

# Acute Effect of a Foam Roller on the Mechanical Properties of the Rectus Femoris Based on Tensiomyography in Soccer Players

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**Abstract** Tensiomyography (TMG) is a relatively new technique to assess the muscles mechanical properties in response to a single electrical stimulus. The purpose of the present study was to assess the acute effect of a foam roller (FR) in the rectus femoris muscle using TMG. Seventeen male professional soccer players (age  $21.4 \pm 3.8$  years, height  $180.5 \pm 7.7$  cm, and mass  $73.6 \pm 10.7$  kg) performed 4 sets of with a duration of 15 s using the foam roller (FR) on the dominant leg with 2 min of rest at 30 beats per minute. TMG measurements were performed at rest after the second and fourth sets for both the dominant and non-dominant leg (control). The TMG parameters analysed included stiffness (Dm), and contraction time (Tc). Substantial differences were not found between the legs at rest. For the non-dominant leg, substantial differences in Dm were found after the second and the fourth sets. For the dominant leg, substantial differences in Dm were not observed after the FR was applied. No differences in Tc were found for any of the measurements. Our results suggest that the use of a foam roller in slowly executed small sets maintains the muscle stiffness and the contraction time of the RF.

**Keywords** Foam Roller, Tensiomyography, Rectus Femoris

## 1. Introduction

Recently, foam rolling has become a popular technique for professional and non-professional athletes as a self-massager and for self-myofascial release. The technique involves small back and forth undulations over a dense foam roller (FR), starting at the proximal portion of the muscle and working toward the distal portion of the muscle or vice versa [1]. Soft-tissue dysfunction can be initiated in various ways, such as trauma, overuse, or muscle imbalances, etc., which can induce injury in athletes. These injuries stimulate the development of inelastic, fibrous adhesions between the

layers of the myofascial system that prevent normal muscle mechanics and decrease soft-tissue extensibility [2-5]. Self-massages or self-myofascial release using a FR aids in the treatment of soft tissue restrictions. The subjects use FRs to exert pressure on the soft tissue, using their own body mass with a constant and fluid movement throughout the muscle belly. This technique massages the muscle to break up the myofascial trigger points and restores the soft-tissue extensibility [3-7]. Trigger points are thought to develop from acute repetitive microtrauma to the muscles or from inappropriate biomechanics during movement or overtraining, creating a limitation in the strength and functional activity of the muscle as a whole and causing the muscle to become susceptible to injury [7,8]. The characteristics and compositions FRs have been shown to affect soft tissue [3]. The use of a multilevel rigid roller for self-myofascial release was shown to induce higher pressure over an isolated contact area compared to a bio-foam roller. Despite the increase in the number of recent investigations of the use of FRs, there are not specific guidelines regarding their specific benefits, forms, mechanisms and recommended duration of use [7,9].

FRs are commonly used as a recovery aid after training or physical activity to alleviate muscle soreness, correct muscular imbalances, improve the range of motion (ROM), decrease joint stress, and improve the muscle function [4,5,7,10-13]. Delayed onset muscle soreness (DOMS) is frequently experienced by many athletes, both amateur and professional, after intense physical activity. Some authors have investigated the effects of the use of a FR on DOMS. McDonald et al. [4] assessed the effectiveness of FR (2 sets of 60 s with a high-density FR) in the recovery of DOMS induced by intense physical activity. They found that FR was beneficial in attenuating muscle soreness and improving other factors, such as vertical jump height, passive and dynamic ROM, and muscle activation compared to the control group. In 2015, Pearcey et al. [12] published the effect of using FRs as a recovery tool, assessing the pressure-pain threshold, sprint time, change of direction,

