Original Article

The Comparison of the Effects of Two Fatigue Protocols on Triceps-Surae Musculotendinous Stiffness in Healthy Female Students

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ABSTRACT

Background: Previous studies have investigated different effects of muscle fatigue on body systems. However, there are no reports on the effect of fatigue protocol and its level on musculotendinous stiffness (MTS) of the tricep-surae. This study was designed to compare the effects of 2 levels of submaximal fatigue contraction on MTS of triceps-surae.
Methods: Twenty female students by simple randomized sampling participated in this study. Triceps-surae musculotendinous stiffness was measured before and after two fatigue protocols. The fatigue protocols were comprised of a continuous isometric voluntary plantar flexion contraction (25% and 70% maximum voluntary contraction) until the contraction could no longer be maintained. The free oscillation technique was used to measure MTS of the triceps-surae. A Kistler force plate was used to measure the force applied.
Results: Musculotendinous stiffness decreased immediately after both fatigue protocols (P≤0.05). Data analysis with RM ANOVA showed that there was no significant difference between the two protocols with respect to the decrease in MTS stiffness of the triceps-surae. Moreover, the decrease in stiffness did not change for 15 min after the two fatigue protocols (P>0.05).
Conclusion: Musculotendinous stiffness of the triceps-surae decreased significantly after both fatigue protocols, and there was no significant difference between the two protocols with respect to change in triceps-surae musculotendinous stiffness. This result may be due to similar type of contraction in protocols, the learning effect, or the effect of central fatigue.

Introduction

Musculotendinous stiffness (MTS) means resistance of musculotendinous unit versus an increase of length [1]. Musculotendinous Stiffness relates to muscle performance and function [1,2] and has an important role in lower limb injuries [3]. Both increases and decreases of the MTS can cause decrement of muscle function [4], while an increase can cause bone damage, a decrease can cause soft tissue injury [3].

Two investigations have reported that after an isometric contraction using the quick release procedureand the implementation of dynamical perturbations, active stiffness of the quadriceps muscles [5] and elbow stiffness [6] were both reduced. However, Hunter and Kearney (1983) reported that ankle stiffness was not significantly altered by a submaximal isometric plantar flexion utilizing dynamical perturbations [7].

The previous studies that have reported alterations in the MTS following fatigue have shown disputable results. In addition, to the best of our knowledge, no research has been done on the effect of different intensity levels of

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isometric contraction on the MTS.

The aim of this study was, therefore, to compare the MTS of the triceps-surae following two fatigue protocols composed of two-level isometric contractions (25% and 70% maximal voluntary contraction).

Methods

Participants: Twenty female university students (means±standard deviation: 22.65±3.18 yr; 161.80±4.75 cm; 58.05±7.33 kg) took part in this investigation. All participants were chosen based on a simple randomized sampling from the School of Rehabilitation Sciences at the Shiraz University of Medical Sciences (Shiraz, Iran). Before enrolment in the study, all participants signed a consent form. Exclusion criteria included a history of chronic or acute lower extremity musculoskeletal damage (within last 6 months), lower extremity surgery or pain, neurologic disturbance, being active in sport (at least 3 times in a week for 45 minutes [8]) and pain during the tests.

Instruments: A Kistler Force Plate was used to assess the applied force. The triceps-surae equipment is similar to that used in other investigations [9]. However, to enhance data collection, some alterations (e.g. use of an elastic medicine ball) were established to apply impulse instead of applying manual force . These alterations were performed in order to provide stability in the magnitude and the direction of the applied forces [10]. Vertical ground reaction force (GRF) was used to assess free oscillation data. In the present investigation, the participants were assessed before and after each fatigue protocol [11]. The method of measuring the musculotendinous stiffness is reliable and valid [12].

Calculation of Maximum Voluntary Contraction: Maximum voluntary contraction (MVC) of the triceps surae was calculated using dynamometer (MIE,LTD,UK). The participants were positioned in long sitting on a dynamometer with the ankle in neutral position (the knee fully extended and the hip flexed at 90°). Velcro straps surrounding the foot and dynamometer foot plate were used to restrict ankle movement. The participants were instructed to apply plantar flexion and exert maximal force for 4 seconds to obtain MVC. Verbal encouragement was provided during this protocol, and the MVC was recorded. This procedure was repeated 2 times with a 3-min gap in between, and the maximum force was determined.

