



A Comparison of the Hamstring to Quadriceps Activation Ratio in the Toe-in or Neutral Toe Position After Triple Jump Spikes in Female Volleyball Players

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Received 2018 December 21; Revised 2019 July 15; Accepted 2019 July 17.

Abstract

Background: Performing exercises or playing sports with an incorrect technique can cause musculoskeletal injuries.

Objectives: The present study was conducted to compare the hamstring to quadriceps activation ratio when landing in a two-way spike in female volleyball players.

Methods: In this cross-sectional study, 15 elite female volleyball players performed triple jump spikes (TJS) with their toe in and in a neutral ankle position. Electromyography (EMG) was used to measure the muscle activity of the biceps femoris, semitendinosus, vastus medialis and vastus lateralis in two phases before and after the initial contact. Data were analyzed using the Wilcoxon test at the significance level of $P < 0.05$.

Results: The ratio of biceps femoris activity to vastus medialis ($P = 0.04$) and vastus lateralis ($P = 0.04$) activities in TJS with a toe-in ankle decreased significantly in the feed-back phase and the ratio of semitendinosus activity to vastus lateralis activity also decreased significantly in the feed-forward phase of TJS with a natural ankle angle ($P = 0.02$).

Conclusions: A lower muscle activity ratio for biceps femoris to vastus lateralis and medialis in the toe-in position may lower hamstring muscle support from the anterior cruciate ligament (ACL) after landing, which might increase the risk of ACL injury when landing.

Keywords: Athletes, Volleyball, Electromyography, Anterior Cruciate Ligament (ACL)

1. Background

Since its inception over 100 years ago, volleyball has been a popular field of sports (1) and more than 800 million people play this sport throughout the world (2). Epidemiological evidence has revealed ankle sprain, shoulder overuse injuries, patellar tendonitis and anterior cruciate ligament (ACL) injury as the most common injuries among these athletes, in respective order (3). The financial issues faced following injury emphasize the need for taking serious preventive measures (4).

Injuries to the lower limbs have been reported in jump-landing (5), and since these injuries reduce players' performance even after improvement (6), researchers are seeking the best techniques to minimize the risk of injury (7). Due to its need for frequent jumping, landing and sudden change of direction, volleyball is among the sports in which ACL injury has become increasingly common in the last decade, especially among women (8).

Recent studies have further examined the mechanism of knee ligament injury and found that ACL injury occurs with minimal collision; that is, it has a non-contact mechanism (9). Landing from jumping during sports such as volleyball has been known as one of the most important non-contact mechanisms of ACL injury (8), and poor landing techniques may be considered an injury risk factor in athletes (9).

Triple jump spike (TJS) is one of the most powerful techniques used to hit the ball in volleyball (10). The landing leg position after TJS may include three positions, namely toe-in, toe-out and natural toe (11). As jumps with a toe-in position make players not touch the line and since it is used as a foot braking technique, this position of jumps is commonly recommended by coaches to prevent lost scores in matches.

Previous studies have shown that landing with the toe-in position may be accompanied by an increase in the in-

ternal torsion of the tibia and knee valgus (12), and increased hip adduction, internal rotation and knee abduction may predispose the knee to ACL injuries (13, 14) and may therefore be considered a risk factor for ACL injuries (15).

The muscle activation pattern plays an important role in sports, and altered muscle activation may predispose athletes to further injuries (16, 17). Hamstring and quadriceps muscles are involved in most activity patterns (skipping and landing) in various sports, including volleyball (18). The co-contraction of the quadriceps and hamstrings can also provide dynamic stability in the knee joint and potentially protect it during exercise (19). Intense quadriceps muscle activity may lead to ACL injury by increasing the anterior shear force on the tibial plateau and decreasing the knee flexion angle while landing (20).

Since TJS with the foot rotated inward may be one of the risk factors for ACL injuries (15), the ratio of hamstring to quadriceps activation can also be involved in the load on the ACL. Based on the researchers' review of literature, there were no studies on the hamstring to quadriceps activation ratio when performing TJS with the toe-in or the neutral toe position.

