Pharmacophore, 8(6S) 2017, e-1173314,Pages 9

Pharmacophore

ISSN-2229-5402

Journal home page: http://www.pharmacophorejournal.com

Pharmacophore
an International Journal
ISSN 2229-5402

THE EFFECT OF A CORRECTIVE EXERCISE PROTOCOL ON KNEE FLEXION ANGLE AND ELECTROMYOGRAPHIC ACTIVITY OF LOWER EXTREMITY MUSCLES WITH ACL INJURY PREVENTION APPROACH

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ARTICLE INFO

Received:
03th Jun 2017
Accepted:
29th Nov 2017
Available online:
14th Dec 2017

Keywords: *Electromyography, Multi-Component Exercises, Anterior Cruciate Ligament, Flexion Angle, Weight Lifting*

ABSTRACT

Background: the present study aimed to investigate the effect of a corrective exercise protocol on knee flexion angle and electromyographic activity of lower extremity muscles with ACL injury prevention approach.

Method: The present study was quasi-experimental and conducted by pretest-posttest design with two control and experimental groups. 30 healthy male weightlifters were selected as samples according to the inclusion criteria and randomly divided into two experimental and control groups. The experimental group performed the exercises 3 times per week and for 6 weeks. electromyographic activity of muscles and kinematic data of both groups were evaluated before and after implementing the exercises protocol. Dependent t-test was used to compare the results within a group and independent t-test was used to compare the results between the groups at the significance level of 0.05.

Results: the results of statistical tests showed that in the experimental group, electromyographic activity of Vastus lateralis, Vastus medialis, Biceps femoris and Semitendinosus muscles significantly increased in response to corrective exercise program ($P \leq 0.05$) and no significant difference was observed in the control group ($P > 0.05$). After performing the exercises, significant difference was observed between the two experimental and control groups in electromyographic activity of muscles ($P \leq 0.05$). Also, significant reduction in the co-contraction level of quadriceps/hamstring ratio (Q: H) in the experimental group was observed to the control group ($P \leq 0.05$). Significant difference was observed between the two groups in the knee flexion angle and the results showed a significant increase in knee flexion angle in the experimental group ($P \leq 0.05$).

Conclusion: the results of the present study showed that using the mentioned exercise protocol can establish balance in Q:H ratio and as its result, knee flexion angle increases. Accordingly, it is recommended to use combined exercises in ACL injury prevention programs.

To Cite This Article: Abolfazl Khouri, Nader Rahnama, Hasan Daneshmandi, Mohammad Hossein Alizadeh, (2017), “the effect of a corrective exercise protocol on knee flexion angle and electromyographic activity of lower extremity muscles with acl injury prevention approach”, ***Pharmacophore, 8(6S),*** *e-1173314.*

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Introduction

Researchers in sports medicine are widely investigating the biomechanical and physiological indices of the lower extremity of athletes when performing exercises, with the aim of identifying factors causing knee injury. The majority of knee injuries (45%) are related to knee ligament injuries, especially the anterior cruciate ligament (ACL). About %70 of ACL injuries are caused by noncontact mechanisms (1). Hence, more research in recent years has been specifically focused on the assessment of the noncontact lower extremity risk factors that can predispose a person to ACL injury.

Weightlifting is a competitive sport based on dynamic power and muscular strength, and consists of two movements of snatch and clean and jerk. In a competitive form, weightlifting is a joint movement sequence including hip extension, plantar ankle flexion, knee extension and trunk extension and the general model of the lower extremity movement during the execution of a full lift is: extension-flexion-extension (2).

The results of the research on the weightlifting league in Iran showed that in weightlifting, the most injuries caused during performing exercises are related to the lower extremities (%45.45) and the maximum cost of the total costs imposed by injuries (direct and indirect costs) is assigned to the knee. Among the knee injuries, ACL injury imposes the maximum cost to the athlete and the club and has a rehab period of about 6 to 9 months (3).

When snatch and clean and jerk movements are performed correctly, the motion resample jump movement patterns that involves quick explosive movements (4). The results of the studies showed that in the noncontact ACL injury, the body is in a position where the flexion of the knee, hip and trunk is reduced. This position contributes to a decrease in motion on the Sagittal plane, which can play a role of risk factor for ACL injury. Reduction of knee motion in the sagittal plane during jumping, landing and suddenly direction change due to effect of knee flexion on contact force can cause ACL injury (5).

