

PREVENTION AND REHABILITATION OF NON-CONTACT ACL INJURY: NEW INFORMATION IN RECENT STUDIES

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Anterior cruciate ligament (ACL) injury is one of the most common injuries in sports. Tremendous efforts have been made to prevent this devastating injury. Recent studies provided new information understanding ACL injury and the prevention and rehabilitation of the injury. Anterior translation of the tibia is the primary mechanism of the injury. Small knee flexion angle in landing tasks is a primary risk factor of the injury. Gender differences in movement patterns are likely due to differences in training and skill levels. New prevention programs need to be developed to improve compliance to prevention programs. Movement patterns may need to be evaluated in actual game conditions.

INTRODUCTION: Anterior cruciate ligament (ACL) injury is one of the most common and devastating injuries in sports. The annual ACL injury incidence rate in the United States reached 1 per 3,000 citizens, while the ACL reconstruction rate in Norway was as high as 34 per 100,000 citizens, which is similar to that in the United States. The ACL injury incidence rate as the number of injuries per 1,000 hour exposures among collegiate athletes in the United States was reported between 0.17 and 0.33. With ACL injury, many patients have significant overall disability in walking and routine daily functional activities, and could not return to their sports at the same level as before the injury.

Most ACL injuries are non-contact injuries, and can be prevented. Although tremendous scientific and clinical research efforts have been made in attempts to understand the mechanisms of ACL injuries, identify risk factors, and develop prevention and rehabilitation strategies, many confusions and misunderstandings still exist in current research and clinical practice. Recent scientific research provided important new information for improving our understanding of ACL injury mechanism and risk factors, and the outcome of prevention and rehabilitation programs. The purpose of this literature review is to summarize new information from most recent studies on ACL injury mechanisms, risk factors, and prevention and rehabilitation programs.

MECHANISM AND RISK FACTORS OF NON-CONTACT ACL INJURY: Early studies found that the female athletes had significantly higher risk for ACL injury in comparison to male athletes, and that female athletes had smaller knee flexion angle and greater knee valgus angle when performing athletic tasks in comparison to male athletes (Malinzak et al, 2001; Chappell et al, 2002). This led to a belief that decreased knee flexion and increased valgus angles might be risk factors of ACL injury. Later studies claimed that sagittal plane biomechanics cannot generate sufficient force to injure ACL (McLean et al, 2004), and showed that increased knee valgus moment was a predictor of ACL injury (Hewett et al, 2005). These later studies strengthened the belief that increased knee valgus motion was the primary mechanism and risk factor of ACL injury. However, our recent review of literature found that many important studies were ignored while interpreting the results of these studies (Yu and Garrett, 2007).

Many early studies demonstrated that anterior draw force at the proximal end of tibia, instead of knee valgus moment, is the primary mechanism to load the ACL. In vitro and in vivo Several studies demonstrated that ACL loading was sensitive to the anterior draw force and knee flexion angle, and that knee valgus and internal rotation moment significantly affected ACL loading only when anterior draw force presented (Markolf et al, 1995; Fleming et al, 2001). An in vitro study

also demonstrated that knee valgus moment could not load and injure ACL until medial collateral ligament (MCL) was ruptured (Mazzocca et al, 2003). These studies do not support the view that knee valgus motion is the primary mechanism and risk factor of ACL injury.

Recent studies provided further evidence that anterior shear force at the knee, instead of knee valgus moment, is the primary ACL loading mechanism, and that knee flexion angle significantly affects the anterior shear force at the knee and ACL loading. An MRI study demonstrated that the medial and lateral condyle bone bruises associated with ACL injuries were symmetric without gender discrimination (Viskontas et al, 2008). These results suggest that tibia anterior translation is the primary injury mechanism of ACL injury for both genders. A most recent study using combined MR and x-ray image analysis technique demonstrated that the bone bruises associated with ACL injuries were caused by tibia anterior translation with little effect from knee valgus motion (DeFrade et al, 2014). Another in vivo study using a similar technique demonstrated that variation in ACL elongation in a stop-jump task was mainly explained by the knee flexion angle (Taylor et al, 2011). An in vitro study demonstrated that knee valgus collapse observed in ACL injury cases was a post injury event (Meyer and Haut, 2008). A case report of an ACL injury in javelin throw compared knee flexion, valgus-varus, and internal-external rotation angles in the injury trial and non-injury trials, and clearly demonstrated that small knee flexion angle was most likely the cause of the injury, and that increased knee valgus angle was most likely a post injury event (Dai et al, 2014).

Recent studies combined with early studies provided strong evidence that tibia anterior translation is the primary mechanism of ACL injury. These studies also demonstrated that anterior shear force is the primary cause of tibia anterior translation, and that knee flexion angle significantly affects anterior shear force and thus ACL loading, and is an important factor affecting the risk of ACL injury.

