Increased knee valgus alignment and moment during single-leg landing after overhead stroke as a potential risk factor of anterior cruciate ligament injury in badminton

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ABSTRACT

Background In badminton, knees opposite to the racket-hand side received anterior cruciate ligament (ACL) injuries during single-leg landing after overhead stroke. Most of them occurred in the backhand-side of the rear court. Comparing lower limb biomechanics during single-leg landing after overhead stroke between the forehead-side and backhand-side court may help explain the different injury rates depending on court position.

Hypothesis The knee kinematics and kinetics during single-leg landing after overhead stroke following back-stepping were different between the forehead-side and backhand-side court.

Study design Controlled laboratory study.

Methods Hip, knee and ankle joint kinematic and knee kinetic data were collected for 17 right-handed female college badminton players using a 3-dimensional motion analysis system. Subjects performed single-left-legged landing after an overhead stroke following left and right back-stepping. The kinematic and kinetic data of the left lower extremities during landing were measured and compared between left and right back-steps.

Results Hip flexion and abduction and knee valgus at the initial contact, hip and knee flexion and knee valgus at the maximum knee flexion and the maximum knee valgus moment were significantly larger for the left back-step than the right back-step (p<0.05).

Conclusion Significant differences in joint kinematics and kinetics of the lower extremity during single-leg landing after overhead stroke were observed between different back-step directions. Increased knee valgus angle and moment following back-stepping to the backhand-side might be related to the higher incidence of ACL injury during single-leg landing after overhead stroke.

INTRODUCTION

Many anterior cruciate ligament (ACL) injuries have been reported during sports activity, with the higher percentage accounted for by non-contact injuries. Although the mechanism of ACL injury has not been understood sufficiently, ACL injuries frequently occur in sports requiring landing from a jump or rapid change of direction, such as seen in basketball, handball and soccer. The focus has been on analysing biomechanical factors of high-risk manoeuvres considered to be associated with ACL injury, and excessive knee valgus angle and knee valgus moment have been reported to be risk factors. Competitive badminton also requires these manoeuvres; however, little attention has been paid to this despite the high incidence of knee injury in this sport. Competitive badminton players hold a racket in their dominant hand, which limits their arm position and leads to asymmetric posture by lateral trunk flexion especially during racket stroke. Furthermore, these players need to move from back to front and side to side rapidly, and return to the centre of the court to prepare for the next shot with unique footwork. According to information from interviews with 21 badminton players who injured their ACLs, the most common mechanism (10 of 21 injuries) was single-leg landing after overhead stroke and 9 of 10 players had injured the knee opposite to the racket-hand side. Furthermore, 7 of 10 players were injured in the backhand-side rear corner of the court. In badminton, a player’s forehead-side is the same side as his playing hand: for a right-handed player, the forehead-side is his right side and the backhand-side is his left side. These injury patterns appear to be due to frequently performed movements while playing badminton, which are also seen in sports such as basketball, handball and soccer, showing a high incidence of ACL injury. In a previous study, lower limb kinematics and kinetics were investigated during lunge in badminton. However, no published studies have investigated the movement patterns of the lower extremities during single-leg landing after an overhead stroke (figure 1), and therefore there is no answer to the question why most ACL injuries after overhead stroke occur in the backhand-side rear court. For the prevention of ACL injuries, it is important to understand the sports-specific characteristics in mechanisms of non-contact ACL injury because this may enable designing neuromuscular training programmes to more effectively avoid risky motions. The purpose of this study was to investigate joint kinematics and kinetics of lower extremities in female college badminton players and compare the different step directions (towards forehead-side rear and backhand-side rear). Because of a discrepancy in the incidence of ACL injury after overhead stroke in forehead-side and backhand-side rear court, we hypothesised that the knee kinematics and kinetics during single-leg landing after an overhead stroke following back-stepping were different between the forehead-side and backhand-side court.

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Accepted 2 March 2011
Seventeen female college badminton players with no history of knee injury participated in this study. The average age was 20.3±1.8 years, height was 158.4±5.4 cm, body weight was 51.7±5.8 kg and athletic experience of badminton was 5.3±2.1 years. All subjects were recruited from Hirosaki University, and were currently participating in an organised badminton club at least four times a week at the time of testing. All subjects were right hand dominant, based on racket holding preference. No subject had any pathological complaints, loss of range of motion or muscular weakness in trunk, lumbar spine, hip, knee or ankle joint in the orthopaedic physical examinations. Approval for participation of human subjects in this investigation was obtained from the Hirosaki University Graduate School of Medicine Institutional Review Board. The subjects read and signed a written consent before participating in this study. Our power analysis showed the smallest study population was 17 for more than 80% of statistical power, if there was a difference of 5° with an SD of 5° of angular measurements between right and left back-step directions.