The flexion angle can affect the risk of ACL injury by modifying the loading. In this regard, the researchers seek to determine the neuromuscular characteristics affecting the knee flexion angle. Quadriceps and hamstrings are potentially stabilizing the knee due to their torque arms. A balanced contraction of quadriceps and hamstrings in the sagittal and frontal planes leads to increased joint compression and subsequently increased knee joint stability. The muscular co-contraction allows loading of the knee joint in the sagittal and frontal planes to be evenly distributed between the tibia joint surfaces and therefore knee joint loading is absorbed and the force is not transmitted to the joint ligament limiters and the ligaments are protected (6,7). Meyer et al. (2004) have reported that neuromuscular factors are modifiable risk factors for ACL injury and the study of these factors is focused on the hypothesis that the risk factors of injury in an athlete are related to the neuromuscular defects (8).

Researchers believe that the occurrence of ACL injuries during performing exercises can be reduced through training intervention programs focused on optimizing neuromuscular activity, increasing the angle of sagittal plane of the knee, and subsequently resisting the loads applied to the sagittal and frontal planes. Most of these programs incorporate various risk factor correction methods (kinematic changes, strength exercise, plyometric exercises, balance exercises, feedback exercises, etc.) (9-13).

The activity of the muscle controlling sagittal plane motion of the knee and the hip has the same effect as the knee flexion during dynamic activities such as jump landing. The more constriction of the hamstring and gastrocnemius muscles can cause more internal torque of knee flexion and thereby positioning the knee in the greater flexion during landing. In contrast, the more constriction of the quadriceps and gluteus maximums muscles can cause more internal torque of knee and hip extension and provide a direct physical position (lower knee and hip flexion). Also, the relative activation of the agonist and antagonist muscles can be a factor affecting the knee flexion. Therefore, the co-contraction of quadriceps /hamstring ratio (Q: H) can be of particular importance, because these are the first muscles controlling the internal pure torque of flexion-extension. Researchers have reported that individuals who have a smaller flexion angle during their landing, have more quadriceps activity. Increased Q:H ratio and overcoming the quadriceps activity results in higher load on ACL and increased injury risk of it due to its effect on knee flexion (14,15).

Considering the importance of modifying the neuromuscular risk factors to reduce the knee injuries and given that the large part of knee injuries are associated with ACL injury in terms of prevalence and cost and researchers have not reached a consensus on a specific method for adjusting these risk factors to prevent ACL injury due to its complexity and its multidimensional nature despite the many studies have been performed in the field of ACL injury prevention programs and since no study has been specifically conducted on male weightlifter in order to investigate these variable in Iran and abroad, it seems necessary to investigate the effect of an ACL injury prevention training program in order to take a step to reduce this injury among weightlifters. For this reason, the present study aimed to investigate the effect of a corrective exercise protocol on knee flexion angle and electromyographic activity of lower extremity muscles with ACL injury prevention approach.

Method

The present study was a quasi-experimental study and of correlational research which conducted in the Sport Injury and Corrective Exercise Laboratory, Faculty of Physical Education and Sport Sciences, Guilan University. Population included all active healthy adult weightlifters in the 21 to 30 age group. Exclusion criteria were to have lower extremities abnormalities (such as Genu Valgum, Genu Varum, femoral anteversion, tibial rotation, flat feet), history of ACL injury, history of participation in previous injury prevention programs, history of musculoskeletal injuries, skeletal, impaired sensory input and motor function. Inclusion criteria were having a record of being invited to a national team or having at least one national championship, having experience of being active for 5 years and doing exercises at least 3 sessions per week. The samples (n=30) were selected according to the exclusion and inclusion criteria and were randomly divided into two experimental and control groups (each group, n=15).

The participants were fully made aware of the process of conducting the research and its conditions, and then the consent forms of participating in the research were received from them. Before starting the exercises, the participants' demographic and anthropometric information was recorded and measured and then their body mass index (BMI) was calculated by dividing the weight by squared height (kg/m^2). Independent variable of the present study is corrective exercise program and dependent variables are electromyographic activities of some quadriceps and hamstring muscles, co-contraction of the quadriceps and the hamstring (Q:H ratio) and their flexion angles.