GENDER DIFFERENCE IN INJURY RATE AND MOVEMENT PATTERNS: Early studies repeatedly reported that female athletes had decreased knee flexion angle, increased knee valgus angle, and increased impact ground reaction forces in selected athletic tasks in comparison to male athletes. These gender differences in movement patterns were interpreted as gender differences in movement control, and believed as the explanation of gender difference in ACL injury rate. A recent systematic review of literature seriously challenged this interpretation. Recent studies provided strong support to this challenge and different interpretations to gender differences in injury rate and movement patterns.

A study on age effect on movement patterns found that there was no gender difference in movement patterns before 13 years of age (Yu et al, 2005). The results of this study indicate that gender difference in movement patterns may be due to physical differences, not a true gender difference in movement control. A study on gender difference in ACL injury rate found that the female-to-male ratios of ACL injury were 4.5:1 among high school basketball and soccer players, 3.63:1 among college players, and 0.95:1 among professional players (Renstrom, et al. 2008). These results indicate that gender difference in ACL injury rate is not a true gender difference either, and is likely a difference in training and skill levels. A most recent study on gender differences in movement patterns revealed that there was no gender difference in movement patterns among those college students who had no training in team sports when performing stop-jump and side-cutting tasks, and that gender differences in movement patterns were observed among athletes who were trained for team sports and apparently associated with the number of years of training (Liu et al, 2011).

The results of these recent studies provide significant information for understanding of the risk, risk factors, and prevention of ACL injury. The observed gender differences in injury rate and movement patterns are differences in training and skill levels, instead of true gender differences in injury rate and movement control. The risk factors of ACL injury may be different for athletes at different training and skill levels. Prevention of ACL injury may need comprehensive

improvements in physical conditions and sports skills through continued training, instead of a single training program.

COMPLIANCE OF PREVENTION PROGRAM: Many prevention programs have been developed to prevent ACL injury by altering lower extremity movement patterns in the last two decades. These prevention programs were demonstrated to be effective in altering lower extremity movement patterns in laboratory studies. However, clinical studies showed that these prevention programs were ineffective in reduce ACL injury rate. Low compliance was one of the explanations of ineffectiveness of the prevention programs. One of the possible explanations of the low compliance within prevention programs is the requirement of additional training time to carry out the prevention programs. Most of the prevention programs require 15 to 90 minutes of additional training time (Dai et al, 2012).

In an effort to develop a new prevention program for non-contact ACL injury that does not require additional training time and assistance from sports medicine professional personnel, a knee extension constraint training device was recently developed to assist athletes or patients in achieving an increase in knee flexion angle during landings in athletic tasks. Previous studies demonstrated that wearing this training device significantly increased knee flexion angle at landings and decreased peak impact ground reaction force in a variety of athletic and daily functional activities. Our most recent study (Liu et al, 2014) further demonstrated the training effects of this training device and the retention of the training effects. Twenty four recreational basketball and soccer players participated in this study. They wore the training device at least twice while playing their sports for a minimum total of 2 hour per week for 4 weeks. They were tested immediately before and after the 4-week training, and 4 weeks after the training. The results of this study showed that recreational athletes significantly increased their knee flexion angle at the time of peak impact posterior ground reaction force and decreased peak impact posterior ground reaction force in a stop-jump task and a side-cutting task after a 4-week knee extension constraint training using the training device. The results of this study also showed that 50% of the training effects were retained 4 weeks after the training. These results set a basis for future clinical trials to determine the effects of increasing knee flexion angle and decreasing impact ground reaction force in landing tasks on ACL injury and re-injury rates.

EVALUATION OF MOVEMENT PATTERNS: Another possible explanation of the ineffectiveness of current ACL injury prevention program is that the laboratory movement testing results may not represent the movement characteristics in actual game conditions. The training effects of current prevention programs on lower extremity movement patterns were tested for well regulated movements in laboratory conditions with participants focused on injury prevention. Our recent study demonstrated that knee flexion angle at time of peak impact posterior ground reaction force was significantly decreased and peak impact posterior ground reaction force when recreational athletes performed the stop-jump task and side-cutting task with focus on performance comparison to with focus on injury prevention. These results indicate that additional information on movement patterns in actual game conditions may be needed to fully understand the laboratory testing results and the effects of prevention programs.

To obtain lower extremity motion patterns in actual game condition, we recently develop a Knee Angle In-field Measurement Device (KAIMD) to measure knee flexion angle and three-dimensional (3-D) tibia acceleration in actual game condition. The KAIMD is instrumented to a light knee sleeve for an athlete to wear during actual games. The KAIMD can record knee flexion angle and 3-D tibia accelerations continuously at a sample rate of 60 samples per second for a maximum two hours. The KAIMD will be further tested and hopefully applied in our future studies on ACL injury prevention and rehabilitation.

CONCLUSION: Anterior tibia translation due to anterior shear force at the proximal end of tibia is the primary mechanism of ACL injury. Small knee flexion angle during landing task is an important risk factor of ACL injury. Gender differences in movement patterns are likely differences in physical conditions and skill levels. New ACL injury prevention programs need to minimize training time to improve compliance. Evaluation of ACL prevention programs needs real-time measurements of movement patterns in actual practice and competitions.

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