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Lower extremity mechanics during landing after a volleyball block as a risk factor for anterior cruciate ligament injury

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ABSTRACT

Objectives: To compare lower extremity mechanics and energy absorption during two types of landing after a successful or unsuccessful block in volleyball and assess the risks of anterior cruciate ligament (ACL) injury.
Design: Cohort study.
Subjects: Fourteen elite male volleyball players (aged 24.5 ± 4.6 years; height 1.94 ± 0.06 m; mass 86.6 ± 7.6 kg).
Interventions: Subjects were required to land on force platforms using stick landing or step-back landing (with the right lower extremity stepping back away from the net) techniques after performing a standing block jump movement.
Main Outcome Measures: Vertical ground reaction force (body weight); knee flexion (degrees); knee moments (Nm/kg); and hip, knee and ankle energy absorption (J/kg).
Results: The right lower extremity showed a greater first peak of vertical ground reaction force, a greater valgus moment, lower energy absorption by the knee, and higher energy absorption by the hip and ankle joints during step-back landing.
Conclusions: The lower extremity may be exposed to a greater risk of ACL injury when stepping back from the net during the initial impact phase after a step-back landing.

1. Introduction

Anterior cruciate ligament (ACL) ruptures frequently occur in non-contact athletic situations such as cutting manoeuvres or landing from a jump (Boden, Dean, Feagin, & Garrett, 2000). ACL injury is both a serious and common problem in volleyball, and often requires medical intervention (Ferretti, Papandrea, Conteduca, & Mariani, 1992). de Loës, Dahlstedt, and Thomée (2000) reported the incidence of ACL rupture as two injured athletes per 100,000 athletes during 1 h in male volleyball.

The combination of high ground reaction forces, rapid loading times, and the high frequency of jumping and landing during practice sessions and games are thought to be significant determinants of injury (Bressel & Cronin, 2005). The typical landing after a volleyball block follows a toe–heel pattern, which is characterized by two peaks (first peak – F1 and second peak – F2) in the vertical ground reaction force (VGRF) component. Ortega, Rodrígues Bíes, and Berral de la Rosa (2010) suggested that the F2 in the force–time curve was a risk factor for injury. However, no evidence was provided for this statement. F2 occurs when the heel contacts the ground during the toe-heel landing (after the forefoot contact). It is unclear how F2 influences the position of the knee and becomes a risk factor for ACL injury. ACL injury appears to occur most often just after the initial contact with the ground or during passive loading when F1 occurs (Boden et al., 2000; Olsen, Mykelbust, Engebretsen, & Bahr, 2004). F2 occurs much later in the landing phase.

Hewett et al. (2005) indicated that the external knee valgus moment generated during a vertical drop-landing jump was a predictor of ACL injury. Withrow, Huston, Wojtys, and Ashton-Miller (2006a) demonstrated that the degree of ACL strain during landing increased with valgus loading during landing impact. The peak ACL strain occurs approximately 40 ms after touchdown (Shin, Chaudhari, & Andriacchi, 2007; Withrow et al., 2006a; Withrow, Huston, Wojtys, & Ashton-Miller, 2006b). A Combination of valgus loading with either knee in internal rotation or external rotation moment increases the tensile force on the ACL (Gabriel, Wong, Woo, Yagi, & Debski, 2004; Kanamori et al., 2000, 2002).

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However, ACL loading due to combined knee valgus and external rotation moments is less than that occurring due to either moment alone (Markolf et al., 1995).

The energy absorption profile may be altered by modifying the kinematics of landing (e.g., initial contact angle in the joints of the lower extremity and range of knee motion), the mechanical load (the height of the jump), or the motion task (Norcross, Blackburn, Goerger, & Padua, 2010). It was assumed that greater energy absorption by the leg muscles may reduce the amount of energy transferred to the capsule-ligamentous tissues (Devita & Skelly, 1992). However, Hughes, Watkins, and Owen (2010) identified a latent phase of muscle activity occurred during the first 100 ms of landing. In addition, Norcross et al. (2010) reported that greater energy absorption by the hip and ankle, and less by the knee, was associated with an increased risk of ACL injury.

There are two basic landing situations that occur when blocking a volleyball spike: 1) a successful block; and 2) an unsuccessful block. A successful block is characterized by the completion of a particular play (the ball lands on the opponent's side of the net after a block), and the player is not subject to time pressure upon landing. Because there is no time pressure on athletes during a successful block landing, they have the opportunity to alter their mechanics during landing. An unsuccessful block is characterized by the continuation of the game (after contact with an attempted block, the ball continues onto the blocker's side of the net, where it is then played for a subsequent attacking move), and the player is forced, upon landing, to step back away from the net prior to a subsequent attacking move. In this case, players must react to the play, and they may not have sufficient time to land safely.