Musculotendinous Stiffness Assessments: Musculotendinous stiffness of the triceps-surae was estimated by the damped frequency of oscillatory movement around the ankle. To assess musculotendinous stiffness, the participant's dominant leg was placed at a 90° angle with the hip, and all participants were barefoot. The knee was also bent, and the ankle was in neutral position. A wooden piece with a height of 10 cm was put on the force plate under the metatarsophalangeal joints, and utilized to uphold the forefoot. In this position, the metatarsophalangeal joints were straightened by the edge of the piece of wood. To provide stability, a weight was applied on the knee joint which was standardized to 30

% of the participant's MVC. The participant's arms were embraced across the chest, and the handle of the tools was put on the knee and fixed in place. Further, an elastic medicine ball (weighing 5 kg) was utilized to produce perturbations. The ball was dropped from 35 cm above the superior surface of knee joint by an examiner, and the participant was asked not to interfere the impact of ball [13,14] (Figure 1).
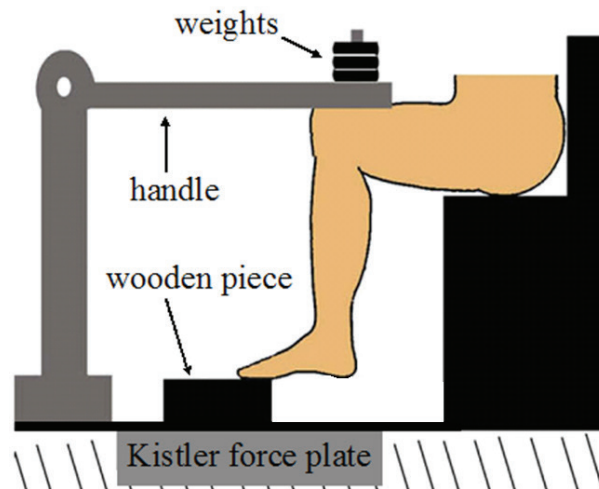

Figure 1: Device for measuring musculotendinous stiffness

The method was first introduced by McNair and Stanley [13]. The participant's eyes were covered. Each participant wore a headset which played recorded voice disturbances (classical music at a low volume) in order to intervene with the participant's concentration from performing a contraction against perturbation. In order to decrease the probability of subjects anticipating the perturbation, they were applied sporatically during 10 second intervals. The participants were instructed to try to maintain a continuous level of plantar-flexion force and not to interfere with the perturbation [15]. The MTS was calculated three times after the fatigue protocol (2 minutes, 5 minutes, and 15 minutes) (Figure 2).

Fatigue Protocol: The participants were in a prolonged sitting position on a dynamometer with the ankle in neutral position (the knee fully extended and the hip bent at 90° angle). Velcro straps around the foot and the dynamometer foot plate were used to restrict ankle movement.

Afterwards, the participants began one of the fatigue protocols, which included a prolonged isometric plantar flexion contraction at either 70% MVC or 25% MVC. The participants attempted to produce the target moment presented on the monitor, and were instructed to hold it as long as possible. The fatiguing contraction was terminated when the participant could not maintain the target moment and they could not return to the target point for five seconds [16,17]. The MTS was calculated before and after the fatigue protocol, as was previously mentioned. The second fatigue protocol was applied 20 minutes after the completion of the first fatigue protocol. The two fatigue protocols were used in random orders.

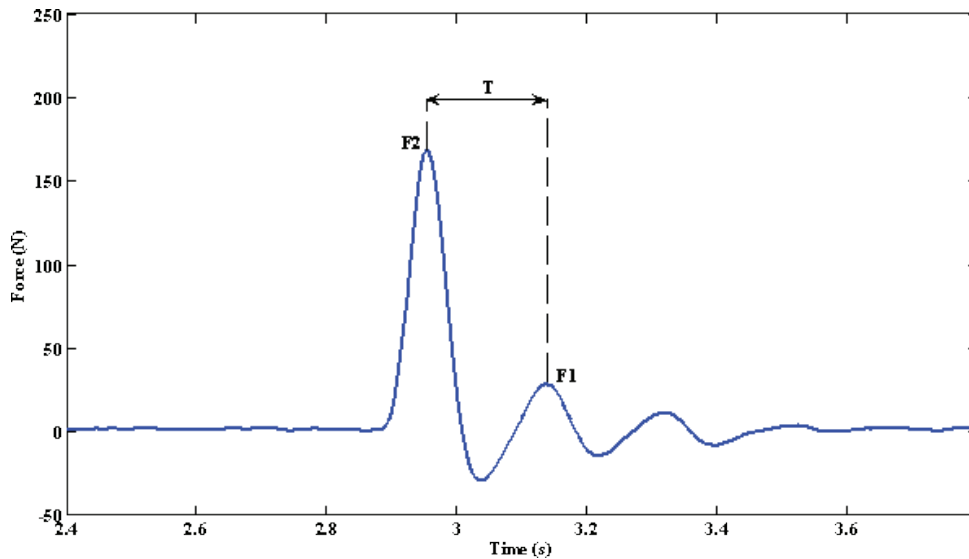**Data Analysis:** Stiffness (k) was calculated by the

