective than the control group.(Wilke et al., 2019) Wilke et al. found foam roller application to result in decreased stiffness. We also observed a decrease in stiffness values after foam roller application, however, these changes were not statistically significant. It is possible that the higher training hours seen in basketball players in comparison to healthy active adults, made it difficult to sufficiently manipulate the myofascial tissue with the body weight applied during foam rolling. Alternatively, the total duration of the foam rolling application may not have been long enough to elicit a meaningful change in the creep response of the tissue. Wilke et al. used 180 seconds as the duration of their study while ours were 60 and 120 seconds. Despite the common recommendation for 60-120 second applications in the literature, this duration may need to be adjusted for athletes.(Schroeder et al., 2021)

Schroeder et al. (2019) reported that a three-second rolling pace did not result in any significant differences in tissue elasticity. We used similar rolling speed, and duration. Also, we found similar results on tissue elasticity. Longer application time could have a greater impact on tissue thixotropy, as rolling may increase tissue temperature through friction and raise fluid pressure of hyaluronan through compression. The raised tissue temperature and fluid pressure could decrease the viscosity of myofascial hyaluronan, resulting in more elastic tissue.

All participants were professional basketball athletes, and their quadriceps mechanical properties may differ from those of individuals in other sports or who are sedentary. Individuals who do not frequently use their quadriceps femoris muscles may not exhibit these effects. Additionally, all of our participants were male, and sex differences may impact the results, as male muscles tend to be stiffer, less elastic, and have higher tone than female muscles.(Ramazanoğlu et al., 2020) We only measured acute effects immediately following foam roller application, so long-term effects may yield different results.

Conclusion

Differences in application speed of the foam roller appear to have effects on acute outcomes. Foam roller applications at or slower than 30 beat per minute does have a reducing effect on tonus. However, it is unclear whether the change in tonus is directly a decrease or a tonus normalization. Therefore, using the foam roller prior to training or competition may lead to a delay in the desired reaction time due to the reduction in tonus, which can increase the risk of joint and ligament injuries in athletes. On the other hand, the significant reduction in tonus may be useful in regulating the increased tonus after training and competition. Studies investigating the acute and long-term effects of application speed and comparing with functional tests are needed in the literature to verify the clinical effects of our results.

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The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author who was an organizer of the study.

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Key points

- The foam roller can decrease muscle tone if applied at or slower than 30 beats per minute.
- Athletes may consider slower foam roller application when they need to decrease high quadriceps femoris muscle tone.
- Foam roller has no significant effect on myofascial stiffness or elasticity.

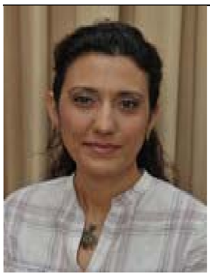
AUTHOR BIOGRAPHY

Atilla Cagatay SEZIK
Employment
Yuksek Ihtisas University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Ankara, Türkiye
Degree
MSc. PhD student
Research interests
Sports Rehabilitation, Injury Prevention, Myofascial Injuries.
E-mail: cagataysezik@hotmail.com

Ozgun UYSAL
Employment
Hacettepe University, Faculty of Physical Therapy and Rehabilitation Ankara, Türkiye
Degree
MSc. PhD student
Research interests
Sports Rehabilitation, Injury Prevention, Cognitive trainings.
E-mail: uysalozgun@gmail.com

Tuzun FIRAT
Employment
Hacettepe University, Faculty of Physical Therapy and Rehabilitation Ankara, Türkiye
Degree
PhD. Prof.
Research interests
Muscle Architecture, Motor Control, Cognitive Trainings.
E-mail: tuzun75@gmail.com

Irem DUZGUN
Employment
Hacettepe University, Faculty of Physical Therapy and Rehabilitation Ankara, Türkiye
Degree
PhD. Prof.
Research interests
Sports Rehabilitation, Shoulder Injuries, Kinetic Chains.
E-mail: iremduzgun@yahoo.com



Volga BAYRAKCI TUNAY
Employment
Hacettepe University, Faculty of Physical Therapy and Rehabilitation Ankara, Türkiye
Degree
PhD. Prof.
Research interests
Knee Injuries, Injury Prevention, Return to Sport.
E-mail: volgamel@yahoo.com

✉ **Atilla Çağatay Sezik**
Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Yuksek Ihtisas University, 06520, Balgat, Ankara, Türkiye