There are several landing techniques used by volleyball players during successful or unsuccessful blocks. Two of these are the 'stick' and the 'step-back' techniques. Players usually use a 'stick' landing after a successful block and a 'step-back' landing after an unsuccessful block. A stick landing does not incorporate a subsequent move. The feet are relatively parallel at the time of ground contact and the player is able to stand upright without over-balancing. A step-back landing is part of the game strategy and results in the player stepping back from the net (to a distance of approximately 3 m) immediately upon landing. The feet are relatively parallel at the time of ground contact, and the player steps backwards with the right lower extremity immediately upon landing.

Therefore, the aim of the present study was to compare lower extremity mechanics and energy absorption during landing after either a successful or unsuccessful block and to examine the possible risks of ACL injury. We hypothesized that the type of landing would affect the mechanics of the knee, which may be related to the risk of ACL injury. We expected that the step-back landing would increase the valgus and internal rotation moments of the knee, increase F1, and reduce energy absorption by the knee during landing.

2. Methods

2.1. Subjects

Fourteen elite male volleyball players (aged 24.5 ± 4.6 years; height 1.94 ± 0.06 m; mass 86.6 ± 7.6 kg) participated in the study. All were centre blockers, receiver-hitters or universal players (6.1 ± 4.2 years of experience playing in the highest league in the Czech Republic). None of the subjects had a history of hip, knee or ankle surgery within the previous 6 months. At the time of testing, they had no injuries that prevented their participation in physical activity. Only subjects who used a step-back with their right limb were recruited for the study. Prior to testing, the aims of the study and the experimental procedures were explained to the subjects. All procedures were approved by the Research Ethics Committee of the University.

2.2. Experimental setup

Two force plates (Kistler, 9286 AA, Switzerland) embedded in the floor were used to determine the ground reaction force, with a sampling rate of 1235 Hz. Simultaneously, a motion-capture system (Qualisys Oqus, Sweden) comprising eight infra-red cameras was used to collect kinematic data, with a sampling rate of 247 Hz. A speaker emitted a beeping sound, which indicated the type of block that the subject was required to perform during each trial. The step-back landing was indicated by a short beep; the stick landing was indicated by a long beep.

2.3. Protocol

The subjects visited the laboratory during the course of 1 day. The experimental setting was based on a real game situation. The upper edge of the net was set 2.43 m above the floor. To normalise the height of the jump, a static volleyball was suspended in the space above the net. The centre of the ball was located 0.35 m above the edge of the net and 0.2 m behind the edge of the net on the opponent's side of the court. The jumping and landing tasks were as realistic as possible to increase the ecological validity of the study.

Retro-reflective markers were placed on each subject prior to data collection (Fig. 1) (Hamill & Selbie, 2004a). Calibration markers were placed bilaterally on the lateral and medial malleoli, the medial and lateral femoral condyles, the greater trochanter, and on the shoe over the first and fifth metatarsal heads. Tracking markers were securely positioned to define the trunk (acromion), the pelvis

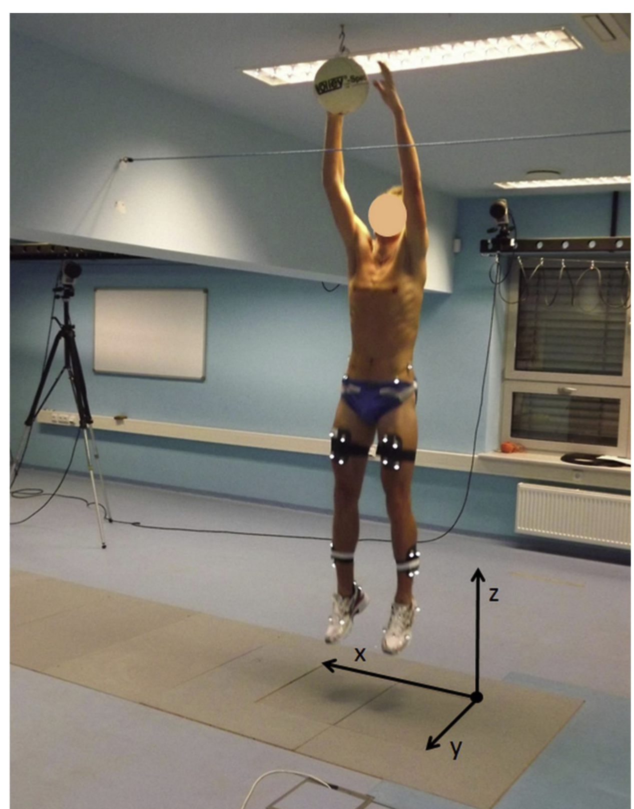

Fig. 1. Experimental setup, with a subject wearing passive reflective markers.