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Original article

Biomechanical characteristics of an anterior cruciate ligament injury in javelin throwing

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Abstract

Purpose: The purpose of this study was to understand the mechanism of an anterior cruciate ligament (ACL) injury in javelin throwing and javelin throwing techniques relevant to this ACL injury.
Methods: The patient in this study was an elite female javelin thrower who completed the first three trials and sustained a non-contact ACL injury on her left knee in the fourth trial of javelin throwing during a recent track and field meet. Three-dimensional kinematic data were collected in the injury and non-injury trials. The kinematic data of 52 male and 54 female elite javelin throwers were obtained from a javelin throwing biomechanical database.
Results: The patient had greater forward center of mass velocity and less vertical center of mass velocity after the first 25% of the delivery phase in the injury trial compared to non-injury trials. The patient had less left knee flexion angle and angular velocity but similar left knee valgus and internal rotation angles during the first 21% of the delivery phase in the injury trial compared to non-injury trials. The video images showed an obvious tibia anterior translation at the 30% of the delivery phase in the injury trial. The left knee flexion angle and angular velocity at the time of the left foot landing and the maximal left knee flexion angle during the delivery phase were not significantly correlated to the official distance for 52 male and 54 female elite javelin throwers.
Conclusion: The ACL injury in this study occurred during the first 30% of the delivery phase, most likely during the first 25% of the delivery phase. A stiff landing of the left leg with a small knee flexion angle was the primary contributor to this injury. Javelin throwers may have a soft left leg landing with a flexed knee, which may help them prevent ACL injuries without compromising performance.

Keywords: ACL injury; Biomechanics; Injury mechanism; Injury prevention; Risk factors

1. Introduction

Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries in sports[1] and has caused significant functional impairments to patients and financial burdens to the society.[2] The majority of ACL injuries are non-contact injuries in nature,[3–8] which indicates that the excessive loading that leads to ACL injuries is likely caused by inappropriate movement patterns. ACL injuries, therefore, may be prevented through training designed to improve movement patterns associated with ACL injury mechanisms and risk factors.[9,10] Understanding the mechanisms and risk factors of ACL injury is essential for preventing ACL injuries, because it will allow us to target the key elements associated with ACL injuries for intervention.

Tremendous efforts have been made to understand ACL injury mechanisms and risk factors for developing effective ACL injury prevention strategies in the last 2 decades.[11–14] Arguments regarding ACL injury mechanisms and risk factors, however, still exist. While evidence has suggested sagittal plane loading including increased anterior shear force and decreased knee flexion angle as the most important loading mechanism for the ACL,[11,12,14] some investigators believe that a frontal plane "valgus collapse" may be the major mechanism for ACL injury, especially in women.[6,15,16] Quantitative biomechanical analysis of ACL injury cases is an effective way to understand ACL injury mechanisms and risk factors. Collecting valid biomechanical data in ACL injury cases, however, is difficult. Several investigators have attempted to obtain kinematic data

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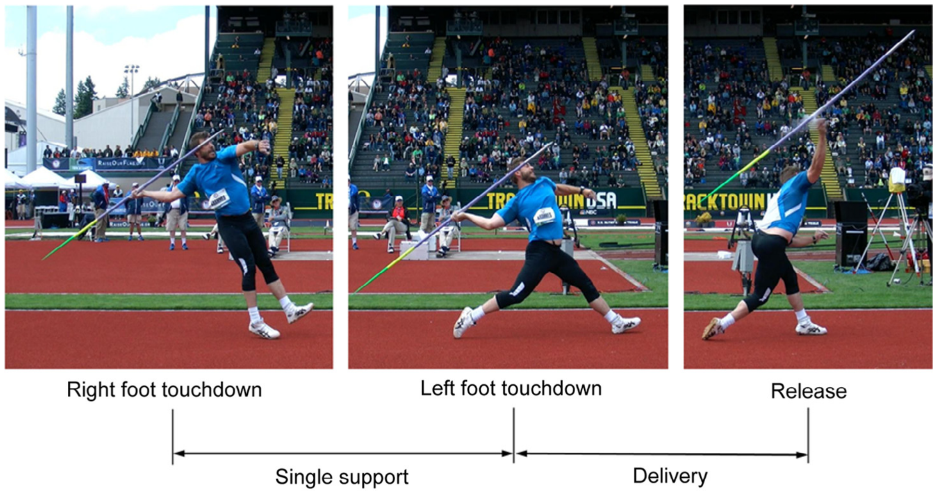