Preparation for testing
Trial data were collected with a 3-dimensional motion analysis system (Vicon; Oxford Metrics, Oxford, UK) with seven infrared cameras. Kinematics data were sampled at 120 Hz and recorded digitally on a Dual Pentium III 1 GHz personal computer. Cameras were positioned so that each retroreflective marker was detected by at least two cameras throughout the task. Ground reaction force was collected at 120 Hz using a calibrated and levelled force plate (model OR6-6-1; AMTI, Watertown, Massachusetts, USA) embedded in the floor and synchronised with the Vicon system for simultaneous collection. Each subject was barefooted and wore black shorts during the testing. Sixteen retroreflective markers (25 mm) were placed on the anatomical landmark (anterior superior iliac spin, posterior superior iliac spin, mid thigh, lateral condyle of the femur, mid lower leg, lateral malleolus of ankle, heel and second metatarsalis) to calculate motion of the hips, knees and ankles in the sagittal, frontal and transverse planes. The 3-dimensional marker trajectories were recorded and kinematic and kinetic variables were calculated using Plug-in Gait in Vicon Workstation (version 4.6; Oxford Metrics, Oxford, UK). Inverse dynamics analyses were used to calculate external joint moments from kinematic data and force plate data with Plug-in Gait. Marker trajectory data were filtered using a Woltering quintic spline filter with a predicted mean square error of 20 mm. The force plate data were filtered through a low-pass Butterworth digital filter at a cut-off frequency of 12 Hz. All kinetic data were normalised by body weight (kg) and height (m).

Testing protocol
Before participation, the testing procedures were explained to each subject. After written consent was obtained, anthropometric measurements including the height, weight, segmental lengths and diameters of the ankles and knees, feet length and
pelvic width were recorded for each subject. The footwork and overhead stroke task were then demonstrated to each of the subjects by a badminton coach who had approximately 15 years of experience as a competitive player. Subjects were asked to perform two different testing tasks: right back-step task and left back-step task. In the right back-step task, the subjects stepped back three steps 45° diagonally to the right from the starting position simulating the back-step towards the forehand-side rear of the badminton court, made an overhead stroke with a racket in their right hand, immediately landed on their left leg on the force plate and then returned to the starting position (figure 2 and supplementary video). In the left back-step task, the subjects stepped back three steps 45° diagonally to the left from the starting position simulating the back-step towards the backhand-side rear of the badminton court, and following an overhead stroke, landed on the force plate and returned to the starting position in the same way as in the right back-step task. Subjects were allowed to practice the tasks several times, and then performed three to five consecutive trials. To avoid any coaching effect on the subjects’ natural performance of the tasks, no other instructions relating to stepping, landing or stroking techniques were provided.

Data analysis

The data analysis was performed using a trial in which the subject successfully landed within the force plate without overrunning to the outside. In general, right-handed badminton players always land on the left leg after an overhead stroke (figure 1), therefore all data were analysed for the left leg. Because non-contact ACL injuries generally occur in the early phase of landing, the data analysis was only focused on the impact phase of the landing after an overhead stroke. The impact phase of the landing was defined as between the initial contact (IC) of the left toe to the floor after an overhead stroke and the maximum knee flexion (MKF), and all kinematic data were time normalised with the impact phase represented ranging from 0% as IC to 100% as MKF. From each trial, the flexion/extension, adduction/abduction and internal/external rotation angles of the left hip, the flexion/extension and varus/valgus of the left knee, and the dorsiflexion/plantar flexion, inversion/eversion and adduction/abduction angles of the left ankle at IC and MKF were determined. The peak values of the external knee valgus moment were extracted from IC to

Figure 3  Values are mean±SD during impact phase. (A) Hip flexion/extension angle; (B) hip abduction/adduction angles and (C) hip internal/external rotation angle.

Figure 4  Values are mean±SD. (A) Knee flexion/extension angle and (B) knee varus/valgus angle.
MKF, and normalised to height and body weight. Statistics (mean and SD) were calculated for all trials. To compare the kinematic and kinetic data during single-leg landing between the right and left back-step tasks, paired t tests with a significance level of 0.05 were used. Statistical analyses were conducted using SPSS Version 16.0 software (SPSS Inc, Chicago, Illinois, USA).