2. Objectives

The present study was therefore conducted to compare the ratio of hamstring to quadriceps activity in TJS with the toe-in position and TJS with the neutral ankle position in landing.

3. Methods

This controlled laboratory study selected 15 willing female volleyball players with a history of playing in either the premier league or a top-level division in Tehran province with at least three years of experience using purposive convenience sampling. The inclusion criteria consisted of age 16 to 20 years, continuous practice three times a week for at least three years and having been invited to a national team or being a member of the premier league in Tehran. The subjects with a history of lower limb orthopedic surgeries, ACL, knee meniscus injury, diseases leading to poor balance, anterior talofibular or deltoid ligament tear in the dominant leg, chronic low back pain during the course of the study or chronic back pain lasting three months were excluded from the study (21).

The selected subjects were briefed on the research process during the introduction session. They then completed informed consent forms and filled out a personal information questionnaire. They were additionally ensured of

the confidentiality of their data throughout the study and their right to leave the research at any time without giving any explanations.

All the tests were carried out at Allameh Tabataba'i University laboratory. The research protocol was approved by the Ethics Committee of the University of Social Welfare and Rehabilitation Sciences under the ethics code IR.USWR.REC.1397.107.

Each subject was first given instructions on having a 10-minute warm-up, including pedaling on a stationary bike and performing dynamic stretches (22). Subsequently, the Sargent jump test was administered to achieve a 50% vertical jump and adjust the height of the jump for spike and landing on the force plate based on the findings of a previous study (22). Before starting the test, the participants were trained on different jump-landing methods and they were each asked to perform the movement three times to familiarize themselves with the test protocol.

Before beginning the test procedure, EMG electrodes were positioned on the hamstring and quadriceps muscles according to the SENIAM protocol as follows: vastus medialis: One-fifth of the line that connects the ASIS to the anterior medial collateral ligament; vastus lateralis: One-third of the line that connects the ASIS to the superolateral part of the patella; semitendinosus: The middle of the line that connects the ischial tuberosity to the medial condyle of the tibia; biceps femoris: The middle of the line that connects the ischial tuberosity to the lateral condyle of the tibia (23).

Before beginning the test, the landing foot of the subjects was identified and they were asked to perform the three steps of spike and land with one foot. The foot with which each subject was comfortable maintaining her balance after landing was identified as the landing foot. The maximal voluntary isometric contraction (MVIC) of each muscle, which was kept for 10 seconds in the corresponding position, was then recorded. Each subject performed the MVIC three times. The MVIC data were analyzed using LabVIEW software, and the RMS values were calculated in 3 to 8 seconds of the three tests, and their mean was used to normalize the data. The MVIC assessment of the muscles was performed similarly to previous studies (23, 24).

To perform the TJS test, 70 cm away from the force plate (in the path of the TJS maneuver) was specified with a line on the ground as the player's final step (by her non-dominant leg), so that the subject put a jumping foot on that line. Then, at the center of the force plate, two lines were drawn by an adhesive tape. One of them was parallel to the spike path and the other was at a 30-degree angle inward to the first line (Figure 1). These two markings helped the subject determine the exact location of landing on the force plate for neutral or toe-in ankle landing maneuvers. The Sargent test was performed similar to the pre-

vious study so as to determine the maximal vertical jump height (22). Then, by hanging an object from the ceiling whose height was set at 50% of the maximum vertical jump height, the required level was determined for the jump height and this indicator was placed in the middle of the distance between the center of the force plate and the 70-cm line before the force plate. The triple jumps began before the line marked 3 meters away from the force plate. The subjects initially performed the TJS three times from the 3-meter line before the force plate.

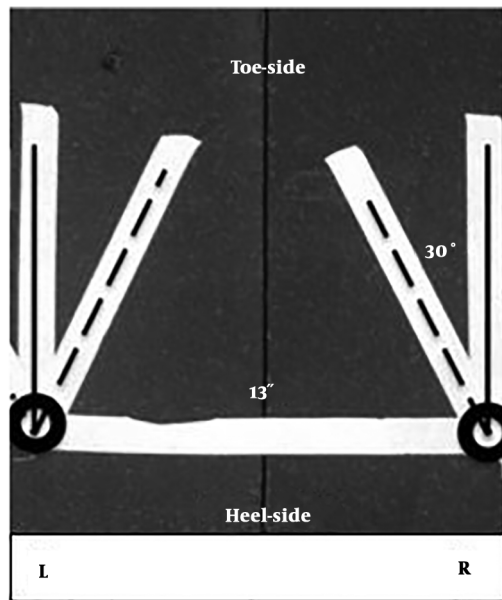


Figure 1. Specifying the toe-in and neutral positions as well as the location of the heel on the force plate for the right and left feet

Each subject performed three acceptable TJSs. In an acceptable spike, a right-handed person would perform the movement by initiating three steps with her left foot, namely jumping with the left foot, touching the marker and landing on the line marked on the center of the force plate. The researchers tried to perform the TJS similar to the conditions in real matches. A landing was considered acceptable when the foot was positioned on the force plate. If the subject hopped after landing on the force plate and lost her balance or landed on the wrong foot, the trial was removed.

The electrical activity of the muscles was recorded by an EMG device (16-channel, manufactured by Baya Med Company, Iran) that was adjusted to a 30 × 40 cm force plate by Danesh Salar Iranian Company. The device preamplifiers had a gain of 4000 and a common mode rejection ratio (CMRR) of 108 dB. The electromyographic data were filtered using a high-pass filter of 490 [INSERT UNIT] and

a low-pass filter of 10. The root mean square (RMS) was extracted as an estimate of muscle activity. For the normalization of the raw data, the RMS of the selected muscles was divided by the MVIC formerly extracted (25). The analysis of the recorded electrical activity of the muscles was performed with LabVIEW.

Once the vertical force of the force plate showed more than 10 N, that point was considered the moment of the initial contact. The activity of each muscle 100 milliseconds before and 100 to 200 milliseconds after the initial contact was extracted and normalized by MIVC.

SPSS-24 and descriptive statistics were used to determine the indicators of central tendency and dispersion of the data. The Shapiro-Wilk test was used to determine the normal distribution of the data. Based on the results, the data did not have a normal distribution. Wilcoxon test was therefore implemented to compare the ratio of hamstring muscle activity to quadriceps in two phases, namely feedback and feed-forward, in the two types of the TJS.

4. Results

The anthropometric data of the subjects were summarized using descriptive statistics and the results are presented in [Table 1](#).

Table 1. The Demographic Characteristics of the Subjects (N = 15 Female Volleyball Players)

Variable	
Number	15
Age, y	1.45 ± 20.60
Height, cm	0.04 ± 1.68
Weight, kg	5.85 ± 60.67
BMI	1.86 ± 21.45
History of playing the sport, y	2.41 ± 7.86

[Table 2](#) summarizes the ratio of hamstring activity to quadriceps in the time interval of 100 milliseconds before the initial contact (feed-forward stage) and 100 to 200 milliseconds after the initial contact (feed-back stage) for both jumping and landing techniques in 15 female volleyball players.

As shown in [Table 2](#), the ratio of activity of the biceps to both the vastus medialis and vastus lateralis in TJS with the toe-in position (P = 0.04) and the ratio of activity of the semitendinosus to the vastus lateralis in the feed-forward phase of TJS also decreased with the neutral toe position (P = 0.02).

Table 2. The Mean \pm SD of the Ratio of Muscle Activity in Two Feed-Forward and Feed-Back Phases

Evaluation Stage/Variable	Landing with Toe-In	Landing with Neutral Toe	P Value
Feed-Forward			
Biceps to vastus medialis	18.20 \pm 10.06	12.15 \pm 6.03	0.46
Biceps to vastus lateralis	4.34 \pm 2.79	2.38 \pm 1.93	0.57
Semitendinosus to vastus medialis	1.22 \pm 1.37	9.80 \pm 4.89	0.33
Semitendinosus to vastus lateralis	1.87 \pm 0.76	1.25 \pm 1.30	*0.02
Feed-Back			
Biceps to vastus medialis	1.87 \pm 1.22	9.13 \pm 6.44	*0.04
Biceps to vastus lateralis	5.92 \pm 2.25	11.40 \pm 9.65	*0.04
Semitendinosus to vastus medialis	5.52 \pm 2.92	5.61 \pm 3.66	0.33
Semitendinosus to vastus lateralis	1.45 \pm 1.19	2.28 \pm 1.90	0.05

