Research Paper

Effects of TRX Suspension Training on Muscle Activity Onset and Its Potential Role in Anterior Cruciate Ligament Injury Prevention Among Female Athletes With Trunk Dominance Impairment

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ABSTRACT

Purpose: Trunk dominance impairment (TDI) is a major risk factor for anterior cruciate ligament (ACL) injury in females. The purpose of this study was to investigate the effect of six weeks of total body resistance exercise (TRX) suspension training on muscle activity onset in selected lumbo-pelvic-hip muscles in female athletes with TDI.

Methods: A semi-experimental design was employed to investigate the effects of TRX suspension training on muscle activity onset in 30 female athletes. Participants were recruited using purposive and convenience sampling. The tuck jump test identified athletes with TDI. Surface electromyography (EMG) recorded muscle activity onset of the transverse abdominis, external oblique, quadratus lumborum, gluteus maximus, and gluteus medius during a single-leg jump-landing task. Following pre-testing, the training group engaged in a six-week TRX suspension training program, consisting of three 30-45 minute sessions per week. A mixed-design ANOVA analyzed the data.

Results: The results of the mixed-design ANOVA revealed that in the post-test phase, muscle activity onset improved only in the training group ($P<0.05$), while there was no significant difference in muscle activity onset between pre-test and post-test phases in the control group ($P>0.05$).

Conclusion: TRX suspension training, due to its unstable nature, requires timely and anticipatory muscle activation. Therefore, it can be claimed that this training method has the potential to improve the muscle activity onset of lumbo-pelvic-hip muscles in female athletes with TDI. Hence, TRX suspension training used in this study is recommended to prevent ACL injury in female athletes with TDI.

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Highlights

● Improved Muscle Activation Timing: Six weeks of TRX suspension training significantly improved the muscle activity onset of key lumbo-pelvic-hip muscles (transversus abdominis, external oblique, quadratus lumborum, gluteus maximus, gluteus medius) in female athletes with TDI.

● Potential for ACL Injury Prevention: By enhancing anticipatory muscle activation and neuromuscular control, TRX training may reduce the risk of ACL injuries in female athletes.

● TRX Training as a Functional Tool: Due to its unstable environment and sport-specific movement simulation, TRX suspension training is an effective preventive intervention targeting neuromuscular deficits associated with ACL injuries.

Plain Language Summary

Anterior cruciate ligament (ACL) injuries are common among female athletes and can lead to long-term physical, emotional, and financial challenges. One of the key risk factors for ACL injury is trunk dominance impairment (TDI), which involves poor control of the trunk during athletic movements like jumping and landing. This can cause dangerous movements in the lower limbs, particularly at the knee joint. Since early muscle activation in the core and hips is essential for safe and stable movement, researchers wanted to see whether a specific type of training—TRX suspension training—could improve muscle response in female athletes with TDI. What did the researchers do? Thirty female athletes aged 18-25 were split into two groups: a training group and a control group. The training group participated in TRX suspension training three times a week for six weeks, while the control group did not receive any special intervention. Researchers used sensors to measure how quickly certain muscles (in the core and hip areas) activated during a single-leg landing task, both before and after the training period. What did they find? Only the athletes who completed the TRX training showed significant improvement in the timing of muscle activation. These changes were not observed in the control group. The improved timing helps the body prepare for landing and other dynamic actions, reducing the chances of abnormal knee movement that can lead to ACL injuries. What do these results mean? This study suggests that TRX suspension training can enhance neuromuscular control in female athletes with poor trunk stability, helping prevent ACL injuries. Coaches and therapists might consider including TRX exercises in training or rehabilitation programs, especially for female athletes in high-risk sports like basketball and handball.