RESULTS

Figures 3–5 show time course of the hip, knee and ankle kinematics during the impact phase. Tables 1 and 2 represent summaries of kinematic data at IC and MKF comparing right and left back-steps, respectively. The hip flexion angle at IC was not significantly different between the right and the left back-step (table 1), whereas the hip flexion angle at MKF after the right back-step was 22.7±6.0° and significantly smaller compared with 34.4±11.5° after the left back-step (p=0.0002) (figure 3A, table 2). The hip adduction/abduction angle at IC was 9.8±6.4° of abduction after the right back-step and 17.0±7.6° of abduction after the left back-step, representing a significant difference (p=0.0004) (figure 3B, table 1). Meanwhile, the significant difference disappeared at MKF (figure 3B, table 2).

There was no significant difference in the hip internal/external rotation angle at IC or MKF (figure 3C, tables 1 and 2).

The knee flexion angle at IC was not significantly different between the right and the left back-step (figure 4A, table 1), whereas those at MKF were 50.4±8.4° and 55.6±10.6°, representing a significant difference (p=0.0304) (figure 4A, table 2). The knee varus/valgus angle at IC was 1.6±4.9° of varus after the right back-step and 1.3±4.1° of valgus after the left back-step (figure 4B, table 1), and those at MKF were 1.6±6.0° of valgus and 8.6±6.3° of valgus, representing a significant difference (p=0.0214 and p=0.0294) (figure 4B, table 2). There was no significant difference in the ankle kinematics at IC or MKF between the right and the left back-step (figure 5A–C, tables 1 and 2). The maximum knee valgus moment was 0.42±0.26 Nm/kg/m after the left back-step and significantly higher compared with 0.28±0.25 Nm/kg/m after the right back-step (p=0.0039) (figure 6).

DISCUSSION

Our hypothesis was supported by the findings obtained from this study that significant differences were detected in knee joint kinematics and knee valgus moment during single-leg landing after overhead stroke in the different step directions. In left back-steps, the subjects demonstrated larger hip and knee flexion angles at MKF and larger abduction angle of hip at IC than in right back-steps. Knee valgus angles at IC and MKF after left back-steps were larger than those after right back-steps, and knee valgus moment after left back-steps was larger than that after right back-steps. All subjects who participated in this study were right-handed, therefore, the right side of the court represents the forehand-side court and the left side of the court represents the backhand-side court. In other words, the badminton players demonstrated larger valgus angles and moment in the knee opposite to the racket-hand side during single-leg landing after overhead stroke in the backhand-side rear corner of the court. Numerous studies identified increased knee valgus angle and moment as increasing the risk of ACL injury, through biomechanical analysis, video analysis of injury and simulation studies. 10–13 Hewett et al 2 reported that female athletes who displayed increased knee valgus angle and increased knee valgus moment during landing were at an increased risk of sustaining ACL injury in a prospective cohort study. The increased knee valgus angle and moment during single-leg landing after an overhead stroke following left back-steps means that players are in a risk posture for ACL injury in the backhand-side rear court, and this may be associated with the higher incidence of ACL injury in the backhand-side rear court. 6

In the current study, the larger hip and knee flexion angle at MKF was seen in backhand-side court where the higher incidence of ACL injury was shown during single-leg landing after overhead stroke. During sagittal plane movement at the knee joint, female athletes have been suggested to have shallow knee flexion angle during landing, jumping and cutting task compared with male athletes. 14–16 However, other studies show no sex difference or even greater knee flexion in females at the time of injury. 17–20 Hewett et al 2 reported that the knee
flexion angle at landing did not appear to predict ACL injury risk in a cohort study. The relationship between the knee flexion angle and the potential for ACL injury has not been explored extensively in the literature. Furthermore, hip flexion angle related to ACL injury is still controversial. Several articles reported that female athletes showed smaller hip flexion angle than male athletes during landing. However, some articles reported that there are no differences in hip flexion angle between male and female athletes. In a video analysis at the time of injury, female athletes showed larger hip flexion angle than male athletes during landing. However, some articles reported that female athletes showed smaller hip flexion angle than male athletes during landing. Comparisons between the right and left back-steps.