Figure 2: Damped time of oscillation estimating musculotendinous stiffness

system radius (r), the damped frequency of oscillation (f), and the mass of the system (m) using the following equation: $K = 4^2 \pi r^2 f^2 m$. System radius was determined by utilizing a clinical tape measure to calculate the space between the second metatarsal head and the posterior border of the Achilles tendon. Damped frequency of oscillation (=1/T) and system mass matched the summary of the leg and foot fragment masses as well as the mass of the used load [9,14] (Figure 2).

All data were analyzed with MATLAB2010A software and SPSS 15. A Kistler Force Plate (model 9286A, Kistler, Switzerland, size: 400×600 cm, low-pass Butterworth filter and cut-off frequency of 12 Hz) was used to assess the applied force. In order to calculate the MTS of triceps-surae immediately after long lasting protocol, a Paired T-test was used. Constancy of MTS of triceps-surae up to 15 minutes after fatigue was estimated via RM ANOVA. The statistical significance level was set at α=0.05.

Results

The normality of the variables was confirmed using a K-S test. The mean time duration to reach fatigue (tolerance time) was shorter for 70% MVC (129.20±91.55

s) than for 25% MVC (619.50±304.96s) (P= 0.001). This finding suggests that the mean of the MTS of triceps-surae following both of the fatigue protocols is lower than pre-fatigue condition (P=0.001), but there is no significant difference between the two protocols with respect to the MTS of triceps-surae (Table 1). RM ANOVA showed that the MTS had no significant change up to 15 minutes following both fatigue protocols (P>0.05) (Table 2).

Discussion

The main results of the present study can be summarized as follows: (1) the MTS reduced immediately after isometric contractions, (2) changes in the MTS at isometric contractions remained constant up to 15 minutes after fatigue protocols, and (3) there was no significant difference between the two fatigue protocols with respect to the MTS of triceps-surae.

One of the principal results of this investigation was that the MTS of triceps-surae decreased immediately after the submaximal contractions. This finding is in accordance with previous studies. A reduction in joint stiffness after prolonged isometric contraction in elbow (the former) and knee (the latter) was observed [18].

Table 1: The comparison of musculotendinous stiffness with 70% and 25% MVC

Measurement	Pre-fatigue stiffness/m (mean±SD)	Post-fatigue stiffness/m		
		2 min (mean±SD)	5 min (mean±SD)	15 min (mean±SD)
25%	319.39±172.24	189.28±105.21	210.52±126.88	215.24±125.64
70%	319.39±172.24	220.70±143.67	223.70±124.36	213.36±150.62
P value		0.17	0.35	0.92

Table 2: Duration of the effect of muscle fatigue (70% and 25% MVC) on musculotendinous stiffness of triceps-surae

Measurement	Pre-fatigue stiffness N/m (mean±SD)	Post-fatigue stiffnessN/m			P value
		2 min (mean±SD)	5 min (mean±SD)	15 min (mean±SD)	
25%	319.39±172.24	189.28±105.21	210.52±126.88	215.24±125.64	0.25
70%	319.39±172.24	220.70±143.67	223.70±124.36	213.36±150.62	0.92

Zhang and Rymer suggested that there was a reduction of stiffness following a submaximal isometric contraction at 60% MVC [6]. In a vivo study, Kubo et al. found an increment in tendon compliance (decrease stiffness) after submaximal isometric contraction in the vastus lateralis.

However, Ettema observed that the stiffness of Gastrocnemius Medialis tendon of rats increased after submaximal repetitive contractions caused by electro stimulation [11]. The difference in tendon elongation following a fatigue protocol in the observation of Ettema was about 7- 8%, which was too low to affect the muscle structurally. The differences between the outcomes of these studies and the present study might be due to the differences in the implemented methods and procedures [11].

Nordez and colleagues observed no changes in local muscle stiffness of the triceps-surae after a fatigue protocol at 40% MVC by elastography technique [8]. Other researchers performed two fatigue protocols on the vastus lateralis that comprised of a long-lasting concentric isokinetic contraction at70% MVC and a long lasting isometric contraction at 25% MVC. They did not discover changes in musculotendinous stiffness of the vastus lateralis after both fatigue protocols [17]. Mademli et al. included two fatigue protocols: long lasting isometric contraction at 40% MVC and long lasting concentric isokinetic contraction at 70% MVC. Their study showed no alteration of musculotendinous stiffness of triceps-surae after both protocols [11].