Introduction

Anterior cruciate ligament (ACL) injuries represent a substantial proportion of sports-related knee injuries [1]. The demographic most affected by ACL injuries is young athletes aged 15 to 25. One study documented an incidence rate of 400 cases per 100,000 athlete-years in this population [2]. Beyond the substantial financial burden of treatment, ACL injury can result in prolonged absence from sports and significant psychological and physical stress, as it is often referred to as the "athlete's nightmare" [1]. Therefore, with the increasing popularity of sports among women and the serious consequences of ACL injury, preventive measures against this injury are becoming increasingly necessary. Identifying the main causes and mechanisms of ACL injury is the first step, as it will help to design preventive measures and programs. Studies have revealed gender disparities in neuromuscular performance, with women demonstrating deficits relative to men, which makes them more susceptible to injury [3]. Among these neuromuscular deficits, trunk dominance impairment (TDI) is one of the most important risk factors for ACL injury in women [4]. Some studies have even identified it as the most important predictor of knee joint injury [5]. Compared to men, women exhibit poorer trunk control capabilities during landing maneuvers, particularly in the sagittal and frontal planes [5]. Additionally, injured women have been reported to exhibit more lateral trunk motion and knee valgus during landing compared to healthy women [4].

Abnormal muscle activation patterns in the trunk and lower extremities can be characterized as a feature of neuromuscular system impairment [6]. Delayed activation of trunk muscles during sports performance tasks can affect trunk and lower extremity alignment and mechanics, ultimately leading to the application of harmful forces to the passive structures of the knee joint and resulting in ACL injury [7]. Biomechanical studies of women's functional movements have shown that the inability of the lumbo-pelvic-hip complex muscles to maintain trunk position leads to unwanted movements, especially in the frontal plane, which can result in uneven distribution of ground reaction forces throughout the trunk and increase the likelihood of knee valgus [8]. Biomechanical research has shown that early activation of the lumbo-pelvic-hip complex muscles before external perturbations stabilizes the trunk and lumbo-pelvic-hip complex and prevents the generation of large and risky torques at the knee joint [9, 10]. Therefore, timing and appropriate activation of the central stabilizing muscles, as well as the muscles of the lumbo-pelvic-hip complex, such as the gluteus maximus and gluteus medius, play an important role in establishing proximal-to-distal control and preventing knee valgus and subsequent ACL injury [11].

It has been shown that early activation of the muscles that control trunk and hip movements before the application of harmful forces to the lower extremities enhances muscle feedforward activity and improves muscle feedback activity through proper spindle function, thereby reducing the risk of injurious movements in the lumbo-pelvic-hip complex and lower extremity joints [12]. Women with TDI have delayed activation of the central stabilizing muscles and the lumbo-pelvic-hip complex [13]. This increases the likelihood of the trunk moving out of alignment and subsequently knee valgus, which is the primary mechanism of ACL injury [9]. It is important to note that this muscle activation pattern can be modified and corrected with preventive functional training [7, 13].

Female athletes are at a higher risk of ACL injuries due to neuromuscular deficits, such as delayed muscle activation and impaired trunk stability. In recent years, researchers have focused on one type of functional training that has a significant impact on activating not only the muscles of the target joint but also the central stabilizing muscles and trunk control [14, 15]. Total body resistance exercise (TRX) suspension training uniquely targets neuromuscular deficits by engaging core and stabilizing muscles in an unstable environment, promoting anticipatory muscle activation. These attributes make it particularly effective in addressing TDIs, a key risk factor for ACL injuries in female athletes. By emphasizing proximal-to-distal control, TRX training aids in mitigating knee valgus and stabilizing lumbo-pelvic-hip mechanics, crucial for ACL injury prevention [15, 16]. Currently, suspension training systems using TRX have become popular due to their small footprint, portability, and ability to perform a variety of exercises. Due to their functional nature, they are popular with sports coaches, physiotherapists, and sports therapists [17]. Another advantage of TRX suspension training is the ability to provide verbal and visual feedback to correct movement errors and improve the execution of functional movements, such as landing [17]. Although previous studies have demonstrated the benefits of TRX training for improving balance, proprioception, and strength [14, 15], there is limited evidence of its impact on electromyographic activation timing, particularly in female athletes with TDIs. Moreover, most research focuses on performance metrics, such as jump height or sprint speed, neglecting the neuromuscular mechanisms underlying injury prevention. This study addressed these gaps by examining the effects of TRX on muscle activity onset, a critical factor in mitigating ACL injury risk.

