Sagittal lower extremity kinematics during single-leg landing in athletes with anterior cruciate ligament reconstruction: A pilot study

Pongthanayos Kiratisin, Komsak Sinsurin and Roongtiwa Vachalathiti

Biomechanics and Sports Research Unit, Faculty of Physical Therapy, Mahidol University, Nakhon Pathom 73170, Thailand

komsak.sin@mahidol.edu

Abstract

The purpose of the study was to investigate the lower extremity angles of sagittal plane during single-leg landing in various directions. Six athletes (four males, two females) with anterior cruciate ligament reconstruction (ACLR) participated. They have returned to sports completely. They were asked to perform single-leg landing from 30-cm height platform in four directions (forward, 30° diagonal, 60° diagonal, and lateral directions). Jump-landing tests were collected using a Vicon™ motion analysis system. Lower extremity angles at initial contact and at peak vertical ground reaction force (GRFv) were reported and compared among directions of jump landing. The statistical analysis was analyzed using the repeated measures ANOVA. At initial contact, knee flexion exhibited a trend of increase while hip flexion angle was showing a decrease from forward to lateral direction. Knee flexion angles were 10.4°, 12.2°, 13.2°, and 15.2°. Hip flexion angles were 34.2°, 35.9°, 33.6°, and 30.7°. At peak GRFv, jump-landing direction significantly influenced ankle dorsiflexion. Significant greater ankle dorsiflexion was observed in lateral (19.1°) and 60° diagonal (14.2°) directions than forward (5.7°) direction. Hip flexion angles showed a trend of increase while knee was showing decrease from forward to lateral direction. However, jump-landing direction did not significantly influence hip and knee flexion angles at both phases. This study showed that, in the situation of returning to sports in athletes with ACLR, a decreased hip flexion and an increased ankle dorsiflexion might lead to increase a risk of knee injury during single-leg landing in diagonal and lateral directions. Physical therapy and rehabilitation program should address these risks of recurrent injury and should develop treatment to prevent the recurrent ACL injury.

Keywords: Kinematics, Angle, Jump-landing, ACL reconstruction, Knee injury

Introduction

Anterior cruciate ligament (ACL) injury is one of the most common and serious injury of lower extremity in sports, especially in jump-landing and cutting sports such as volleyball, basketball, and football [1,2]. In 2016, Sanders et al reported that incidence of ACL injury was 68.6 persons per 100,000 persons [3]. Athletes with ACL insufficiency have an impairment of physical activity performances [4].

Mechanism of ACL injury could be divided into 2 types including contact and non-contact ACL injuries. Contact ACL injury is the injury from the external force to the knee joint directly. Non-contact ACL injury is the injury which does not have the direct external force to the knee joint. Non-contact mechanism is the most common ACL injuries and seventy percent have been reported [5]

Non-contact ACL injury is frequently found in the decelerating movements such as landing and rapidly directional change in sports [1,6]. When athletes perform the decelerating movement, the quadriceps muscles may generate an excessive force by eccentric contraction. This involves an anterior shearing force at the knee that could induce the ACL strain [5]. Greater risk of ACL injury has been reported in the single-leg landing than the double-legs landing [7]. The single-leg landing exhibited greater peak of proximal tibia with anterior and lateral shear force compared to double-legs landing [8].

ACLR is believed as the gold standard treatment for ACL injury and shows high successful rate for return to normal knee function and level of sports activities [9]. Biomechanical changes of lower extremity after ACLR in landing has been reported that more stiff landing, a decrease of hip and knee flexion, was observed.

Athlete with ACLR preferred to use ankle strategy with reducing hip and knee extensor moments during landing [10]. This factor could lead to ACL injury.

Nowadays, there is no gold standard for assessment before returning to sports in athletes after ACLR. The rehabilitation goal is safe and quick to return to pre-injury level performance in sports. After rehabilitation, many evaluations such as isokinetic test and hop test have been used to assess for determining the decision of returning to sports [11]. Forty-three to ninety-two percentages of athletes with ACLR can return to sports within 6 - 12 months after surgery [12,13]. However, the high rate of secondary ACL injury has been reported as 12% to 17.2% within 5 years after ACLR [14,15]. In addition, people with ACLR have 15 times for secondary injury when compare with non-ACL injury people [16]. From literature review, the research of lower extremity biomechanics is still needed for better understanding and developing the assessment method before returning to sports in athletes with ACLR.

In real sport games and practices, athletes perform in multiple directions of landing. The different directions of jump landing might be the risk of ACL injury especially in the lateral direction of landing. An increase of knee valgus and decrease of hip and knee flexion at initial contact were reported compared with forward direction [17,18]. Besides, a risk of repeated ACL injury after ACLR is a competitive side-stepping and jumping [14]. Therefore, we were interested in the lower limb movement in athletes with ACLR after returning to sports. Moreover, adding the complexity of jumping direction is interesting for assessing lower extremity biomechanics in athletes with ACLR after returning to sports.

Materials and Methods

Six professional athletes (four males and two females) who were involved in jumping and landing sports at least 3 to 5 times per week and participated in a competition. Inclusion criteria included unilateral ACLR using patellar tendon or hamstring tendon techniques. Time from surgery was six to twenty-four months and returned to sports completely. Participants with other serious injury of lower extremity, partial or total menisectomy, revision ACLR, history of low back pain or lower extremity problems with receiving medication or physical therapy in 6 months before testing were excluded from the study.

Vicon™ motion analysis system was used to collect kinematics data at 200 Hz sampling frequency by using 16 reflective markers based on lower body marker set. In addition, AMTI force plate was used to collect kinetics data at 1000 Hz sampling frequency. Before testing, the researchers explained the protocol for each participant. Participants were allowed to practice 3-5 times of jump landing. Participants were asked to stand on a tested leg at the starting point on 30 cm height wooden platform. Non-tested leg was knee flexion at 90 degrees and hip neutral position. Participant's hands were placed on the waist to control variability in mechanic of arm-swing during landing. Then, participants jumped and landed on the center of force plate. The participants were instructed to jump without action of upward and to look forward during jump-landing tests. If participant was not able to land on the center of force plate, to maintain single-leg balance on the force plate, or to maintain the hands on the waist; it is considered as unsuccessful trial. The unsuccessful data then were recollected.

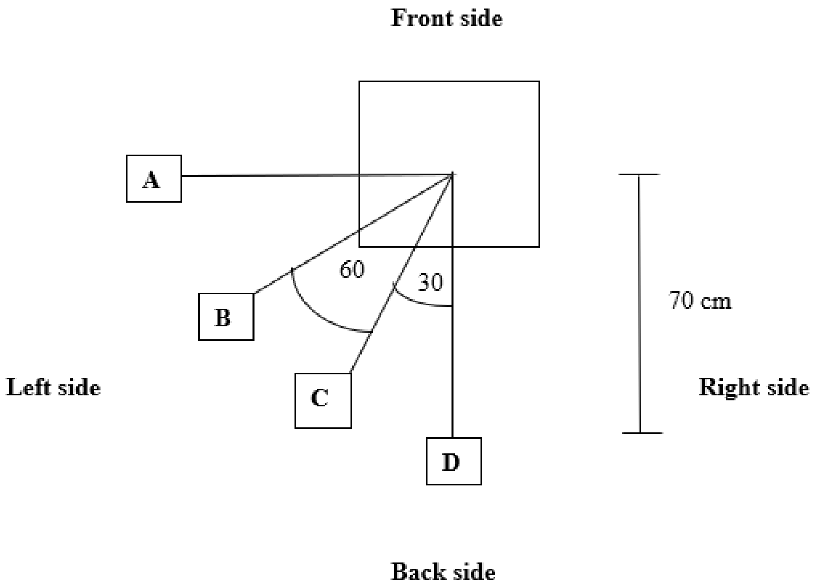

Figure 1 Research setting (top view). A represents the starting position of lateral jump landing (A). starting position of 60 degrees diagonal landing (B), starting position of 30 degrees diagonal landing (C), starting position of forward landing (D). The square in the center is the force plate. This figure shows for right-leg landing. If left side was tested, the settings of starting position were reversed to opposite side except with D position.

The data of jump-landing test were processed and analyzed. An average of 3 successful trials of each direction was reported.

The data of kinematics were analyzed at two phases of landing; at initial contact phase and at peak GRFv. The initial contact phase used the first frame that the subject contacted the ground with more than 10 newtons of GRFv. The kinematic data at peak GRFv was selected at the time frame of the maximum GRFv.

The gaps in kinematic data were filled by the cubic spline interpolation and copy pattern techniques. Both GRFs and kinematic data were filtered by a low pass zero-lag, 4^{th} order, Butterworth filter. The cut-off frequencies of Butterworth filter were 40 and 7 Hz for GRFs and kinematics, respectively. The cut-off frequency was determined by residual analysis technique.

The statistical analysis was analyzed using SPSS program version 24. The Kolmogorov-Smirnov Goodness of Fit test was used to test distribution of data. One-way ANOVA with repeated measures was used for comparing the effect of directions. Pairwise comparisons and Bonforroni correction were used to determine differences of kinematics data among directions. The level of statistical significance was set at p-value less than 0.05

Results and Discussion

From Table 1, the direction did not significantly influence to hip flexion, knee flexion, and ankle plantarflexion at initial contact phase. At peak GRFv phase, ankle dorsiflexion was significantly observed in lateral and 60^{o} diagonal directions compared with forward ($p<0.05$) and 30^{o} diagonal direction ($p<0.05$).

Table 1 Lower extremity angles (degrees) at initial contact phase and peak GRFv phase in 4 directions. (Mean±SD).

Direction	**Forward**	**30^{o} diagonal**	**60^{o} diagonal**	**Lateral**
At initial contact				
Hip flexion	34.2±3.9	35.9±2.9	33.6±3.6	30.7±3.8
Knee flexion	10.4±0.9	12.2±0.9	13.2±1.0	15.2±1.3
Ankle plantarflexion	10.8±2.1	10.7±4.2	12.6±1.3	11.2±2.3
At peak GRFv				
Hip flexion	41.1±3.9	42.5±2.8	40.6±2.6	38.4±3.4
Knee flexion	27.9±1.9	28.3±2.3	31.9±1.5	31.9±1.5
Ankle dorsiflexion	5.7±1.6	6.4±1.6	14.2±1.3$^{*,\gamma}$	19.1±1.1$^{*,\gamma}$

*Statistically significant difference compared with forward direction ($p<0.05$)

$^{\gamma}$Statistically significant difference compared with 30^{o} diagonal direction ($p<0.05$)

From the result at initial contact phase and peak GRFv phase, lateral direction showed less hip flexion compared with others. ACL injury occurred at the peak GRFv after initial contact to the ground [19]. Less hip and knee flexion at initial contact phase is one factor of knee injury by high GRF [20]. Podraza *et al*. [21], found that knee flexion 0^{o} - 25^{o} occurred a high GRFs can cause the non-contact ACL injury. GRFs can be reduced by muscles and joints around hip, knee and ankle that absorb impact energy from landing. Landing with less lower extremity flexion or stiff landing exhibited increasing knee adductor moment, increasing vastus lateralis EMG, and decreasing energy absorption at hip and knee joints compared with high lower extremity flexion or soft landing group; this may lead to increase a risk of knee injury [22]. The current study exhibited that less hip flexion in lateral direction in both phase might relate to stiff style landing.

An increase in a trend of knee flexion angle was supported with Sinsurin's (2013) study. Sinsurin *et al.* [23] showed the increasing of knee joint flexion from forward to lateral direction during single-leg landing at initial contact phase suggested that there was a pre-program to set the greater knee flexion for energy absorption and prevent injury from impact force in lateral direction which is the difficult task when comparing with forward direction. ACL injury mostly occurs in 40 ms after initial contact with the ground [24]. Peak vertical GRFs in one-leg landing after jumping have been estimated range from 2 to 18 times body weight [25]. ACL loading during landing most occur at the time of peak vertical ground reaction force (VGRF) immediately after initial contact [19]. Time to peak anterior translation of tibia, peak ground reaction force, and ACL injury were close about 40-60 milliseconds after initial contact [26]. Therefore, at peak GRFv phase is important for predicting the risk of injury.

Landing by using ankle strategy was defined as stiff landing [27], increasing in hip and knee flexion during landing is defined as soft landing that suggested for reducing impact loading [19]. To prevent knee injury, increasing in hip and knee flexion should be suggested for single-leg landing in various directions rather than using ankle for landing. In current study, significantly increased ankle dorsiflexion angles were found at peak GRFv phase from forward to lateral landing that could relate to stiff landing. Eventhough athletes with ACLR already returned to sports, they should aware about recurrent injury when landing in multi-directions. This might lead to increased risk for recurrent ACL injury. Soft landing and postural awareness should be suggested for reducing the risk of recurrent knee injury.

Conclusions

Although athletes were obtained the effective treatment after ACLR and already return to sport, from the current study found a landing in various directions significantly increased ankle using and showed increased knee flexion while reduced hip flexion during lateral landing. A reducing in hip flexion and using of ankle strategy that is similar to stiff landing may lead to increased risk of knee injury. For preventing an injury of lower extremity in single-leg landing, an increase in hip flexion and decrease in ankle strategy should be suggest for athletes.

Ethic Committee No.

COA NO 2016/051.0704 MU-IRB 2016/035.2902

References

[1] JM Hootman, R Dick, J Agel. Epidemiology of collegiate injuries for 15 sports: Summary and recommendations for injury prevention initiatives. Journal of athletic training. 2007;42(2):311-9.

[2] TE Hewett, TN Lindenfeld, JV Riccobene, FR Noyes. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. The American Journal of Sports Medicine. 1999;27(6):699-706.

[3] TL Sanders, HM Kremers, AJ Bryan, DR Larson, DL Dahm, BA Levy, et al. Incidence of anterior cruciate ligament tears and reconstruction: A 21-Year Population-Based Study. The American Journal of Sports Medicine. 2016;44(6):1502-7.

[4] SR Filbay, IN Ackerman, TG Russell, EM Macri, KM Crossley. Health-related quality of life after anterior cruciate ligament reconstruction: a systematic review. The American journal of sports medicine. 2014;42(5):1247-55.

[5] LY Griffin, J Agel, MJ Albohm, EA Arendt, RW Dick, WE Garrett, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. The Journal of the American Academy of Orthopaedic Surgeons. 2000;8(3):141-50.

[6] Y Shimokochi, SJ Shultz. Mechanisms of noncontact anterior cruciate ligament injury. Journal of Athletic Training. 2008; 43(4): 396-408.

[7] E Pappas, M Hagins, A Sheikhzadeh, M Nordin, D Rose. Biomechanical differences between unilateral and bilateral landings from a jump: Gender differences. Clinical Journal of Sport Medicine 2007;17(4):263-8.

[8] LI Wang. The lower extremity biomechanics of single-and double-leg stop-jump tasks. Journal of Sports Science & Medicine. 2011;10(1):151-6.

[9] EJ de Valk, MH Moen, M Winters, EW Bakker, T R amminga, HV der Hoeven. Preoperative patient and injury factors of successful rehabilitation after anterior cruciate ligament reconstruction with single-bundle techniques. Arthroscopy 2013;29(11):1879-95.

[10] MJ Decker, MR Torry, TJ Noonan, A Riviere, WI Sterett. Landing adaptations after ACL reconstruction. Medicine and Science in Sports and Exercise. 2002;34(9):1408-13.

