BILINGUAL PUBLISHING CO.
Pioneer of Global Academics Since 1984

Journal of Advances in Medicine Science
https://ojs.bilpublishing.com/index.php/jams

Biomechanical Risk Assessment of Non-Contact Anterior Cruciate Ligament Injury in Taekwondo Athletes

Rongqiang Zheng[1*] Jingyi Zhou[2] Teng Zhang[3]

1. Shandong Sports Science Research Center, Jinan, Shandong, 250001, China
2. Jinan Fifth People's Hospital, Jinan, Shandong, 250011, China
3. Shandong Sport University, Jinan, Shandong, 250001, China

ARTICLE INFO

Article history
Received: 25 May 2020
Revised: 6 June 2020
Accepted: 24 July 2020
Published Online: 31 July 2020

Keywords:
Knee
Anterior cruciate ligament
Biomechanics
Risk assessment

ABSTRACT

Non-contact anterior cruciate ligament (ACL) injury can occur in many sports. It is interrelated with gender, anatomy, biomechanics, and neuromuscular control. Taekwondo athletes have a higher incidence of ACL injury than athletes from other sports. **Objective:** This study aimed to determine the biomechanical gender differences and mechanism of taekwondo athletes with ACL injury. **Methods:** A total of 28 taekwondo athletes (aged 14–19 years) were randomly selected and grouped by gender. Feet high floor, one foot high floor, and single leg squat were analyzed by a Vicon motion analysis system and Kistler 3D force platform for action. The knee joint angle and ground force were evaluated. **Results:** Results demonstrated biomechanical differences in knee joint between male and female athletes. **Conclusion:** ACL injury in taekwondo female athletes indicated the biomechanical mechanism of the knee joint, and it can be prevented by neuromuscular control training.

1. Introduction

Non-contact anterior cruciate ligament (ACL) injury is usually caused by abnormal stress of the ACL due to its own action without an external force. Approximately 80% of ACL injuries are caused by non-contact events[1,2]. Epidemiological studies have shown that female athletes have 2~8 times the incidence of injuries than male athletes[3–5]. No gender difference in ACL injury before puberty has been reported, and the incidence is small. Many differences in anatomy, endocrine control, and neuromuscular control exist between males and females during puberty (14~19 years old), which may be the factors leading to gender differences in injury[6–9]. Among many factors, anatomy, endocrine, joint relaxation, and genetic factors are inherent in the human body, whereas biomechanical factors and neuromuscular control can be changed through intervention.

ACL injuries happen occasionally in various sports, so strengthening the risk factor assessment study of ACL injuries is important to prevent injuries[10,11]. In our work, we found that ACL injury is a common injury in taekwondo. Among the 26 members of the provincial taekwondo team, 7 athletes, 6 females, and 1 male reported ACL injuries in the past 2 years, among which 6 cases were non-contact ACL injuries. Taekwondo mainly involves attacking and defending the lower limbs. A single leg is required for scoring moves, such as a cross kick or a

**Corresponding Author:*
Rongqiang Zheng,
Male, associate researcher;
Research direction: the prevention and rehabilitation of sports injury;
Corresponding address: Shandong Sports Science Research Center, Jinan, Shandong, 250001, China;
E-mail: zhengrong615@163.com.

 DOI: https://doi.org/10.30564/jams.v3i3.1908

downward split. In taekwondo, the striking leg moves into rapid knee extension while supporting the leg with rotation and forward and backward movement. For example, the uncoordinated contraction of the quadriceps and hamstrings can cause a sudden increase in ACL stress, leading to injury. This study assessed the risk of ACL injury by analyzing the biomechanical risk factors of lower limbs and neuromuscular control factors of taekwondo athletes.

2. Research Methods

2.1 Research Objects

This study involved 13 male and 15 female taekwondo team members, aged between 14 and 19 years. The differences in age, height, weight, and sports years between men and women were determined.

Table 1. Comparison of height, weight, age, and sports years of male and female athletes

	Age	Height (cm)	Weight (kg)	Sports year
Male (n=13)	16.2±2.7	178±6.8	68.6±9.5	6.3±3.1
Female (n=15)	16.5±2.9	175±5.6	65.7±7.3	5.9±2.9

No significant difference in height and weight was found between males and females. All athletes had no history of ACL injury or serious knee injury (e.g., meniscus injury, collateral ligament injury, and traumatic synovitis).