On the other hand, a review of the literature on suspension training using TRX shows that research has mainly focused on the effect of this training method on variables other than electromyographic variables of muscles, such as pain, performance, and muscle strength [15, 16]. Given the rising popularity of TRX suspension training in sports, its potential to prevent ACL injuries warrants investigation. The study hypothesized that a six-week TRX suspension training program will significantly improve muscle activity onset in lumbo-pelvic-hip muscles in female athletes with TDI, thereby contributing to ACL injury prevention.

Materials and Methods

Research design

This study employed a quasi-experimental design, comparing a training group and a control group using pre- and post-intervention assessments.

Participant

The study population consisted of female athletes from basketball and handball teams. The study sample consisted of 30 members of the statistical population with an age range of 18 to 25 years who met the inclusion criteria for participation in the study. Sample size determination was based on a 95% confidence level and 80% statistical power, referencing a previous study that investigated similar variables [13]. The minimum required sample size was calculated as 13 per group. To account for potential dropouts, the sample size was increased to 15 per group. The study samples were purposefully selected

Figure 1. Tuck-jump test.

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from among the active students in the handball and basketball teams of universities in Tehran. Demographic factors, including age, height, weight, and body mass index (BMI) were equivalent between the two groups.

The inclusion criteria were female gender, regular sports history in one of the two sports of basketball and handball (at least three consecutive years and two sessions per week), TDI (based on the results of the tuck-jump test), an age range between 18 and 25 years, normal body composition index (18 to 25), no history of surgery or injuries to the lower trunk and extremities, no history of low back pain in the past year, no participation in TRX training and other exercise interventions with an injury prevention approach in the past year. Participants were excluded if they withdrew consent, experienced excessive pain during testing, failed to adequately participate in the study as determined by the researcher, did not complete the post-test within one week of training completion, missed two consecutive training sessions, or consumed sedatives or alcohol within 48 hours of testing.

Tuck-jump test procedure

This test is used to identify individuals with TDI during functional tasks [7]. It is a highly valid method for identifying individuals with TDI and maps multiple biomechanical factors. The advantage of this method is the use of recorded videos to provide feedback and verbal feedback to correct technique and thus prevent injurious movements in the trunk and lower extremities [18]. Accordingly, in this study, individuals who were unable to land at the starting point of the jump, whose thighs were not parallel to each other and parallel to the ground at the peak of the jump, and who performed jumps with interruptions for 10 seconds were identified as having TDI.

Participants performed 10 consecutive tuck jumps, aiming to achieve maximum knee height and ensure their thighs were parallel to the ground at the peak of the jump. Video analysis using Kinovea was conducted from two camera angles. Individuals who failed to maintain a starting position, achieve a parallel thigh position, or perform uninterrupted jumps for 10 seconds were classified as having TDI [7, 19] (Figure 1).

After selecting the subjects based on the inclusion and exclusion criteria and dividing them randomly into two control and experimental groups, and providing complete explanations and general information on the research process and how to perform the research tests, they were asked to be present at the Research Laboratory of the Physical Education Research Institute at the appointed time and according to the scheduled table.

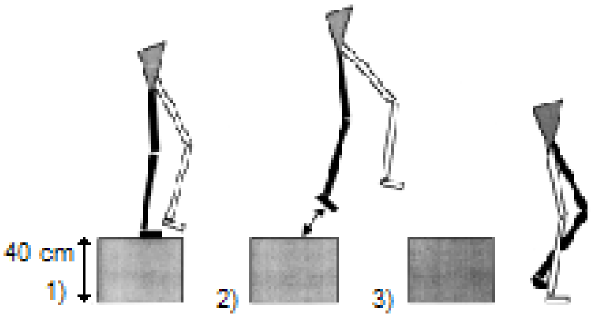

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Figure 2. Landing technique: (1) The subject stands on the platform with the non-test leg; (2) The subject jumps off the platform with the non-test leg; (3) The subject lands on the test leg (white leg in the image) in the center of the foot switch.

Subject preparation

Upon arrival at the laboratory, subjects underwent initial preparations, including wearing appropriate sportswear and trimming excess hair at the electrode attachment sites for electromyography (EMG). General information was collected and anthropometric measurements were taken. Subjects were then asked to cycle on an ergometer for 5 minutes, followed by general warm-up and stretching exercises.