In the present study, the post-fatigue MTS was lower than pre-fatigue protocols. Two possible reasons may explain this decrease. Firstly, an increase in intramuscular temperature caused by exercise could have changed the viscoelastic characteristics of the muscle–tendon unit. However, Magnusson et al. have found that 30 min of uninterrupted running caused a significant augment of 3.8° in hamstrings intramuscular temperature, but did not influence the viscoelastic hamstring characteristics [19]. In this study, we only used one type of contraction (isometric) and one muscle group (triceps-surae). Isometric contraction obstructs blood flow in the muscle tissue more than other types of contractions [20]. Consequently, after the contraction is stopped, the compensatory mechanism that may be liable for the increment blood flow and intramuscular temperature may be elevated during isometric contraction than during other types of contraction. This may explain why a greater decrement in the MTS was observed when compared to the study of Magnusson et al. Accordingly, it is suspected that the increase in intramuscular temperature (caused by our fatigue protocols) may have changed muscle viscoelastic characteristics. In addition, the fatigue protocols in this study were continued for a considerable duration, with a mean time to fatigue of 619.50 s.

Structural changes in the muscle could also explain the decrease in the post-fatigue MTS. Previous studies reported the change of tendon arrangements, the augment in muscle pennation angle, and the decline in fascicle length express the creep event that occurs in tendons throughout contraction [11,21,22]. According to these findings, it appears that our results are more consistent with the idea that the creep would cause alterations in muscle mechanical characteristics after exhausting contractions [18].

The differences between our outcome and previous studies can possibly be attributed to: (1) the kind of musculotendinous stiffness measurement, (2) the type of contraction used in the study, (3) the type of muscle, or (4) differences in sample type (animal or person).

The present study also showed that the MTS was constant for 15 minutes following the completion of the fatigue protocols. There is no evidence about the constancy of the effects of muscle fatigue on the MTS. Some investigators have suggested that the tendon recovers 10 minutes after submaximal isometric exercise [23]. However, the mentioned study was carried out in an experimental environment and was performed on a rat tail.

Constancy of the effects of muscle fatigue on the MTS may depend on many factors such as the type of contraction (isometric, isotonic, eccentric), intensity of contraction (maximal or sub maximal), muscle type (slow twitch or fast twitch), and level of physically fitness of the participant. If the protocol of fatigue takes more time, recovery will take more time as well. This may be another reason for constancy of the increment of intramuscular temperature and alternations of neural control following repeated contractions.

The constancy of the MTS in this investigation can be the result of the following:

I. existence of mechanical and morphological changes in the tendon

II. increase of tolerance time

III. type of studied muscle (gastrosoleus are postural muscles)

IV. increase of intramuscular temperature

V. alterations of neural control following repeated contractions

VI. preparation for resistance versus further loads

The results showed that both fatigue protocols decreased the MTS, but they had no significant difference between them. This effect persisted up to 15 minutes following both fatigue protocols. These results may be due to several reasons:

I. In both protocols, the type of contraction was isometric. Contraction type is an important factor with respect to the effects on tissue structure.

II. Learning phenomenon in participants. Because of the repetition of measurements (three times in each fatigue protocol), participants learned to respond to the load in a similar pattern, and despite different levels of contraction in both fatigue protocols, MTS had no significant change between them.

III. Central fatigue. Central fatigue may be more likely to develop via isometric contraction as compared to other contractions, and despite the difference in the level of contraction, central fatigue following isometric contraction may influence muscle function in the same way.

The finding showed that change in the MTS resulting from the fatigue protocol at 70% MVC occurred faster than the fatigue protocol at 25% MVC. This may be attributed to activation of the larger motor units, which are more fatigable than smaller motor units recruited in the protocol at 25% MVC.

There might be some methodological factors affecting the pre and post exhausting contractions. There is also the possibility of participants resisting the perturbations. In addition, alterations in the first length of the tendon and aponeurosis and associated contributions of the Gastrocnemius Medialis, Gastrocnemius Lateralis, and Soleus by EMG could not be assessed in this study.

Conclusion

In conclusion, it can be said that the MTS of the triceps-surae, when assessed by free oscillation technique following isometric plantar flexion (at 70% MVC and 25% MVC) is significantly altered; however, there was no significant difference with respect to the two fatigue protocols. This result may be due to the similarity in the type of contraction implemented in two protocols, the learning, and the effect of central fatigue.

Acknowledgement

Conflict of Interest: None declared.

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