The exercise protocol was a combination of feedback, strength, balance, and plyometric exercises, in other words, it included corrective multi-component exercises (8,12,16). The exercises were performed for 6 weeks,3 sessions per weak for 90-min. The participants warmed up for 10 minutes by Swedish stretching exercises focusing on the leg and cardiovascular activity (slow running, long knee, power jump) before starting exercises and also, they were cooled down after doing exercises (17).

The return phase of clean and jerk technique was used as a functional test for assessing changes in electromyographic activity of the muscles. It was explained to the participant how the test is done and 70% of one rep max of each person was considered for measurement (4.18).

Electromyography device ME6000 (made by Mega Electronic Ltd., Finland) was used to record the activity of anterior and posterior hip muscles. The muscles studied were Vastus lateralis, Vastus medialis, Biceps femoris and Semitendinosus muscles. The locations of the electrodes (the anterior and posterior part of the hip) were grinded softly and completely cleaned with cotton and alcohol. This reduces the electrical impedance at the attachment points of lids and reduces the skin's superficial resistance and the lids are attached to the skin more easily and better. The electrodes used in this study were single-pole ECGs made by the Skin-Tekt Company, and also made of silver alloy with Silver Chloride.

The locations of the electrodes were determined according to the SENIAM instruction, as follows; external hamstring muscle: Half of the distance between the Ischial tuberosity and the lateral epicondyle of Tibia, Semitendinosus muscle: half of the distance between the Ischial tuberculosis and the medial epicondyle of Tibia, Vastus lateralis: two thirds on a line from the upper anterolateral to the outer side of the patella, Vastus Medialis: 80% on the line from the anterolateral thoracic area to the knee joint space (16). In order to measure the amount of electrical activity of the muscles, the root mean square (RMS) was used in the window widths of 20 milliseconds. The muscle activity was calculated 200 milliseconds before and after full flexion. For each subject, 2 attempts were used with minimum differences in muscle activation in order to calculate the mean and analyze the data (19). Electromyographic signal was processed using Megawin software. After these steps, Maximal Voluntary Isometric Contraction (MVIC) test of muscles was performed for 5 seconds to standardize the electromyographic data. The MVIC of the quadricep muscles was determined while the participant was performing the movement of opening the knee with the dominant foot on the test bed. For this purpose, after fixation of the anterior part of the participant's leg, while the resistance was applied in this area, the participant was asked to apply force with maximum power. To determine the MVIC of the hamstring muscles, the participant lied in a prone position and flexed the upper leg to 90 degrees. Then, while the posterior part of the leg was fixed with the strip, and resistance was applied to the area, the participant was asked to apply force with maximum power (20). In this way, the activity of the muscle was normalized using MVIC.

The total ratio of the activity of quadricep muscles to hamstring (Q: H) was calculated by dividing the total median and lateral quadricep muscles activity by mean activity of lateral and medial hamstring muscles. The ratio close to 1 represents the balance between the activities of the quadriceps and hamstring muscles (21).

In order to record the kinematic data of the participant' lower extremities during the performance of functional test, the reflective markers were used on the outer ankle, the center of patella, in the line of the big Trochanter of the hip, the middle of the two ankles, the protuberance of the hip bone (behind the patella) and in the line of the anterior inferior iliac spine of the participants. The movement of reflective markers was recorded using two high speed cameras (Casio made in Japan, model: CASIO-Ex-F1) with the capable of shooting at 300 frames per second, and external memory of 16GB. These cameras were placed on a tripod at a height of 102.22 cm and a distance of 366.75 cm from the place where the participant was in and the motion was recorded from both the lateral and anterior views during the functional test (22). The participants were taught to stand calm and to coordinate himself with the coordinates of the cameras as closely as possible. After performing the functional test, the data was analyzed using Kinova software. In order to analyze the data obtained from the cameras, the image related to the frame showing the maximum knee flexion (full flexion) was selected by investigating the frames and the flexion angle was calculated using Kinova software.

SPSS V.21 software was used to analyze the statistical data. Kolmogorov-Smirnov test was used to examine the normality of data distribution. Then, dependent t-test was used to compare the results within a group and independent t-test was used to compare the results between the groups. Significance level was considered 0.05 (P-value<0.05).

Results

Demographic characteristics of participant are listed in experimental and control groups in Table1.