Different sports place different constraints on the motion of the arms during activities to hold a ball, stick or racket. There are few reports on lower extremity biomechanics with sport-dependent arm position related to knee injury. Chaudhari et al. investigated a side-cutting manoeuvre with three different arm positions: holding a lacrosse stick, holding a football on the plant side and holding a football on the cut side. They reported that arm position significantly affected the knee valgus moment with an increase in trials of lacrosse and the plant side in football. Müntermann et al. showed that trunk sway greatly contributed to changes in the knee adduction moment. Although the kinematics of the upper extremity and trunk were not assessed in this study, the badminton-specific movement in the upper extremity and trunk motion during an overhead stroke might affect the hip and knee joint kinematics and kinetics. In badminton, right-handed players take off with the right leg and land on the left leg after overhead stroke (figure 1). During overhead stroke in the left rear court, it is more difficult to keep the body in balance than in the right rear court because players have to laterally bend their trunk to their left side as their arm comes through (figure 7). Furthermore, the players have to return to the initial court position immediately after overhead stroke. Because right-handed players always land on their left leg after overhead stroke, the knee and hip joint have to prepare the different kinematics to return in the different directions after the right and left back-steps (figure 7). These characteristics of motion pattern and preparation for subsequent event might result in different hip and knee joint kinematics and kinetics during single-leg landing between the right and left back-steps.
Our study had several limitations including the relatively small sample size and small number of repeated trials taken for each subject. There is a limit to the generalisability of this study as we investigated only female collegiate athletes. All participants of this study were right-handed, and thus it is questionable whether the left-handed player shows same pattern of the joint kinematics and kinetics. We did not assess the skill level of the subjects who participated, which potentially could affect the results. The results of this study may not be applied to young high school or elite athletes with different experience or training backgrounds. Further studies exploring the influence of experience and training will help to design a sports-specific prevention programme for badminton players. The laboratory conditions in this study did not reproduce those seen in typical games or practice. In this study, the subjects took strokes without a shuttlecock and performed barefoot on the carpeted floor, and these might affect their movement in this study.

Despite these limitations, this is the first English language article to describe lower extremity kinematics and kinetics during single-leg landing after an overhead stroke in badminton, focusing on the potential risk of ACL injury. Specific intervention programmes including teaching landing techniques may modify these patterns and possibilities reduce injury risk in badminton players. Deficits in neuromuscular control of the trunk may contribute to lower extremity joint stability and injury.\textsuperscript{27} Landing requires high levels of neuromuscular control to maintain stability and performance.\textsuperscript{28} Neuromuscular training that may increase trunk and hip control\textsuperscript{29, 30} should be included in ACL injury prevention strategy for female badminton players. The effect of the prevention programmes should be addressed in future studies.

**CONCLUSIONS**

The badminton players demonstrated increased knee valgus angle and moment during single-leg landing following back-steps to the backhand-side rear compared with back-steps to the forehand-side rear. This might be related to the high incidence of ACL injuries occurring during single-leg landing after overhead stroke in the backhand-side rear court. For the prevention of ACL injury in badminton players, it is suggested that an understanding of the ‘at risk’ posture and adaptation of training methods to teach landing techniques considering badminton-specific movements may be needed.

**What is already known on this topic**

It was reported that increased knee valgus angle and moment during landing or cutting was a risk factor of anterior cruciate ligament (ACL) injury. For the prevention of ACL injuries, it is important to study the sports-specific characteristics in order to train players to exert these movements in a correct physiological way with respect to knee joints.

**What this study adds**

The badminton players demonstrated increased knee valgus angle and moment during single-leg landing following back-steps to the backhand-side rear compared with back-steps to the forehand-side rear. This might be related to the numerous anterior cruciate ligament injuries in badminton that occur during single-leg landing after an overhead stroke in the backhand-side rear of the court.

**Acknowledgements**

The authors thank Eiki Tsushima, PhD, Hirosaki University School of Health Science, for statistical analysis, and Satoshi Toh, MD, Hirosaki University Graduate School of Medicine, for crucial comments and suggestions.

**Funding**

This study was funded by research grants from the Japanese Society for the Promotion of Science (#16300198 and #21500678) and the Japanese Sports Medicine Foundation (2006 and 2007).
Competing interests None.

Patient consent Obtained for figures 1 and 7 and the supplementary video.

Ethics approval This study was conducted with the approval of the Hiroasaki University Graduate School of Medicine Institutional Review Board.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES