

Research Paper

Feedforward and Feedback Function of Selected Lower Limb Muscles Following Plyometric Exercises and Cryotherapy



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ABSTRACT

Purpose: Despite the widespread use of cryotherapy in sports, there is no specific evidence of its impact on muscle activation, especially following fatigue-induced exercises. This study aimed to assess the impact of cryotherapy alone and after plyometric exercises on knee muscle activation during the drop jump task.

Methods: A total of 35 active female subjects (Mean±SD age of 22.74±2.10 years, mean body mass index [BMI] of 20.02±2.55 kg/m²) participated in this quasi-experimental study with a pretest-Post-test design. There were three experimental groups (20-minute cryotherapy, plyometric, and plyometric-cryotherapy) and a control group. Electromyography (EMG) amplitudes of knee muscle activation (rectus femoris [RF], biceps femoris [BF], tibialis anterior [TA], medial gastrocnemius [MG]) were measured and compared in three phases of the drop-jump task (one feedforward preactivation and two feedback eccentric and concentric phases). Skin temperature was recorded before and after cooling intervention as well. For comparisons, repeated measure analysis of variance (ANOVA) was used at a significant level of 0.05.

Results: The results showed that the skin temperature decreased significantly after cryotherapy and was maintained for 20 minutes. No significant changes were observed in the EMG of knee muscles in the feedforward and concentric phase of the drop jump task in any groups (P>0.05). However, RF activation decreased following cryotherapy immediately and after 20 minutes as an eccentric phase (P=0.01) and had a significant difference from the control group (P=0.01); besides, EMG activation decreased in cryotherapy, plyometric, and plyometric-cryotherapy groups immediately (P=0.01). However, no significant differences were seen between them and the control group (P>0.05).

Conclusion: According to the present results, cryotherapy alone and after fatigue-induced plyometric training had a minor effect on the knee muscle activation during a functional jumping movement, but the impact of these changes on knee biomechanics is insignificant; hence, further studies are essential for a better conclusion.

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Highlights

- The skin temperature decreased significantly after cryotherapy and was maintained for 20 minutes.
- Cryotherapy has no significant effect in most of knee muscle activities in the feedforward and concentric phase of the drop jump task.
- RF activation decreased following cryotherapy immediately and after 20 minutes as an eccentric phase.

Plain Language Summary

Despite widespread use of different cold mods in sport fields, it's certain effects are not very clear, so this study intended to assess the effect of cold alone and after training condition on muscle activity and biomechanical changes on knee joint. In order that 35 active females participated in the research. They divided to Three groups of a 20-minute cryotherapy, plyometric, and plyometric-cryotherapy. Testing was jumping task in which EMG activity of selected muscle was recorded. Results showed minimal effect of cryotherapy alone or after training on muscle activation parameters.

1. Introduction

All body movements are controlled by two feedforward and feedback mechanisms. In plyometric movements, the feedforward function, including the pre-landing or pre-activity stage, is defined as pre-programmed neural activation essential in preparing muscle activity to maximize contact forces and store elastic energy in the musculotendinous structure during the next eccentric phase [1]. Muscle activity at this stage leads to increased muscle stiffness and joint stability, which reduces the likelihood of injury due to unexpected perturbations [2].

Feedback performance in plyometric movements consists of two phases, eccentric and concentric phases. During the eccentric phase, the muscle-tendon unit is stretched, and elastic energy is stored. In addition, the muscle spindles activate the stretching reflexes. Increasing muscle activity during the eccentric phase improves energy storage, increasing power in the concentric phase; therefore, muscle activation is vital during each phase of a plyometric movement [3].

Cryotherapy is an immediate treatment widely used by athletes during competitions, musculoskeletal injuries, and post-exercise fatigue to reduce pain, swelling, and inflammation. Despite its widespread use, there is conflicting evidence on how cold affects an athlete's muscle activity or performance [4, 5]. Some studies have shown that cryotherapy reduces lower limb muscle activity [6, 7], proprioceptive receptors activity [8], and maximal exercise performance [9]. Therefore, it can increase the

likelihood of injury in athletes. In others, no significant effects have been reported following cryotherapy [10, 11] or have shown that not only does cryotherapy increase the risk of injury but also has a positive effect on the athlete to return to competition [12, 13]. For instance, in one study, the motor neuron function of the soleus muscle was facilitated following 30 minutes of cooling the ankle joint using crushed ice [13].