power and dynamic strength-endurance. FR therapy was executed at 50 beats per minute (bpm) during 45 s of work followed by 15 s of rest and was used once on each muscle group in each lower extremity. The authors concluded that the FR enhanced muscle recovery, alleviated muscle pain and increased voluntary activation. Consequently, the decrement of physical performance associated to the DOMS [12,14] in dynamic movements was reduced. However, isometric and isokinetic measures of single-joint muscle performance were unaffected. The relationship between muscle performance and use of FRs was studied by McDonald et al. [4] to determine whether acute self-myofascial rolling affects the evoked quadriceps muscle force and improves knee joint ROM. They reported a significant increase in knee joint ROM without concomitant detrimental effects on neuromuscular force production after applying a FR to the quadriceps. Sullivan et al. [5] investigated the effects of the use of a FR on the ROM in hamstrings. They applied different variations of sets at a constant pressure at 13 kg: 1 set of 5 s, 1 set of 10 s, 2 sets of 5 s and 2 sets of 10 s. The maximal voluntary contraction and the ROM throughout sit and reach tests were evaluated. The use of the FR was more effective for ROM, particularly when used for a longer duration, without any effect on muscle strength. Mohr et al. [11] measured passive hip-flexion ROM the effects of a FR, static stretching, and the combination of both in hamstrings. Their results suggested that the use of a FR combined with static-stretching is beneficial. However, Miller and Rockey [15] assessed a FR protocol in hamstrings corresponding to 3 sets of 1 min followed by 1 min of rest that was applied three times per week over eight weeks. The authors did not find improvements in the ROM. The effects of the use of FRs on biological stress have also been studied. Kim et al. [16] examined the effect of self-myofascial release -induced using a FR on the reduction in stress by measuring the serum concentration of cortisol. There was not a significant difference between the control and the experimental groups after the use of the FR on the spine, cervix, thorax, quadriceps, hamstring, tensor fascia latae or calf. Scientific evidence regarding the benefits of FRs indicate that it is a very useful tool for recovery after intensity activity. However, there is limited scientific evidence regarding the physiological effects of the use of a FR on muscle properties.

Neuromuscular function has been extensively assessed using various measurement techniques, such as evoked contractions, mechanical power, surface electromyography, magnetic resonance imaging, ultrasound, or a combination of these techniques. Tensiomyography (TMG) is a relatively new technique based on the quantification of radial muscle belly displacement in response to a single electrical stimulus [17]. In recent years, TMG measurements have been successfully used to assess various muscle groups [18] to investigate muscle atrophy [19], muscle endurance [20,21] and muscle belly stiffness [22]. TMG parameters correlate with the spatial distribution of fibre types in human muscles [23-25]. Some authors have used TMG to assess the

immediate effect on the muscle properties after various activities, such as high-volume and high-load training [26] or kinesio taping [27], and to test the immediate and prolonged effects of recovery strategies [28,29]. Several authors have evaluated the rectus femoris in their investigations, being probably the most employed muscle using TMG [21,28-33].

The purpose of this study was to assess the acute effect of the use of a foam roller on TMG parameters Dm and Tc of the rectus femoris in Chinese soccer players.

## 2. Materials and Methods

### 2.1. Participants

Seventeen male professional soccer players (age  $21.4 \pm 3.8$ , height  $180.5 \pm 7.7$  cm, and mass  $73.6 \pm 10.7$ ) who play in the Chinese SuperLeague as part of the reserve team participated in this study. Individuals were excluded if they had experienced any lower extremity injuries in the previous month.

Before starting, verbal guidelines of the study were given to the participants and an informed-consent form was signed by all participants. The experimental protocol was assessed and approved by the Ethical Committee of the University of Pablo de Olavide, from Seville (Spain) and was in accordance with the guidelines of the ethical standards of Harriss & Atkinson [34].

### 2.2. Study Design

The acute effects of the use of a FR on the mechanical responses of the rectus femoris (RF) muscle were assessed via TMG (GK 40®, Panoptik d.o.o., Ljubljana, Slovenia). Each subject was tested three times via TMG: once after warm-up, once after two sets of using a FR, and once after four sets of using a FR. The FR was used only over the dominant leg, and the other leg was considered a control. Substantial differences were not found between the dominant and non-dominant leg for Dm (maximum radial displacement of the muscle belly in millimetres) and Tc (time in milliseconds from 10% to 90% of the peak contraction) at the beginning of the study.