The mean and standard deviation of activity of muscles (in %MVCI) of participants before and after implementing the exercises protocol are listed in Table2.

As shown in Table2, the results of the dependent t-test showed that in the experimental group, the electromyographic activity of Vastus lateralis, Vastus medialis, Biceps femoris and Semitendinosus muscles of active healthy adult weightlifters in the experimental group increased in response to 6-week corrective exercises program (P≤0.05) while no significant change was observed in the control group (P>0.05).

Table1. The participants' demographic characteristics

Group	**Experimental group (n=15)**	**Control group (n=15)**
Variable	mean±standard deviation	mean±standard deviation
Age(year)	26.47±2.30	25.87±2.22
Height(cm)	176.03±7.41	172.53±5.90
Weight (kg)	87±27.24	91.58±16.71
BMI (kg/m^2)	27.83±7.19	30.76±4.9

Table2. The results of dependent t-test of activity level of participants' muscles before and after implementing the exercises program (%MVIC)

	Group	**Test**	**mean±standard deviation**	**Sig.**
Vastus lateralis	Experimental	Pretest	71.37±13.02	0.034*
		posttest	80.08±3.76	
	Control	Pretest	76.80±3.07	0.58
		posttest	77.48±3.61	
Vastus medialis	Experimental	Pretest	64.34±3.98	0.000*
		posttest	76.31±3.62	
	Control	Pretest	63.12±3.04	0.21
		posttest	64.52±2.62	
Biceps femoris	Experimental	Pretest	36.15±2.00	0.000*
		posttest	46.06±2.29	
	Control	Pretest	39.08±2.99	0.46
		posttest	38.20±3.59	

Semitendinosus	Experimental	Pretest	28.96±3.80	0.000*
		posttest	35.44±1.83	
	Control	Pretest	29.44±1.56	0.69
		posttest	29.71±1.83	

p≤0.05*

The results of independent t-test showed significant differences between the experimental and control groups in response to exercises program for the activity of Vastus lateralis (P=0.000), Vastus medialis (P=0.000), Biceps femoris (P=0.000) and Semitendinosus muscles (P=0.000). In the experimental group, all the muscles showed greater activity of the muscles compared to the control group so that in the experimental group, electromyographic activity of Vastus lateralis, Vastus medialis, Biceps femoris and Semitendinosus muscles of active healthy male weightlifters increased as much as %3.32, %11.79, %7.86 and %5.73 compared to the control group.

Figure 1 shows the effect of the exercises protocol on the flexion angle in the two control and experimental groups. As shown, the results of statistical test showed significant increase in knee flexion angle in the experimental group (P≤0.05) while no significant change was observed in the control group (P>0.05). Also, the results of independent t-test showed that the changes in the knee flexion angle of weightlifters of the experimental group were significantly greater compared to the control group.

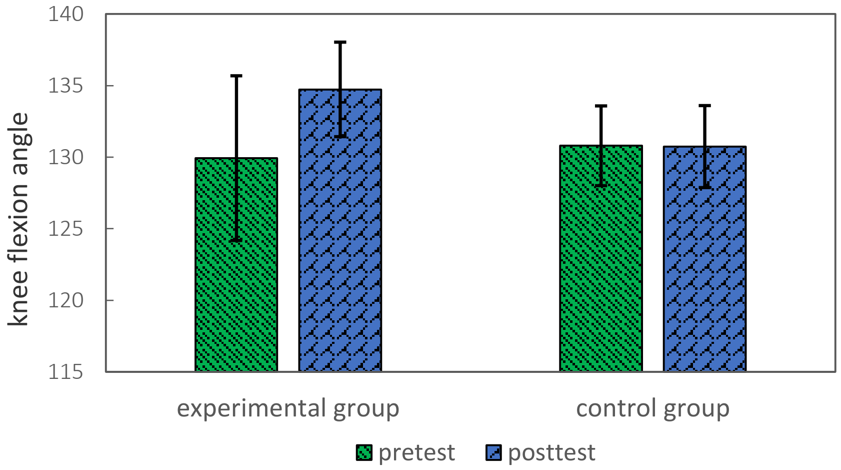

Figure 1. The effect of the exercises program on the knee flexion angle in both experimental and control groups