The effect of fatigue after exercise on muscle activity is also one of the topics discussed in various studies [14]. Fatigue can lead to changes in muscle neuromuscular control and EMG activity, thus predisposing the joint to injury [15-18]. However, some studies have shown that post-fatigue cold can improve muscle function [19]. For many athletes, it is important to maintain performance for long periods despite fatigue. Therefore, it is necessary to know the factors affecting skills, especially explosive and plyometric movements during sporting events. There is little evidence of the effect of cryotherapy on muscle activity after fatiguing conditions of functional or plyometric jumping exercise; therefore, the results of the previous research may be irrelevant or inapplicable for athletes engaged in explosive and intense movements. Accordingly, this study was conducted to answer the question of whether knee joint cryotherapy after functional fatigue can affect the muscle activity of the lower limb during different phases of the drop-jump movement in active young women. The answer to this question can be found in improving performance and preventing injury in athletes.

2. Materials and Methods

Study design and subject:

This study was quasi-experimental with a pretest-Post-test design approved by the Ethics Committee with the ethical code of IR.UUMS.REC.1399.431. First, 40 active female students (age range of 20 to 30 years) were selected in the field of physical education, and due to the dropout of 5 subjects, only 35 subjects participated in the study, who were selected by convenient sampling method and randomly divided into three experimental groups (cryotherapy, $n=10$; plyometric, $n=7$; and plyometric-cryotherapy, $n=8$) and one control group ($n=10$). The inclusion criteria included healthy subjects who were physically active, exercised regularly at least 3 times a week, and had full knee range of motion. The exclusion criteria included having any cold and ice allergies, a history of lower limb injuries for the past six months, lower limb surgery, or neuromuscular and cardiopulmonary diseases. In addition, the subjects were asked to avoid drugs and caffeine for at least 24 hours before the test. Repeated measures ANOVA and Bonferroni post hoc test with a significance level of 0.05 was used to analyze the data. Table 1 presents the subjects' demographic characteristics in the experimental and control groups.

Data collection

Before conducting the tests, a session was allocated to subjects due to get familiar with the laboratory environment, how to perform the tests, and landing skills. Also, the purpose and process of testing were fully explained to the subjects. After signing the consent form, the history of their medical and orthopedic injuries was recorded. In the test sessions, all variables were measured in the experimental groups in 3 stages: pretest and two Post-

tests with a time interval of 20 minutes after the intervention (cryotherapy, plyometric, and plyometric-cryotherapy groups). In the interval between the first and second Post-test, the subjects were lying on their backs. The subjects in the control group performed only the tests without intervention. The measurement of research variables was repeated 3 times in the pretest and Post-test, the average of which was used for statistical analysis.

Cryotherapy

To apply the cold, the subjects were asked to lie on their backs. Then the ice pack was placed on the anterior and inner part of the knee joint (area $12 \times 20 \text{ cm}^2$) [7] for 20 minutes without applying pressure by hand or bandage. The weight of the ice pack was about 0.6 kg [7, 20]. Before and after cooling, as well as 20 minutes after cooling, skin temperature was recorded using an electronic infrared thermometer (Manoli, made in the UK).

Plyometric fatigue-induced protocol

In the plyometric and plyometric-cryotherapy groups, the subjects performed the fatigue plyometric training protocol presented in Table 2. The subjects did the exercise, which included single and double jumping tasks using a 20 cm step after a 15-minute warming-up period (3 minutes of slow running, 13 minutes of dynamic stretching movements).

Drop-jump task

A 30-cm step was used for doing the drop-jump task on the dominant foot [7]. The subjects should stand on the stairs and release themselves from the platform without any contraction in the leg muscles after hearing the sound of the sound stimulus. Then, the subjects were asked to jump up and land on the earth as soon as their

Table 1. Demographic characteristics of subjects and between-group comparisons results

Variables	Mean \pm SD			
	Age (y)	Weight (kg)	Height (cm)	BMI (kg/m ²)
Control	22.9 \pm 2.28	56.2 \pm 9.02	164.8 \pm 7.77	20.72 \pm 2.93
Cryotherapy	23 \pm 2.26	52.5 \pm 5.12	164.4 \pm 7.02	19.46 \pm 1.93
Plyometric	23.28 \pm 2.62	55.28 \pm 9.79	167 \pm 7.89	19.79 \pm 2.77
Plyometric-cryotherapy	21.75 \pm 0.88	53.75 \pm 6.69	165.3 \pm 6.25	20.03 \pm 2.04
Total mean	22.74 \pm 2.10	54.4 \pm 7.54	165.55 \pm 5.28	20.02 \pm 2.55
Sig.	0.5	0.73	0.85	0.71

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Table 2. Plyometric fatigue-induced training

Training Type	Hop on R Foot	Hop on L Foot	Step Vertical Single-leg Jump (Forward)	Forward Jump from Step (R)	Forward Jump from Step (L)	Side Jump from Step (R)	Side Jump from Step (L)	Back Jump From Step (R)	Back Jump From Step (L)
Rep	2	2	2×10	2×10	2×10	2×10	2×10	2×10	2×10

Repetition (Rep), Right (R), Left (L)

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upper legs touched the ground. They were asked not to use their hands while moving. They should put their hands on their backs so that the jump-landing task was performed equally by all subjects [21].

Electromyography (EMG) measurement

The muscle activity of rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius was recorded using a surface EMG device (ME6000-T8 Mega Electronics, Kuopio, Finland)) at a frequency of 1000 Hz during the drop-jump movement. The knee joint angle was measured by Biometrics SG150 electrogoniometer, and the moment of foot contact and foot separation from the ground was recorded by footswitch and mega amplifier. The footswitch was placed under the big toe. All data were recorded in Megawin Software version 3.1-b13. Muscle activity was recorded for 5 s. The placement of electrodes was determined and marked using the surface electromyography for the non-invasive assessment of muscles (SENIAM) method. Data processing was performed in MATLAB software (2010). The data were filtered using a bandpass (20-400 Hz), and then a notch filter (50 Hz) was used to remove noise from the electronic devices. After rectifying, data related to the feedforward phase: pre-activity, 100 ms before the moment of foot contact, and feedback phases: a) eccentric, from the moment of foot contact to the maximum knee joint angle, and b) concentric, from the maximum knee joint angle to the moment of jump, were separated [7, 22], the Maximal Voluntary Activations (MVCs) were determined, and the data were normalized to peak values and calculated as a percentage. Then the root mean

square was calculated for each muscle in each phase. Changes in the range of motion of the knee were recorded by the electro-goniometer, and the data related to the footswitch and the electro-goniometer was also filtered (50 Hz notch filter).

3. Results

According to the results of the analysis of variance (Figure 1), cryotherapy decreased the skin temperature significantly in Post-test 1 and 2 (P=0.00) and decreased temperature changes significantly (P=0.00) compared to other groups without cryotherapy intervention. In addition, the skin temperature was similar in all groups during the pretest (P=0.04), and no significant changes were observed in the control group (P=0.13), indicating the stability of environment temperature. Based on the results of statistical analysis (Tables 3 and 5), changes in muscle signal amplitude in the pre-activity phase (feedforward) and concentric phase (feedback) in the cryotherapy, plyometric, and plyometric-cryotherapy groups did not show a significant change (P>0.05). In the eccentric (feedback) phase, the changes in the mean amplitude of the rectus-femoris muscle (cryotherapy group) and for medial-gastrocnemius muscle (cryotherapy, plyometric, and plyometric-cryotherapy and control groups) were significant (P≤0.05) (Table 4).

4. Discussion

The results showed that cryotherapy exercises alone or after fatigue due to plyometric activity could not change

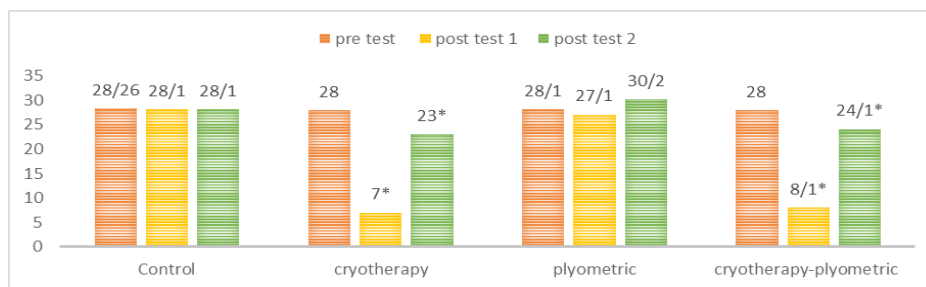


Figure 1. Skin temperature in each group in pretest and Post-test 1 and 2

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* Significant differences with a pretest.