### 2.3. Procedures

TMG measurements were performed with the subject lying in the supine position with his knee over a triangular wedge foam cushion to maintain it fixed at a  $120^\circ$  angle, where  $180^\circ$  corresponds to full extension of the knee, in a static and relaxed position [17]. The extent to which this method may be reproduced and is considered valid was assessed in a previous study [28] following the measurement protocol proposed by Tous-Fajardo et al. [17] and Rey et al. [29]. The dependent variables measured were the following: (1) Dm; to assess the stiffness or muscle tone; and (2) the Tc. For the TMG, a portable device was used to produce an

electrical stimulus that was applied percutaneously to elicit a muscle contraction detected by a digital transducer located above the muscle belly [18]. Two 5cm x 5cm square self-adhesive electrodes (Compex Medical SA, Ecublens, Switzerland) were placed from the measurement point to 5 cm ( $\pm 3$  cm) proximal (anode) and distal (cathode) to the sensor. The measurement point of the sensor was set perpendicular to the anatomic point of the maximal muscle belly displacement, according to Delagi et al. [35], and was marked with a dermatological pen to ensure the electrodes were placed at the same position for each subsequent measurement. These contractile properties were recorded for both legs using a digital displacement transducer (GK 40®, Panoptik d.o.o., Ljubljana, Slovenia), which incorporated a spring of  $0.17 \text{ N}\cdot\text{mm}^{-1}$ . A controlled initial pressure of  $1.5 \times 10^{-2} \text{ N/mm}^2$  was used. This response was evoked by the individual maximal electrical stimulation using a TMG-S1 stimulator (EMF-Furlan and Co. d.o.o., Ljubljana, Slovenia) to apply a pulse of 1ms and an initial amplitude of 30 mA. For each TMG assessment, the intensity was progressively increased by increments of 20mA until there was no further increase in Dm or the maximal stimulator output (110 mA) was reached [28]. A rest of 15s was allowed between consecutive measurements to minimize the effects of fatigue and potentiation [27]. An online host computer was used to record the displacement of the sensor at a sampling rate of 500 Hz.

## 2.4. Protocols

Each soccer player performed a warm-up in a cycle ergometer at 70 revolutions per minute (rpm) and 1 kilopond of resistance for eight minutes. Next, the muscle mechanical properties were assessed in the RF of both legs via TMG. Then, a FR was applied over the RF in only the dominant leg for 2 sets of 15 s, with 2 min of rest between each set. After the sets, TMG was used to measure the muscle parameters in the RF muscles of the dominant and non-dominant legs. Thereafter, the soccer players performed another two sets using the FR in the RF of only the dominant leg in the same manner described above, and TMG was again applied. The FR used was constructed of a polyvinyl chloride pipe (10.16 cm outer diameter and 0.5 cm thickness) surrounded by neoprene foam (1 cm thickness), which was selected because previous studies have suggested that high-density FRs induce greater pressure on soft tissues than low-density FRs [3]. The subjects were instructed to begin using the FR at the most proximal portion of the RF in the dominant leg and roll the FR down the thigh until reaching the most distal portion of the RF, placing all of their body mass over the leg and using their arm to make the movement. To prevent contact of the non-dominant leg with the FR, the subject used the left lateral portion of the instrument to work, and the non-dominant leg was placed over the dominant leg. The

athletes used a digital metronome set to 30 bpm to maintain a consistent speed. The duration of each set was 15s with 2min of rest between sets. This protocol was designed by us to assess the effects of the FR in a shorter and slower set.

## 2.5. Statistics

The results are presented as the mean  $\pm$  SD. The analysis of independent variables reported by Hopkins [36] was applied to compare both legs. To compare the evolution of the differences within each leg, the analysis of dependent variables reported by the same author was used. A 90% confidence level was used, and all other variables were log-transformed to reduce bias due to nonuniformity of error. The differences were assessed according to qualitative probabilistic terms using the following scale: <0.5%, certainly not or extremely unlikely; 0.5-5%, very unlikely; 5-25%, unlikely or probably not; 25-75%, possibly; 75-95%, likely; 95-99%, very likely; >99.5%, extremely likely or almost certainly [36-39]. The scale considers that a magnitude of change is substantial when there was a  $\geq 75\%$  likelihood of the effect being equal to or greater than the smallest worthwhile change estimated as 0.2x between subject standard deviation and classified as trivial to moderate [40]. Cohen's d effect size was also calculated using a confidence interval of 90%. The thresholds applied to the effect size were according to the proposal of Cohen [41]: trivial (0.0 - 0.19), small (0.2 - 0.59), moderate (0.6-1.1), large (1.2 - 1.9) and very large (>2.0) [36-38].