Electrode placement

EMG electrodes were placed on the skin to record the onset of muscle activity in the transversus abdominis, external oblique, quadratus lumborum, gluteus maximus, and gluteus medius muscles. Disposable electrodes with a 1-cm diameter conductive surface were used. Electrode placement was performed using a bipolar technique with an inter-electrode center-to-center distance of 20 mm [7]. The European standard was followed to determine the electrode attachment sites. To identify the exact electrode placement, bony landmarks were palpated and maximal isometric muscle contractions were performed. The electrodes were then adhered to the skin along the muscle fibers[7].

Following electrode placement, participants received detailed instructions on the single-leg jump and landing task. A practice session was conducted to familiarize them with the procedure. Subsequently, with the EMG device activated, participants executed five single-leg jumps and landings, separated by 30-second rest periods.

Single-leg jump and landing task

Neuromuscular impairments are often evident during dynamic and functional tasks, such as jumping and landing. Landing from a height of 40 cm effectively challenges the lumbo-pelvic-hip complex and mimics the anterior cruciate ligament (ACL) injury mechanism. Therefore, in this study, the single-leg jump and landing task was used to simulate the ACL injury mechanism and investigate the EMG indices of the muscles during this movement.

To perform the single-leg jump and landing task, subjects were instructed to stand on a 40-cm step, as shown in Figure 2, with their hands placed on their iliac crests. They were asked to flex the test leg (dominant leg) at the knee and keep it relaxed and free while standing on the opposite leg (non-dominant leg) on the step opposite the foot switch. Subjects were then asked to jump upwards by 5 cm and land on the test leg (dominant leg) in the center of the foot switch, maintaining balance for 3 seconds. Each subject performed this task five times, and the average of three correct repetitions was used to calculate the muscle EMG indices [7, 13].

Muscle activity onset

Muscle activity onset was determined through EMG signal analysis. Initially, the EMG signal was rectified. Subsequently, a threshold, calculated as three times the baseline standard deviation, was established to identify the start of muscle activation. Muscle activity onset was defined as the point, at which the EMG signal consistently exceeded this threshold for a minimum of 25 milliseconds [20]. In this study, this method was used during the 300 milliseconds before foot contact with the ground. To perform these calculations, the files recorded in the Megawin software were first converted to ASCII format and then analyzed in the MATLAB program. The EMG signals were processed through a 50 Hz notch filter in the MATLAB environment, which was developed by an electronics specialist, and the aforementioned considerations were used to detect the muscle activity onset.

Training protocol

After completing the pre-test, the training group subjects underwent six weeks of suspension training using TRX [17]. The training sessions were conducted three times per week, with each session lasting between 30 and 45 minutes. During this period, they were instructed not to perform any other exercise that could affect the research results. The control group was also asked not to perform any exercise that focused on the core stabilizers and lower extremity muscles during these six weeks. However, all subjects were allowed to continue their normal daily activities but were advised to avoid exercises that could affect the research results. After the training period, all subjects in both groups performed all of the pre-test measures again in the post-test.

Statistical analysis

Demographic characteristics were compared using independent t-tests. Data normality was assessed through the Shapiro-Wilk test. The impact of training on muscle onset times was examined using a mixed-design repeated measures ANOVA. Effect sizes were determined using eta-squared (η^2), with values of 0.01, 0.06, and 0.14 representing small, medium, and large effects, respectively [21]. Statistical analyses were conducted using SPSS software, version 21, with a significance level of α=0.05.

Results

The demographic information of the subjects, including age, height, weight, and BMI, is reported for each group in Table 1.

Independent t-tests revealed no significant differences in demographic characteristics between the groups. Data normality was confirmed using the Shapiro-Wilk test. To assess the training effect, a mixed-design repeated measures ANOVA was conducted. The results indicated a significant improvement in muscle activity onset post-training in the intervention group (P<0.05). Conversely, the control group showed no significant change in muscle activity onset between pre- and post-tests (P<0.05) (Table 2).

Discussion

The TRX suspension training group demonstrated significant improvements in muscle activity onset for the transversus abdominis, external oblique, quadratus lumborum, gluteus maximus, and gluteus medius muscles post-intervention (P<0.05). Conversely, the control group exhibited no significant changes in muscle activity onset for any of the assessed muscles (P<0.05). The results of the present study are consistent with those of previous studies that have investigated the effects of suspension training on muscle activity onset [20, 22-24, 7]. These studies have shown that suspension training can improve the timing of muscle activation, which may be due to the increased demands of the unstable environment on the neuromuscular system.

Table 1. Results of the independent t-test for comparing demographic characteristics of the two groups

Variables	Control Group	Training Group	P
Age (y)	22.3±2.1	22.5±2.2	0.68
Height (cm)	168.5±5.2	169.1±5.4	0.47
Weight (kg)	65.1±7.3	66.2±7.5	0.32
BMI (kg/m²)	23.4±2.1	23.6±2.2	0.56

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Table 2. Mean±SD of muscle activity onset in the two groups at pre- and post-test phases

Muscle	Group	Mean±SD		Time	Group	Interaction	Effect Size
		Pre-test	Post-test				
Transversus abdominis	Control	-107.3±15.2	-110.1±14.8	0.005	0.004	0.001	0.031
	Training	-109.4±16.1	-133.2±13.9				0.243
External oblique	Control	-79.1±14.5	-81.2±14.1	0.001	0.011	0.001	0.016
	Training	-75.8±15.4	-97.7±13.2				0.161
Quadratus lumborum	Control	-78.2±13.8	-77.1±13.4	0.001	0.001	0.001	0.027
	Training	-80.5±14.9	-98.3±12.8				0.199
Gluteus maximus	Control	-69.6±16.2	-67.3±15.8	0.004	0.001	0.001	0.011
	Training	-64.9±17.1	-95.2±15.4				0.411
Gluteus medius	Control	-61.4±15.1	-63.3±14.7	0.001	0.001	0.001	0.042
	Training	-57.2±16.4	-88.9±14.2				0.282

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The results of the present study are inconsistent with the findings of Sadeghi Gohari et al. [25] and Henry et al. (2010) [26]. Sadeghi Gohari et al. found that six weeks of plyometric training does not affect the onset times of the peroneus longus muscle in healthy individuals. Henry et al. found that six weeks of plyometric training followed by an inversion perturbation did not affect the feedback-related onset times of the peroneus longus muscle in healthy individuals. Discrepancies between the current findings and those reported by these researchers may be attributed to variations in participant characteristics, training protocols, and muscle activation measurement techniques. The first and most significant consequence of poorly timed activation of the muscles that control trunk and lower extremity movements is a loss of dynamic knee stability [7]. Appropriate timing of lumbo-pelvic-hip muscle activity triggers the appropriate feedforward patterns for movement and joint position control during injury-provoking maneuvers. In the absence of appropriate timing of muscle onset, the risk of ACL injury increases [7, 27]. In addition to emphasizing proper activation of the muscles around the knee when faced with external perturbations, research has also placed a strong emphasis on controlling the movement patterns of the proximal joints of the lower extremity and trunk [28]. The activation of the proximal muscles of the lower extremity before the application of external perturbations creates stability in the lumbo-pelvic-hip complex and prevents the generation of large and risky moments in the lower extremity [20]. For example, these moments include extensor and abductor moments produced by the gluteus maximus and gluteus medius muscles, which prevent excessive trunk displacement and rotation, and internal rotation of the femur during functional activities [29]. It has been shown that the lack of stability in the lumbo-pelvic-hip complex is one of the most important risk factors for injury in the joints of the lower extremity, especially the knee joint [23]. Research has demonstrated that the muscles of the trunk and those surrounding the hip joint control the movements of the femur [29]. This has a direct impact on how the lower extremity, and especially the knee joint, is positioned and moved during various tasks. This type of control is referred to as proximal-to-distal control of the lower extremity [30].

Swanik et al. reported that improved sensorimotor system function and subsequent neuromuscular adaptations due to the continuous activity of sensory receptors in the muscles and joints involved in functional training can lead to the recovery and reprogramming of movement programs stored in the nervous system [31]. It has also been reported that rapid changes in length/tension during the eccentric phase of plyometric training lead to adaptations in muscle spindles and Golgi tendon organs [31]. It is worth mentioning that a significant portion of the movements used in the suspension training protocol employed in the present study involved jumping and landing activities. Therefore, the improvement in the onset times of lumbo-pelvic-hip muscle activation can be attributed to this. The improvements in muscle activity onset observed in this study can be attributed to the proprioceptive challenges posed by TRX suspension training. The unstable environment activates mechanoreceptors in muscles and joints, enhancing afferent signaling and facilitating quicker central nervous system (CNS) responses. Over time, this leads to more efficient motor unit recruitment and earlier activation of stabilizing muscles, such as the gluteus medius and multifidus. These neuromuscular adaptations are critical for maintaining dynamic knee stability during high-risk movements, thereby reducing the likelihood of ACL injuries [15].

Increased muscle spindle sensitivity enhances afferent inputs to the CNS and improves proprioception. In addition, as muscles are repeatedly stimulated, proprioceptive accuracy increases, resulting in improved awareness of joint position sense [15]. Proprioceptive information is an essential component of learning and improving motor control programs. Any changes or modifications to pre-stored motor control programs are dependent on proprioception [32]. The lack of proper proprioception leads to delayed muscle activation, incorrect movement execution, and an inability to respond effectively to sudden demands, and also prevents learning and proper adaptation to functional needs. Conversely, when accurate, sufficient, and appropriate information is sent from joint proprioceptors to the centers of the nervous system, the nervous system can correct and restore disrupted motor programs and send correct movement commands to the muscles responsible for controlling and executing movement in different joints [20].

One of the most important principles of Lederman's rehabilitation training codes is the principle of similarity between training movements and the movement demands of the specific sports. Exercises that are performed with a preventive or rehabilitative approach should include movements that the individual repeatedly performs during competitions [15]. This can be considered one of the strengths of TRX suspension training, as this training method allows for the simulation of many movement tasks in sports, such as basketball, volleyball, and handball [17]. Zazulak et al. stated that impaired trunk movement control during functional tasks, such as jumping and landing can be considered one of the most important predictors of knee injury [33]. Therefore, athletes with trunk dominance deficits are more prone to ACL injury. Coaches should incorporate TRX exercises, such as single-leg squats and planks into athlete training programs to enhance lumbo-pelvic-hip stability and reduce compensatory trunk movements. Clinicians can use TRX as part of rehabilitation protocols for ACL injury prevention, focusing on exercises that mimic sport-specific movements, like lateral lunges and resisted rotation. Trainers are encouraged to progress exercises by increasing suspension angles and integrating plyometric elements to further challenge proprioception.

The findings are limited to young female athletes in specific sports (basketball and handball), restricting generalizability to other populations. The six-week duration may not reflect long-term neuromuscular adaptations, and a lack of follow-up data limits understanding of persistence. Future studies should explore these variables in diverse cohorts and over extended periods.

Conclusion

TRX suspension training, due to its performance in an unstable and unpredictable environment, requires timely activation and anticipatory muscle activity. Therefore, based on the results of the present study, it can be claimed that this training method has the potential to activate lumbo-pelvic-hip muscles in a timely manner in female athletes with TDI. Therefore, considering the importance of timely activation of lumbo-pelvic-hip muscles in trunk movement control and subsequently lower extremity movements, especially the knee joint, it is suggested that the suspension training used in the present study be used to prevent ACL injury in female athletes with TDI. This study is novel in its focus on EMG activation timing as a preventive metric for ACL injuries using TRX suspension training. Future research should explore the application of this protocol in male athletes, investigate its effects on other high-risk populations, and assess the long-term sustainability of neuromuscular improvements.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Sport Sciences Research Institute of Iran (Code: SSRI.REC-2302-2093).

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Authors' contributions

All authors contributed equally to the conception and design of the study, data collection and analysis, interception of the results and drafting of the manuscript. Each author approved the final version of the manuscript for submission.

Conflict of interest

The authors declared no conflict of interest.

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