Table 3. Mean±SD and Statistical Results of EMG signal activation (%) in the pre-activation phase of drop jump task

Muscles	Group	Mean±SD			Within-Group (Sig.)
		Pre-test	Post-test		
			1	2	
Rectus femoris	Co (n=10)	6.74±4.47	5.98±2.67	7.67±5.96	0.3
	Cr (10)	8.09±6.02	7.32±5.2	5.73±3.56	0.3
	P (7)	7.3±57.58	6.2±85.55	8.4±95.91	0.3
	CP (8)	5.3±58.43	5.2±74.33	7.3±15.67	0.3
	Between-group (Sig.)	0.87	0.87	0.87	0.12
Biceps femoris	Co (n=10)	14.42±4.01	14.84±7.06	14.64±6.58	0.14
	Cr (10)	14.15±9.14	13.16±8.76	11.52±6.74	0.14
	P (7)	18.4±92.65	16.4±95.16	15.3±36.12	0.14
	CP (8)	9.5±74.61	8.3±64.99	10.6±29.74	0.14
	Between-group (Sig.)	0.11	0.11	0.11	0.27
Tibialis anterior	Co (n =10)	14.03±6.4	11.45±4.38	13.75±5.41	0.11
	Cr (10)	13.5±30.15	12.4±16.31	12.95±4.19	0.11
	P (7)	14.4±15.91	13.3±98.93	13.4±66.61	0.11
	CP (8)	12.4±57.92	12.3±25.31	10.3±54.24	0.11
	Between-group (Sig.)	0.81	0.81	0.81	0.18
Medial gastrocnemius	Co (n=10)	18.62±5.25	14.65±3.05	14.5±3.33	0.45
	Cr (10)	15.17±4.37	16.53±3.61	17.19±4.67	0.45
	P (7)	16.3±54.41	14.4±94.08	15.5±76.35	0.45
	CP (8)	16.4±4.46	15.3±44.24	15.5±78.73	0.45
	Between-group (Sig.)	0.99	0.99	0.99	0.4

Co, control; Cr, cryotherapy; P, plyometric; CP, plyometric-cryotherapy.

muscle activity (rectus femoris, biceps, tibialis anterior, and internal gastrocnemius) in the preactivation (feed-forward) and concentric (feedback) phase in drop-jump movement. However, in the eccentric phase (feedback) of the drop-jump movement, the mean amplitude of the rectus femoris muscle decreased immediately (17%) and after 20 minutes (18%) in the cryotherapy group. Also, the mean amplitude of the medial gastrocnemius muscle decreased immediately after the intervention in all cryotherapy, plyometric, and plyometric-cryotherapy groups. The amount of reduction of medial gastrocnemius muscle activity was more in the plyometric group (15%) than in the other groups. It should be noted that the muscles of the anterior tibialis and biceps femoris in the eccentric stage did not show any changes following

cooling interventions, fatigue-induced plyometric training, and post-exercise cooling.

The effect of cooling on the changes observed in the muscles of the rectus femoris and medial gastrocnemius was similar to that of Schmid et al. (2010). However, in their research, the effect of cooling on muscle activation was not investigated following fatigue training [7].

In another study, they examined post-exercise cryotherapy and found that it improved the EMG function of the knee muscles during maximal muscle contraction (vastus lateralis), although the rectus femoris muscle showed no changes following cooling [23]. However, in another study on the rectus femoris, cryotherapy increased the

Table 4. Mean±SD and statistical results of EMG signal activation (%) in the eccentric phase of drop-jump task