## 3. Results

The Table 1 shows the mean and the SD of Dm and Tc for each TMG measure of the dominant and non-dominant legs. Tables 2 and 3 show the statistical analyses of the independent and dependent variables, respectively, using the approach reported by Hopkins [36-38].

Substantial differences were not found between the dominant and non-dominant legs in the Dm and Tc values of the first TMG measure, indicating that the legs are statistically similar. In addition, no differences in these values were found after the second and fourth sets using the FR between the dominant and non-dominant legs (Table 2).

Table 3 shows the changes in the muscle mechanical properties assessed via TMG. The use of the FR on the dominant leg did not induce an increase or decrease the Dm. However, in the control leg (non-dominant), increased Dm values were observed after two sets of FR use compared to rest and after four sets of FR use compared to rest, as measured via TMG. No substantial differences in Tc were observed between the dominant and non-dominant legs for the different measurements performed.

**Table 1.** Mechanical properties of the RF muscle (mean  $\pm$  SD) for the three tensiomyography measurements: (1) after warm-up, (2) after the 2<sup>nd</sup> set and (3) after the 4<sup>th</sup> set. \*Substantial different (>75) from Dm<sub>1</sub>. †Effect size *d* Cohen small (0.2-0.59). ††Effect size *d* Cohen moderate (0.6-1.1).

	Dm <sub>Pre</sub>	Dm <sub>Post 1</sub>	Dm <sub>Post 2</sub>	Tc <sub>Pre</sub>	Tc <sub>Post 1</sub>	Tc <sub>Post 2</sub>
Dominant	10.1 $\pm$ 2.6	10.3 $\pm$ 1.9	10.8 $\pm$ 2.6	29.0 $\pm$ 4.3	28.9 $\pm$ 4.4	28.8 $\pm$ 3.9
Non-Dominant	9.5 $\pm$ 2.0	10.3 $\pm$ 3.0*†	10.6 $\pm$ 1.9*††	28.1 $\pm$ 3.9	28.6 $\pm$ 3.7	29.0 $\pm$ 5.1

**Table 2.** Results of the statistical analysis using the approach reported by Hopkins (2007) for the independent variables between both legs (dominant and non-dominant) in the TMG measures for the pretest (TMG<sub>Pre</sub>), after two sets of FR use (TMG<sub>Post 1</sub>) and after four sets of FR use (TMG<sub>Post 2</sub>).

	Dm			Tc		
	TMG <sub>Pre</sub>	TMG <sub>Post 1</sub>	TMG <sub>Post 2</sub>	TMG <sub>Pre</sub>	TMG <sub>Post 1</sub>	TMG <sub>Post 2</sub>
Dif. Groups	9-34-57	28-45-27	21-44-35	11-37-51	20-43-36	31-44-24
Qualitative Chance	Possibly, maybe (not)	Possibly, maybe (not)	Possibly, maybe (not)	Possibly, maybe (not)	Possibly, maybe (not)	Possibly, maybe (not)
Effect Size <i>d</i> Cohen	-0.26 $\pm$ 0.57	0.01 $\pm$ 0.57	-0.07 $\pm$ 0.57	-0.21 $\pm$ 0.57	-0.08 $\pm$ 0.57	0.04 $\pm$ 0.57

**Table 3.** Results of the statistical analysis based on the approach reported by Hopkins (2007) for the dependent variables comparing the effect of FR use on the tensiomyography values (Dm and Tc) after two and four set in the dominant and non-dominant legs. The pre-test (Pre) was compared to after two sets of FR use (Post 1) and to after 4 sets of FR use (Post 2). Additionally, the results of Post 1 and Post 2 were compared.