2.2 Experimental Methods

2.2.1 Landing Biomechanics Test Method

Given that most of the ACL injuries of taekwondo athletes occur when the supporting leg jumps to the ground or moves forward and backward, the kinematics changes in the arrangement of the hip, knee, and ankle joints of the lower limbs when landing at a high place should be tested to monitor the risk of knee ACL injuries. Foreign studies have confirmed that internal rotation of the hip joint and valgus and rotation of the knee joint are risk factors of ACL injury when landing at a height. The high peak of ground reaction force and the lack of effective buffer are also known risk factors. Through the biomechanical test of landing on high ground, we explored whether any difference exists between male and female taekwondo athletes. The landing on high ground movements we designed included landing on two feet, landing on one foot, and squatting on one leg. We hypothesized that there is a clear difference in the biomechanical performance of the lower limbs when male and female athletes land on high ground; there is a difference in ground cushioning between male and female athletes when they land; and the biomechanical indexes of lower limbs of male and female athletes in special movements differ.

2.3 Data Processing

A pelvic coordinate system, thigh coordinate system, and leg coordinate system were established based on the coordinates of marker points. The pelvic coordinate system is determined by the right anterior superior iliac spine point, the left anterior superior iliac spine point and the midpoint of the posterior superior iliac spine. On the basis of the research data of Bell et al. and the pelvic coordinate system, the center coordinate of hip joint rotation was calculated. The thigh coordinate system is determined by the medial femoral condyle point, the lateral femoral condyle point, and the hip joint center point. The center of rotation of the knee was the midpoint of the medial and lateral condyles of the femur. The leg coordinate system was determined by the outside malleolus point, the inside malleolus point, and the knee joint center point. Knee joint angle was defined as the Euler angle between the thigh coordinate system and the calf. The first rotation around the x axis was used to obtain the flexion angle (negative angle of flexion); the second rotation around the y axis was used to obtain the adduction and abduction angle (positive angle for adduction and negative angle for abduction); and the third rotation around the z axis was used to obtain the internal and external rotation (positive angle of internal rotation and negative angle for external rotation).

2.4 Statistical Analysis

Mixed ANOVA was conducted to determine the influence of gender, movement, and before and after training on biomechanical indexes of lower limbs. The dependent variables of ANOVA included the impact peaks of the front, back, up, and down directions of the ground reaction force at the first peak moment of the ground reaction force after the feet touched the ground, as well as the knee valgus angle and knee flexion angle. The significance of statistical analysis was defined as a type of error probability not greater than 0.05, and all statistical analysis were performed in SPSS16.0 software.

2.5 Results

As reported by domestic and foreign research, in the process of landing foot touchdown within 30~100 ms, buckle valgus knee joint, and stretching angle is too large, a lack of buffer is an ACL injury main biomechanical factors, studies the ground directly to the eversion of the knee joint angle as an ACL injury risk factors predicted. Thus, this research adopted the vertical ground reaction

DOI: https://doi.org/10.30564/jams.v3i3.1908

force, ground level backward reaction force, angle of knee flexion, and knee valgus angle as a measure of athletes' ground movement. The single first step was squatting on the ground, so only the knee joint angle was measured. The measurement index was the value when the ground reaction force was the maximum during landing. The average angle of the knee joint of the left and right lower extremities upon landing of both feet was determined. The ratio of ground force to body weight was standardized.

As shown in Table 2, there is a significant difference between men and women in the vertical reaction force of the ground and the knee flexion angle when landing on both feet. The knee flexion angle has obvious gender difference, and women are smaller than men. There is no significant difference in horizontal backward force and knee valgus angle.

In the one-foot landing movement, the vertical reaction force of the female athlete on the ground is greater than that of the male, and there are obvious differences. There was no significant difference in knee flexion angle and ground level backward force. There is no significant difference between men and women in knee valgus angle.

When squatting on one leg, no significant difference was observed between the flexion angle and eversion angle of the knee.

3. Discussion

In foreign studies, the main research is on the mechanism of ACL injury in football, basketball, handball, rugby, skiing, etc. The applied movements include landing, lateral cutting, sudden stop, and takeoff [12–15]. The present study mainly analyzed the biomechanics of the knee joint during the landing process, including landing on both feet, landing on one foot, and squatting on one leg. These movements were related to the technical characteristics of taekwondo.

We adopted several indicators that have been proven in foreign countries to predict non-contact ACL injury with high sensitivity, including ground vertical reaction force, ground horizontal backward reaction force, knee flexion angle, and knee eversion angle. Among these indicators, the vertical ground reaction force represents the body's buffering ability during landing, and landing without buffering will Increase knee stress and risk of injury. The valgus angle of the knee joint is considered the most sensitive predictor of non-contact ACL injury. The simultaneous action of forward and rotating violence of the knee joint when the knee joint is in the internal buckle of the semi-flexion position can lead to an instant increase in ACL stress, which will lead to ligament fracture.