Fig. 1. Javelin throwing.

from videographic records of ACL injury cases.[3–7,17] The kinematic data collected in these studies, however, are questionable due to either the two-dimensional (2D) nature of the data or a lack of calibration of cameras when attempting to reduce three-dimensional (3D) data. Krosshaug and Bahr[18] have developed a model based manual image-matching technique to reconstruct 3D body movements from uncalibrated video cameras. This method has been applied to collect kinematic data from videographic records of ACL injury cases in football,[19] skiing,[20] team handball, and basketball.[8] However, even using multiple cameras, the minimal root-mean square errors were still 7.5° ± 12.4° for knee flexion angle, 3.9° ± 9.6° for knee valgus/varus angle, and 7.5° ± 13.9° for knee internal/external rotation angle, respectively,[18] which significantly downgraded the validity of the findings in these studies. To truly understand the biomechanical characteristics of ACL injury cases, motion data need to be collected using valid measurements with minimal errors.

An elite woman javelin thrower sustained a non-contact ACL injury during a recent track and field meet. The injury occurred well within the views of two video camcorders calibrated for the direct linear transformation (DLT) procedure[21] for quantitative video analysis. The DLT procedure has been shown as a reliable and valid measurement with high accuracy.[22,23] This injury case, therefore, provided a unique opportunity for understanding the mechanism and risk factors of ACL injury. The purposes of this study were (1) to understand the mechanism of this ACL injury through kinematic comparisons between the injury and non-injury trials of this female thrower in the same competition; and (2) to understand the relationship between javelin throwing technical factors relevant to this ACL injury and javelin throwing performance. The results of this study would provide significant information for understanding the specific mechanism and risk factors of ACL injury in javelin throwing as well as general mechanisms and risk factors of ACL injury in other sports. The results of this study would also provide information for the feasibility to modified javelin throwing techniques to prevent ACL injury without compromising performance in javelin throwing.

2. Methods

2.1. *Study design*

The current study included two components. The first component was a case study to compare selected biomechanical variables between the injured and non-injured trials of a female javelin thrower. The second component was a cross-sectional study with elite javelin throwers to determine the effect of identified risk factors on performance of javelin throwing.

2.2. *Javelin throwing*

For a right-hand thrower, javelin throwing starts with an approach run followed by a delivery strike (Fig. 1), in which the thrower releases the javelin for the longest official distance. The delivery strike can be divided to a single support phase and a delivery phase. The single support phase starts with the right foot landing and ends with the left foot landing. The delivery phase starts with the left foot landing and ends with the release of the javelin. The official distance is the distance between the nearest mark made by the javelin in the throwing sector and the front edge of the foul arch (Fig. 2).

2.3. *Subjects*

The patient in this study was an elite female javelin thrower who competed in the women's javelin throw final of a recent

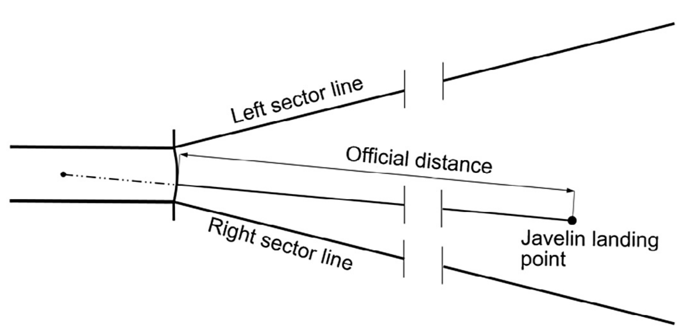

Fig. 2. Official distance in javelin throwing.