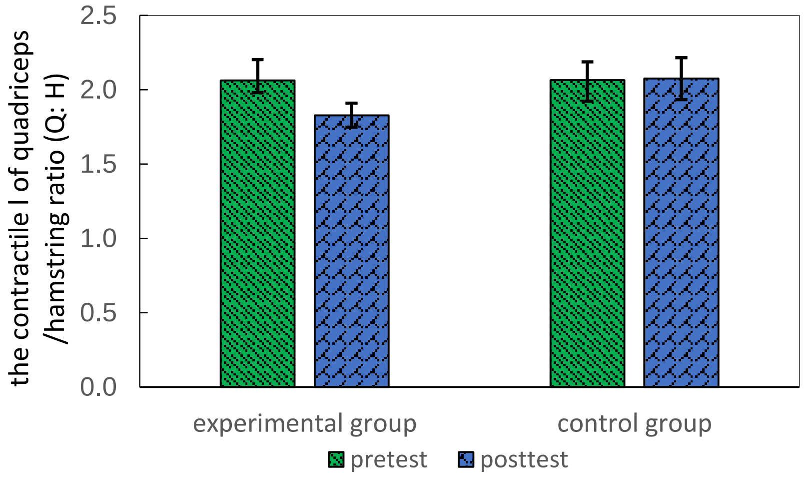

Figure 2. The effect of the corrective exercises program on the electromyographic activity of quadriceps: hamstring muscles in both experimental and control groups.

Figure 2 shows the effect of the exercises program on the total quadriceps: hamstring ratio in both experimental and control groups. The results of dependent t-test showed that the total quadriceps: hamstring ratio of active healthy male weightlifters of the experimental group significantly reduced in response to the corrective exercises program ($P \leq 0.05$) while no significant change was observed in the control group ($P > 0.05$).

Discussion

Comparing the two groups in terms of electromyographic activity of muscles after performing the exercises showed the significant effect of exercises protocol on the activity of the participants' Vastus lateralis, Vastus medialis, Biceps femoris and Semitendinosus muscles in response to 6-week corrective exercises program in the experimental group and no significant change was observed in the control group. Also, in both groups, quadricep muscles (Vastus lateralis and Vastus medialis) had more electromyographic activity compared to hamstring muscles (Biceps femoris and Semitendinosus) and these results are consistent with the results of the studies by Escamilla et al. (2001), Hwang et al. (2009) and Yavuz et al. (2015) (18, 23, 24).

Since the hamstring muscles are two-joint muscles, their electromyographic activity was less than compared to quadricep muscles and this means these muscles influence the motion in both joints simultaneously. Therefore, during the landing-jumping and squat movements, the co-operation of the hamstring muscles with Gluteus maximums through involuntary contraction or controlled flexion in the hip reduces the activity of these muscles to control and stabilize the knee joint. The decrease in the activity of hamstring muscles in the situations with greater extension can be explained by the interaction of muscle length and the anatomical position of the tendons. When the knee is in full extension, the hamstring tendons are very close to the knee joint, which provides a very weak lever arm for flexion and this is a sign of its weakness as a knee flexor and a creator of posterior stretch. In addition, these muscles should function in the knee and hip joints simultaneously and the interaction of these two factors may cause low electromyographic activity. On the other hand, the domination of the quadriceps causes an imbalance between the strength and the patterns of activation of the hamstring and quadricep muscles. Excessive emphasis on the quadricep muscles in exercises can lead to a large imbalance in the strength between quadriceps and hamstring muscles and the activity pattern that is associated with the dominance of the quadricep muscles, leading to significant anterior displacement in the tibia and stress on the ACL. Therefore, reduced activity of hamstring muscles to quadricep muscles increases ACL injury. Imbalance in muscle activity can be assessed through the Q:H ratio. Simultaneous activity of active muscles around the joint is defined as Q:H ratio (25, 26, 27, 28).