	Dominant			Non-Dominant		
	Dm <sub>Pre</sub> - Dm <sub>Post 1</sub>	Dm <sub>Pre</sub> - Dm <sub>Post 2</sub>	Dm <sub>Post 1</sub> - Dm <sub>Post 2</sub>	Dm <sub>Pre</sub> - Dm <sub>Post 1</sub>	Dm <sub>Pre</sub> - Dm <sub>Post 2</sub>	Dm <sub>Post 1</sub> - Dm <sub>Post 2</sub>
Dif. Groups	11-55-35	26-73-1	61-36-3	82-14-4	89-8-3	53-4-3
Qualitative Chance	Possibly, maybe (not)	Possibly, maybe (not)	Possibly, maybe (not)	Likely, probable	Likely, probable	Possibly, maybe (not)
Effect Size <i>d</i> Cohen	-0.11 $\pm$ 0.45	0.14 $\pm$ 0.18	0.25 $\pm$ 0.37	0.51 $\pm$ 0.65	0.73 $\pm$ 0.76	0.21 $\pm$ 0.34
	Tc <sub>Pre</sub> - Tc <sub>Post 1</sub>	Tc <sub>Pre</sub> - Tc <sub>Post 2</sub>	Tc <sub>Post 1</sub> - Tc <sub>Post 2</sub>	Tc <sub>Pre</sub> - Tc <sub>Post 1</sub>	Tc <sub>Pre</sub> - Tc <sub>Post 2</sub>	Tc <sub>Post 1</sub> - Tc <sub>Post 2</sub>
Dif. Groups	22-68-10	26-63-11	4-93-3	45-50-5	42-47-11	1-97-2
Qualitative Chance	Possibly, maybe (not)	Possibly, maybe (not)	Possibly, maybe (not)	Possibly, maybe (not)	Possibly, maybe (not)	Possibly, maybe (not)
Effect Size <i>d</i> Cohen	0.06 $\pm$ 0.43	0.07 $\pm$ 0.46	0.01 $\pm$ 0.17	0.17 $\pm$ 0.38	0.15 $\pm$ 0.51	-0.02 $\pm$ 0.13

## 4. Discussion

The objective of this study was to determine the acute effects of the use of a FR on the maximum radial displacement and the time of contraction of the RF muscle, which were assessed via tensiomyography in Chinese soccer players. Our results showed that 1) that FR use for 15 s maintained the stiffness of the RF muscle, whereas stiffness decreased (increased dm) in the RF of the control leg on which the FR was not applied, and 2) the time of contraction was not affected by FR use on any of the legs during the series of treatment sets. These findings are important for evaluating the effects of short-term FR applications on muscle mechanical properties and applicable for the development of therapeutic tools for activating muscles before exercise or for designing strategies to prevent work- or rehabilitation-related injuries.

Post-warm-up, no differences were observed in the Dm and Tc TMG measurements. Few studies have assessed muscle mechanical properties using TMG in the rectus femoris muscles of soccer players. Our results are similar to those reported by Rey et al. [29] in professional players.

However, Rusu et al. [31] reported smaller displacements in mm and less time of contraction in a junior soccer team compared to those observed in the present study.

Several studies have recently reported the effects of the FR on kinematic variables, such as sprint speed, the speed of changes in direction, and vertical jump [12,13]; the ROM [4,5,11,13]; mechanical responses such as isometric force, the rate of force development, and dynamic strength-endurance [4,5,12,13]; the characteristics of muscle activation via electromyography [5]; muscle soreness [12,13]; and even biological factors such as cortisol levels [16]. However, TMG has not been used to assess muscle mechanical properties after FRs treatment. This tool (TMG) has been used to study the consequences of various types of exercise, exercise intensities, effort, and recovery strategies to assess the muscle mechanical properties, above all muscle belly displacement [26-29,31]. Nevertheless, most studies regarding the use of FRs on the ROM have found an increase in the ROM after the FR was applied [4,5,7,9,11,13]. Among the previous reports, only Miller and Rockey [15] did not report an increase in the ROM. Here, we report that the use of

the FR prevented an increase in the Dm in the leg in which the FR was applied, whereas Dm increased in the control leg. Moreover, leg stiffness was maintained without enhancing or impairing the contractile performance compared to the control leg. Some authors have reported similar results regarding the contractile properties based on assessments with other techniques and tools, such as knee extensor force, muscle activation, and maximum voluntary contraction, etc. [4,5]. Only MacDonald et al. [13] observed improvements in vertical jump and muscle activation. Professional athletes or athletes from a specified and concrete sport activity were not evaluated in any of these cases.

The effects of FR use have been widely studied by various authors. However, in each study, a different form and duration of self-myofascial release was employed [9]. For example, previous studies have employed durations of 5 or 10 s [5], 30 s durations in sets of 3 or 6 min [16], and or sets of 1 min of duration [4,11,13]. The speed of execution has also varied in previous studies. For example, under strict control with the aid of a metronome, 50, 60 or 120 bpm were utilized in the investigations by Pearcey, Mohr and Sullivan, respectively [5,11,12]. In other cases, verbal guidelines were given to the subjects to modulate undulating movements in a fluid motion [4,13]. In our study, we utilized a different approach: the FR was used in a slow movement and in a shorter set than previously published studies. These differences in the FR use could explain why the muscle mechanical properties were not affected, the muscle displacement was maintained, and consequently, the stiffness was unchanged, whereas other works have reported an increased ROM [4,5,11-13]. Although the tools used in previous studies differ from the TMG employed here, we expected similar results that the Dm would increase after FR use, similar to the reported increases in the ROM in others studies. Surprisingly, this result was not observed, likely because the FR was applied in a different manner and duration, i.e., it was applied slower and over a shorter duration compared to other cases. Therefore, differences in the use of the FR, such as the speed and duration of application, could induce variable consequences in the muscle function properties. Upon short and slow applications of pressure, the stretch reflex reacts to the excess pressure by stimulating the muscle fibres to prevent excess stretching, thus increasing or maintaining the stiffness. However, over longer periods of time, the muscle spindle may increase the threshold of stretching, consequently increasing the muscle length and ROM. Another factor is the increase in the Dm in the non-dominant control leg. An in-depth analysis with more studies regarding the origin of the decrease in stiffness without direct intervention in this leg is necessary.

Various limitations of our study should be considered. It was not possible to assess the subjects after 24 or 48 h because the groups were participating in an official championship and were therefore training every day. Therefore, our results could be influenced by the effects of the training. It would be interesting to re-evaluate the

dominant and non-dominant legs after one week, although this was not possible for practical reasons. Futures studies should consider additional variables, such as ROM tests, electromyography recordings, and strength functional tests, in addition to TMG to assess the effects of the use of FR based on additional parameters and how the duration and execution speed FR use affect the muscle properties and function. More studies are also necessary to evaluate how long the effects of one treatment session last [9]. Another important factor is the pressure that the roller exerts on the muscle. Some of the studies cited above controlled the pressure of the FR to maintain a constant pressure during the experiments [5] or the pressure was recorded during the test [3]. However, in practical applications of daily self-myofascial therapy, pressure cannot be controlled during execution. Therefore, we selected not to include pressure control in our study, but rather provided guidelines to the subjects regarding the appropriate technique, the range of displacement over the foam based on their anthropometry characteristics, and the control of the speed of execution using a digital metronome.

## 5. Conclusions

In summary, our findings suggest that the use of a foam roller in slowly executed small sets maintain the level of the stiffness and the time of contraction in the RF muscle. Therefore, foam rolling is a useful therapy for activating muscle and can be included in programs aimed to maintain the level of the muscle stiffness. In addition, FR use in one leg caused a decrease of the stiff of the opposite leg. However, this result should be further assessed in future studies to determine whether the use of the FR in one leg is cause of the decreased stiffness in the opposite leg. Furthermore, guidelines regarding the duration and speed of execution of FRs for therapeutically adjusting muscles properties, and their functional performance should be established in the future, as other authors such as Stevens have already argued. Finally, additional investigations regarding the origin of the changes induced by the use of FRs at physiological and neural levels should be performed.

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