In the landing process, the intercept time of the test index is adopted from the time when the foot touches the ground to the time when the maximum reaction force reaches the ground. Foreign studies reported that non-contact ACL injury usually occurs in 30-100 ms when the foot initially touches the ground after landing [16].

The ground reaction force and landing knee flexion angle significantly differed between male and female athletes before the intervention. In women, ground vertical reaction after the intervention was significantly lower than that before training, and the knee flexion angle increased before training. After training, the knee flexion angle between male and female athletes showed no obvious difference. Our research shows that male and female athletes have no significant difference in knee valgus angle during landing. By contrast, most foreign studies believe that the knee valgus angle of female athletes increases, and there are significant differences between male and female athletes. This difference may be related to our research objects and sample size. Most foreign studies tested non-professional college or high school athletes and involved thousands of test samples [17–19]. Our test samples were young elite athletes, whose training years were 4–6 years. After systematic strength training, our test samples were only 30. However, the increased valgus angle of the landing knee joint was mostly due to the weak strength of the hip joint, the obvious development of height and bone

Table 2. Biomechanical index treatment of landing limbs before and after training for male and female athletes

	Landing on both feet		Landing with one foot		Squatting on one leg			
	Male	Female	Male	Female	Male		Female	
Vertical ground reaction force	4.35±0.64	6.48±0.87*	5.06±0.96	6.81±1.24 a				
Ground level backward reaction force	1.18±0.56	1.45±0.63	1.34±0.75	1.67±0.53				
Angle of knee flexion	43.4±5.4	35.6±5.1*	14.2±3.1	13.8±4.7	89.4±10.4		81.4±8.1	
Knee valgus angle	7.5±1.5	8.4±2.4	9.7±2.1	8.6±1.6	13.7±3.7		13.2±4.7	

* indicates a significant difference between male and female athletes ($p<0.05$).

 DOI: https://doi.org/10.30564/jams.v3i3.1908

in adolescent females, and lack of muscle strength and neural control. The vertical ground reaction force reflects the cushioning ability of landing, which varies greatly from individual to individual. When the knee flexes at a small angle, the vertical ground reaction force is large but decreases when the reaction force is strong. In this respect, male and female athletes show some differences, which may be related to the strength of the leg muscles.

No relevant study on landing on one foot has been conducted abroad, but we chose this index because taekwondo athletes move and jump on one leg in most cases. The research results were similar to those of landing on two feet, and significant differences were noted between male and female athletes in the ground vertical response and knee flexion angle.

Single-leg squats have been used in several studies to clinically measure knee control of hip muscle function. Athletes stand on one leg, place their hand on the hip, squat as hard as they can, and stand up again without losing their balance. Researchers stood in front of the athletes and observed the position of the lower limbs and knee joints during the squats. Three levels were suggested: 0 to 2.0 for good action, 1 for average completion, and 2 for poor performance. Level 0 exhibits no significant pelvic tilt, no significant knee eversion, and no significant outward or inward movement of the knee. Level 1 demonstrates a tilt of the pelvis, a slight valgus of the knee, and a slight medial or lateral movement. Level 2 indicates significant lateral tilt of the pelvis, significant eversion of the knee, and medial and lateral movement [20,21,23].

In non-contact ACL injuries, such as cutting step, rotation, acceleration, deceleration, or high landing, fatigue can increase the incidence of injury [24–26]. Decreased knee flexion angle, greater hip flexion angle, knee eversion, increased internal rotation of hip joint, internal and external rotation of patella, and flat foot have been reported as the mechanisms of ACL injury. Which effect occurs at the time of injury or immediately after has long been under debate in the field. The video analysis of ACL injuries revealed that most ACL injuries occur within 30–100 ms after landing [27]. Non-contact ACL injury occurs after the foot touches the ground, with internal rotation and adduction of hip joint, strong contraction of quadriceps, and knee flexion angle is less than 30 degrees. The eversion of the knee is compensated for rotational displacement after ACL injury.

Reference

[1] Faigenbaum AD, Kraemer WJ, Blimkie CJ, et al. Youth resistance training: updated position statement paper from the National Strength and Conditioning Association. J Strength Cond Res. 2009;23(5 suppl):S60–79.

[2] Hewett TE, Lindenfeld TN, Riccobene JV, et al.of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. Am J Sports Med.1999;27: 699–706.

[3] Kim S, Bosque J, Meehan JP, et al. Increase in outpatient knee arthroscopy in the United States: a comparison of National Surveys of Ambulatory Surgery, 1996 and 2006. J Bone Joint Surg Am. 2011;93:994–1000.