5. Discussion

The present study was conducted to compare some of the electromyography variables predicting ACL injury in two types of spike techniques in female volleyball players. In this research, the ratio of activity of external hamstring muscle to vastus medialis and vastus lateralis muscles in the feed-back phase of TJS was lower in the toe-in position than the neutral toe position. The ratio of internal hamstring muscle activation to vastus lateralis activation in the feed-forward phase of TJS had a significant increase in the toe-in position compared to the natural toe position.

According to previous kinematic studies, landing with the toe-in position due to increased hip adduction, internal knee rotation, knee abduction and knee valgus may increase the risk of ACL injuries, and athletes have been recommended not to do jump-landing with this pattern (13).

Although no research was found that specifically addressed the subject of the present research, the ratio of activity of the hamstring muscle to the quadriceps by gender showed a decrease in the ratio of activity of hamstring to quadriceps in women in the feed-forward phase, which may explain the increase in the prevalence of this injury among women compared to men (21). Another study found that the lower strength of the hamstring compared to the quadriceps can be the reason for the higher rate of ACL injuries in female athletes. Muscle activation balance between the hamstring and quadriceps may therefore be important in preventing ACL injuries (19). According to the results of the present study, toe-in TJS reduces the hamstring muscle activity compared to quadriceps femoris activity. Walsh et al. stated that the reduced activity of the hamstring and gastrocnemius muscles in athletes can be associated with a reduction in the knee flexion angle while landing (20).

Moreover, hamstring and quadriceps are the main dy-

namic knee stabilizers, since the reduction of hamstring activity relative to the quadriceps causes an increase in the anterior shear forces on the joint. By decreasing hamstring activity, the supportive effect of this muscle is also removed from the ACL (20).

Another finding showed that the ratio of external hamstring to quadriceps activity increases in the feed-back phase, which may be associated with the increased dynamic support of the hamstring on the knee. According to Krosshaug et al. ACL injuries occur approximately 17 to 50 milliseconds after the foot impact with the ground during the landing phase (26). It can thus be concluded that the increased feed-back activity of the hamstring may not have an efficient role in the prevention of ACL injuries.

The results of the present research can be criticized from a number of perspectives. First, because of the cross-sectional nature of the study, the relationship between these findings and knee injury cannot be proposed with 100% certainty. Further prospective and longitudinal studies are required for clarifying this relationship. Second, the laboratory conditions were different from the actual training conditions, which could have reduced the generalizability of the data. Third, since previous studies have shown that the mechanics of jump-landing differ in women from men (5, 6), it seems that the findings cannot be generalized to male athletes; therefore, similar research is recommended to be carried out in men.

5.1. Conclusions

Toe-in TJS with a reduced external hamstring activity relative to the vastus medialis and vastus lateralis muscles in the feed-forward phase may predispose athletes to ACL injuries. Athletes and coaches are advised to be more cautious in recommending and implementing landing with the toe-in ankle position.

Acknowledgments

The present article has been extracted from a master's dissertation in Sport Pathology and Corrective Actions at Allameh Tabataba'i University in Fall 2018.

Footnotes

Authors' Contribution: Rahman Sheikhhoseini and Sara Pourheidary developed the original idea and the protocol, abstracted and analyzed the data, wrote the manuscript and are its guarantors. All the authors contributed to the development of the protocol, data abstraction and manuscript preparation.

Conflict of Interests: The authors have no conflict of interests to declare.

Ethical Approval: The research protocol was approved by the Ethics Committee of the University of Social Welfare and Rehabilitation Sciences under the ethics code IR.USWR.REC.1397.107.

Funding/Support: The researchers received no financial support to disclose.

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