Muscle	Group	Mean±SD			Within-Group (Sig.)
		Pretest	Post-test		
			1	2	
Rectus femoris	Co (n=10)	20.18±6.83	19.22±68.1	19.32±7.03	0.71
	Cr (10)	21.7±9.96	17.81±7.67	17.61±6.99	0.01*
	P (7)	22.5±4.27	23.4±26.75	23.6±59.91	0.4
	CP (8)	13.4±77.38	15.3±86.17	17.5±47.7	0.2
	Between-group (sig)	0.09	0.13	0.27	0.01**
Biceps femoris	Co (n=10)	18.16±3.56	17.22±5.25	16.3±38.07	0.06
	Cr (10)	17.41±8.68	17.49±7.45	17.63±6.77	0.06
	P (7)	23.4±12.43	21.3±45.33	20.4±40.27	0.06
	CP (8)	17.10±80.59	16.7±27.49	15.11±50.39	0.06
	Between-group (Sig.)	0.43	0.43	0.43	0.82
Tibialis anterior	Co (n=10)	17.13±6.19	16.3±64.02	16.17±4.82	0.51
	Cr (10)	19.05±6.90	18.89±6.64	19.14±5.71	0.51
	P (7)	18.3±29.4	18.4±62.98	18.5±45.81	0.51
	CP (8)	19.7±33.31	20.5±57.4	17.4±72.75	0.51
	Between-group (Sig.)	0.66	0.66	0.66	0.79
Medial gastrocnemius	Co (n=10)	17.81±41.79	15.95±5.85	17.66±3.85	0.01***
	Cr (10)	17.34±4.56	16.63±3.47	17.34±4.10	0.01***
	P (7)	22.5±31.06	18.4±84.7	19.4±65.44	0.01***
	CP (8)	14.3±97.79	13.3±68.35	15.6±74.37	0.01***
	Between-group (Sig.)	0.1	0.1	0.1	0.64

Co, control; Cr, cryotherapy; P, plyometric; CP, plyometric-cryotherapy.

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* Significance between pretest and post-test 1 and between pretest and post-test 2.

** Significance of time-group interaction.

*** Significance between pretest and post-test 1.

activity of this muscle as well [6]. In justifying the results of the present study, it seems that knee joint cooling reduces the information of joint and skin proprioceptive receptors to some extent and consequently reduces the motor efferent signals of the muscle.

Decreasing the activity of the rectus femoris muscle due to the cold can reduce the shock absorption role of the muscle in the knee joint, which is mainly responsible for protecting the knee joint against additional loads [24] and the main transmitter of power from the thigh to the knee in jumps [25].

The limitation in proprioceptive activity following the clod application can alter the central neural program and reduce muscle activity in the pre-landing and eccentric phases during a plyometric motion, which may reduce elastic energy in the tendon in the eccentric phase and subsequently reduces functional performance in the concentric phase [7].

Rectus femoris muscle amplitude in the eccentric phase in the plyometric and plyometric-cryotherapy groups did not show significant changes in the present study. This finding shows that using cold after exer-

Table 5. Mean±SD and statistical results of EMG signal activation (%) in the concentric phase of drop jump task

Muscle	Group	Mean±SD			Within-Group (Sig.)
		Pretest	Posttest		
			1	2	
Rectus femoris	Co (n=10)	27.72±4.68	21.97±5.22	23.57±4.07	0.61
	Cr (10)	23.53±3.69	21.67±4.37	21.10±3.57	0.61
	P (7)	22.2±2.84	21.2±68.99	21.1±99.62	0.61
	CP (8)	20.3±90.74	21.4±87.73	23.3±15.91	0.61
	Between-group (Sig.)	0.93	0.93	0.93	0.33
Biceps femoris	Co (n=10)	14.33±3.08	15.87±2.8	16.6±3.88	0.11
	Cr (10)	14.41±2.95	15.79±3.48	15.34±2.78	0.11
	P (7)	16.04±27.08	14.3±74.58	15.4±60.26	0.11
	CP (8)	13.98±4.12	15.4±92.82	15.2±3.62	0.11
	Between-group (Sig.)	0.97	0.97	0.97	0.16
Tibialis anterior	Co (n=10)	14.38±5.75	15.17±5.13	15±5.68	0.68
	Cr (10)	16.10±8.30	16.2±8.32	15.73±8.26	0.68
	P (7)	16.6±99.75	16.6±68.48	17.6±16.31	0.68
	CP (8)	16.7±50.07	14.6±66.5	14.7±77.58	0.68
	Between-group (Sig.)	0.93	0.93	0.93	0.29
Medial gastrocnemius	Co (n=10)	18.89±4.27	19.10±4.01	19.57±4.02	0.53
	Cr (10)	19.75±4.10	20.43±3.68	20.29±3.71	0.53
	P (7)	23.4±14.71	20.3±35.01	21.3±45.44	0.53
	CP (8)	21.4±21.74	21.4±1.08	21.3±84.59	0.53
	Between-group (Sig.)	0.45	0.45	0.45	0.45

Co, control; Cr, cryotherapy; P, plyometric; CP, plyometric-cryotherapy.

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cise may not cause dysfunction of the rectus femoris muscle. Consistent with these results, Ahmadabadi et al. did not observe a significant difference in rectus femoris muscle amplitude due to fatigue induced by plyometric training [26].

The decrease in medial gastrocnemius muscle activity in the cryotherapy and plyometric-cryotherapy groups may be attributed to a change in the firing rate of the skin afferents through reflex mechanisms [27]. Contrary to these results, Halder et al. did not observe significant changes in muscle amplitude after cryotherapy [28].

Since cryotherapy did not change the muscle activity of most of the selected knee muscles, this study can be con-

sistent with some of the other studies which mentioned that long-term cooling (one hour) at different temperatures does not affect knee muscle activity [29, 30].

Internal gastrocnemius muscle activity also decreased following fatigue-induced plyometric training intervention, while other muscles did not show any changes in muscle activity following exercise. It may be due to the higher effect of exercise on this muscle compared to other muscles and causes more fatigue in this muscle because the medial gastrocnemius is a muscle that plays a major role in ankle plantarflexion during jumping movements. Therefore, the decrease in the activity of the internal gastrocnemius muscle in the plyometric group can confirm the nervous fatigue caused by the

plyometric training, which, as a result, reduces the use of muscle motor units [31]. Some other studies have shown the effect of fatigue on the decrease in muscle activity [32, 33] which is associated with an increased chance of anterior cruciate ligament (ACL) injury [34]. The medial gastrocnemius muscle is one of the main muscles in the concentric phase for functional performance. Decreased activity in the eccentric phase may affect energy storage in the eccentric phase and subsequent functional performance in the concentric phase.

This muscle plays a crucial role in absorbing the impact of foot contact by increasing plantarflexion when the knee flexion is reduced. Decreasing muscle activity in the pre-landing phase can increase the risk of knee injuries during foot contact [35]. However, since no change in muscle activation was observed in the pre-activity phase, the decrease in muscle activity in the eccentric phase may negatively affect the lower limb mechanics and consequent injuries. On the other hand, since there was no difference between intervention groups of cryotherapy, plyometric, and plyometric-cryotherapy, it seems that the effect of cold after exercise-induced fatigue adversely affects gastrocnemius muscle activity as much as cold and fatigue conditions alone.

It is worth mentioning that the limitation or weakness of this study was the inability to control the individual differences in terms of nutrition, motivation, or emotional status during testing or the lack of comparing the results with injury cases in similar conditions. However, the strength of this research is the evaluation of cryotherapy effects at different times and after fatigue conditions which are caused by functional plyometric training and not just following fatigue-induced caused by a contraction of a muscle group.

5. Conclusion

The results of the present study showed that cryotherapy alone and following fatigue-induced plyometric exercise had little effect on the function and activity of various muscles around the knee joint and only affected the rectus femoris and medial gastrocnemius muscles to some extent, although the extent of these small changes on the knee joint biomechanics and injury risk is unclear; hence, further studies are needed to achieve comprehensive and definitive results. In particular, it is suggested to evaluate simultaneous EMG and kinematic changes after cryotherapy or functional fatigue condition in healthy or injured cases by considering other lower limb joints.

Ethical Considerations

Compliance with ethical guidelines

All athletes read and signed a written informed consent before testing and completed a detailed injury history form. The study participants were informed about the purpose of the research and its implementation stages. They were also assured of the confidentiality of their information. Moreover, they were allowed to discontinue participation in the study as desired. Finally, if desired, the results of the research would be available to them.

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Authors' contributions

All authors equally contributed to the preparation of this article.

Conflict of interest

The authors declared no conflict of interest.

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