[4] Miyasaka KC, Daniel DM, Stone ML. The incidence of knee ligament injuries in the general popluation. Am J Knee Surg. 1991;4:43–48.

[5] Gillquist J, Messner K. Anterior cruciate ligament reconstruction and the long-term incidence of gonarthrosis. Sports Med. 1999;27:143–156.

[6] Gray J, Taunton JE, McKenzie DC, Clement DB, et al. A survey of injuries to the anterior cruciate ligament of the knee in female basketball players.Int J Sports Med. 1985;6:314–316.

[7] Lohmander LS, Englund PM, Dahl LL, et al. The longterm consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. Am J Sports Med.2007;35:1756–1769.

[8] Lohmander LS, Ostenberg A, Englund M, et al. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury.Arthritis Rheum.2004;50:3145–3152.

[9] G-ffin H,Agel J,Albohm MJ,et al. Non-contact anterior cruciate ligament injuries: risk factors and Prevention strategies.J Ame and Orthop Surg,2000,8:141-150.

[10] Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. Am J Sports Med.1995;23:694–701.

[11] Chandy TA, Grana WA. Secondary school athletic injury in boys and girls: a three-year comparison. Phys Sportsmed. 1985;13:106–111.

[12] Hewett TE, Lindenfeld TN, Riccobene JV, et al. The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. Am J Sports Med.1999;27: 699–706.

[13] Malone TR, Hardaker WT,Garrett WE, et al.Relationship of gender to anterior cruciate ligament injuries in intercollegiate basketball players. J South OrthopAssoc.1993;2: 36–39.

[14] Andrish JT. Anterior cruciate ligament injuries in the skeletally immature patient. Am J Orthop (Belle Mead NJ).2001;30:103–110.

  DOI: https://doi.org/10.30564/jams.v3i3.1908

[15] Gallagher SS, Finison K, Guyer B, et al.The incidence of injuries among 87,000 Massachusetts children andadolescents: results of the 1980–81 Statewide Childhood InjuryPrevention Program Surveillance System.Am J Public Health. 1984;74:1340–1347.

[16] Hewett TE, Myer GD, Ford KR. Anterior cruciate ligamentiInjuries in female athletes: Part 1. Mechanisms and risk factors. Am J Sports Med.2006;34:299–311.

[17] Quatman CE, Ford KR, Myer GD, Hewett TE. Maturation leads to gender differences in landing force and vertical jump performance: a longitudinal study. Am J Sports Med.2006;34:806–813.

[18] Quatman-Yates CC, Quatman CE, Meszaros AJ, et al.A systematic review of sensorimotor function during adolescence: a developmental stage of increased motor awkwardness?Br J Sports Med.2011 Apr 1. [Epub ahead of print]

[19] Boden BP, Dean GS, Feagin JA, Jr, et al. Mechanisms of anterior cruciate ligament injury. Orthopedics 2000;23:573–8 .

[20] Olsen OE, Myklebust G, Engebretsen L, et al. Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. Am J Sports Med 2004;32:1002–12 .

[21] Griffin L Y, Teitz CC. Video analysis of ACL injuries. In: GriffinL Y, ed. Prevention of noncontact ACL injuries. Rosemont, IL: American Association of Orthopaedic Surgeons, 2001:87–92 .

[22] Krosshaug T, Nakamae A, Boden BP, et al. Estimating 3D joint kinematics from video sequences of running and cutting manoeuvres: assessing the accuracy of simple visual inspection. Gait Posture 2007;26:378–85 .

[23] Markolf KL, Graff-Radford A, Amstutz HC. In vivo knee stability. A quantitative assessment using an instrumented clinical testing apparatus. J Bone Joint Surg Am 1978;60:664–74 .

[24] Berns GS, Hull ML, Patterson HA. Strain in the anteromedial bundle of the anterior cruciate ligament under combination loading. J Orthop Res 1992;10:167–76 .

[25] Arms SW, Pope MH, Johnson RJ, et al. The biomechanics of anterior cruciate ligament rehabilitation and reconstruction. Am J Sports Med 1984;12:8–18 .

[26] DeMorat G, Weinhold P, Blackburn T, et al. Aggressive quadriceps loading can induce noncontact anterior cruciate ligament injury. Am J Sports Med 2004;32:477–83 .

[27] Withrow TJ, Huston LJ, Wojtys EM, et al. The effect of an impulsive knee valgus moment on in vitro relative ACL strain during a simulated jump landing. Clin Biomech 2006;21:977–83 .

 DOI: https://doi.org/10.30564/jams.v3i3.1908