According to the results of the study, significant difference was observed between the experimental and control groups in terms of total Q:H ratio. The results showed that in response to corrective exercise protocol, the Q:H ratio in the experimental group reduced and this shows that this ratio became more balanced but in the control group, no significant change in this ratio was observed. Quadricep muscles are the antagonists of hamstring muscles and depending on the knee flexion angle, they create a force within a range from 2000 to 8000 N during the maximum quadriceps voluntary contraction, therefore, if hamstring muscles do not resist with this force, it will cause strain on the ACL and this can be of the factors causing injuries (29, 30). Quadricep muscles strengthening regardless of hamstring muscles contraction to counteract the anterior tibia transitional force, which applies a high tensile load on the ACL, can be one of the causes of injury (29, 30). Baratta et al. (1988) and DeMorat et al. (2004) stated that people who have very large quadricep muscles have less contraction of the hamstring muscles due to the inhibitory involving antagonistic muscle (27,31,32). Also, the results of a study by Walsh et al. (2012) showed that in designing interventional exercises programs to prevent ACL injury, increased activity of hamstring muscles is effective in reducing level of Q:H ratio and positioning the knee joint in a more stable position (33).

The results of the present study showed that using corrective exercises protocol is effective in changing participants' maximum flexion angle. Compared to the control group, the changes in flexion angle in the experimental group were significant so that the participants can significantly increase their maximum flexion angle and this reduced the risk of ACL injury in smaller flexion angles. It should be noted that correcting flexion angle significantly reduces the vertical response force of the surface as well as the flexion torque and reduction in these two factors reduces the risk of ACL injury during jumping-landing activities (34). This result is consistent with the results of the studies by Myer et al. (2005), Lim et al. (2009) and Chappell et al. (2008) (12, 14, 35).

Increase in flexion angle during landing-jumping has been one of the first improvement in the interventional exercises programs and previous studies showed that increase in flexion angle during landing-jumping reduces the risk of ACL injury. Increase in flexion angle is an efficient intervention because favorably changes the risk factors related to ACL injury (36, 37, 38). Understanding exercise of flexion angle modification program is easy for people and it can be achieved and practiced with performing least exercises. Its anther advantage is that the measurement of the flexion angle can be done simply by various laboratory tools.

Myer et al. (2005) have reported the effect of a comprehensive 6-week neuromuscular exercises program on the function and biomechanics of female athletes' lower extremities and increased motion range of knee flexion. They used a protocol which was similar to the weightlifting movements in terms of motion pattern. In these combined exercises, lower extremities were involved and they helped explosive movements.

Lim et al. (2009), in their study reported the increased knee flexion angle and reduced Q:H ratio after performing ACL injury preventive exercises in female basketball women.

Chappell et al. (2008) have found that primary knee flexion and maximum knee flexion angle increase during landing-jumping after performing low-level neuromuscular exercises in female basketball and soccer players.

Contraction of the quadricep muscles apply an anterior shear force on the tibia through the tendon of patella. When the range of knee flexion has reduced and hamstring doesn't apply enough posterior shear force, this shear force can cause ACL injury. Limiting the anterior tibia displacement by hamstring occurs at all angles of the knee flexion, except for the angle near full flexion. The ACL strain increases in the knee flexion angle of 45-degree or smaller and reduced in the knee flexion angle of 60 degrees or greater (39). Olsen et al. (2004), in their study, reported that ACL injury occurs in the small knee flexion angle (40). At these small flexion angles, the quadriceps, in contrast to hamstrings, contract in order to stretch the anterior tibia. While in larger flexion angles, the quadricep muscles contract as synergy in order to stretch the posterior tibia muscles and as a result, the effect of the strain on ACL is reduced (41). These findings suggest that in designing ACL injury prevention programs, increase in the flexion angle, balancing the Q:H Ratio and in other words, increase in the hamstring activity in the interaction with the quadriceps should be considered and this places the knee in a more flexible position while movement. According to the results of present study, the used exercise protocol has an effective role in increasing the flexion angle and balancing Q: H ratio. A more balanced Q:H ration increases the flexion angle and this can reduce the risk of ACL injury. The results showed the effects of exercises on the increased EMG activity of quadriceps and hamstring muscles. Increased activity increases the stiffness of muscle. Due to the increased stiffness of muscles, the loads applied on the joints are absorbed into the tenomuscular units to be transmitted through the joint structures. Increased activity of muscles is a dynamic inhibitory mechanism that can protect ligation-capsular structures against contraction (42, 43). Therefore, it seems exercise protocol, which is a combination of feedback, strength, balance and plyometric exercises, is a good choice to improve the kinematic and neuromuscular risk factors, and subsequently to reduce ACL injury.

Acknowledgement

Hereby, we thank the authorities of the faculty of Physical Education at the Guilan University and all the participants who help us to conduct this study.

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