[11] E Narducci, A Waltz, K Gorski, L Leppla, M Donaldson. The clinical utility of functional performance tests within one-year post-ACL reconstruction: A systematic review. International Journal of Sports Physical Therapy. 2011;6(4):333-42.

[12] S Czuppon, BA Racette, SE Klein, M Harris-Hayes. Variables associated with return to sport following anterior cruciate ligament reconstruction: a systematic review. British Journal of Sports Medicine. 2013.

[13] Time Line for Noncopers to Pass Return-to-sports criteria after anterior cruciate ligament reconstruction. Journal of Orthopaedic & Sports Physical Therapy. 2010;40(3):141-54.

[14] L Salmon, V Russell, T Musgrove, L Pinczewski, K Refshauge. Incidence and risk factors for graft rupture and contralateral rupture after anterior cruciate ligament reconstruction. Arthroscopy 2005;21(8):948-57.

[15] RW Wright, RA Magnussen, WR Dunn, KP Spindler. Ipsilateral graft and contralateral ACL rupture at five years or more following ACL reconstruction: a systematic review. The Journal of Bone and Joint Surgery American. 2011;93(12):1159-65.

[16] MV Paterno, MJ Rauh, S LC chmitt, KR Ford, TE Hewett. Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. Clinical Journal of Sport Nedicine. 2012;22(2):116-21.

[17] K Sinsurin, R Vachalathiti, W Jalayondeja, W Limroongreungrat. Altered peak knee valgus during jump-landing among various Directions in basketball and volleyball athletes. Asian Journal of Sports Medicine. 2013;4(3):195-200.

[18] K Sinsurin, R Vachalathiti, W Jalayondeja, W Limroongreungrat. Different sagittal angles and moments of lower extremity joints during single-leg jump landing among various directions in basketball and volleyball athletes. Journal of Physical Therapy Science. 2013;25(9):1109-13.

[19] B Yu, CF Lin, WE Garrett. Lower extremity biomechanics during the landing of a stop-jump task. Clinical Biomechanics. 2006;21(3):297-305.

[20] JS Dufek, BT Bates. The evaluation and prediction of impact forces during landings. Medicine and Science in Sports and Exercise. 1990;22(3):370-7.

[21] JT Podraza, SC White. Effect of knee flexion angle on ground reaction forces, knee moments and muscle co-contraction during an impact-like deceleration landing: implications for the non-contact mechanism of ACL injury. Knee. 2010;17(4):291-5.

[22] CD Pollard, SM Sigward, CM Powers. Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments. Clinical Biomechanics. 2010;25(2):142-6.

[23] K Sinsurin, R Vachalathiti, W Jalayondeja, W Limroongreungrat. Different sagittal angles and moments of lower extremity joints during single-leg jump landing among various directions in basketball and volleyball athletes. Journal of Physical Therapy Science. 2013;25(9):1109-13.

[24] H Koga, A Nakamae, Y Shima, J Iwasa, G Myklebust, L Engebretsen, et al. Mechanisms for noncontact anterior cruciate ligament injuries: Knee joint kinematics in 10 injury situations from female team handball and basketball. The American Journal of Sports Medicine. 2010;38(11):2218-25.

[25] BP Boden, FT Sheehan, JS Torg, TE Hewett. Non-contact ACL injuries: Mechanisms and risk factors. The Journal of the American Academy of Orthopaedic Surgeons. 2010;18(9):520-7.

[26] DL Miranda, PD Fadale, MJ Hulstyn, RM Shalvoy, JT Machan, BC Fleming. Knee biomechanics during a jump-cut maneuver: Effects of sex and ACL surgery. Medicine and Science in Sports and Exercise. 2013;45(5):942-51.

[27] SN Zhang, BT Bates, JS Dufek. Contributions of lower extremity joints to energy dissipation during landings. Medicine and Science in Sports and Exercise. 2000;32(4):812-9.