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PURSUIT

Effects of Altered Surface Inclinations on Knee Kinematics during Drop Landing

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Though it is well known that landing in an excessively inverted and plantar-flexed position commonly causes lateral ankle sprains, this landing motion has not been well studied for its effects on the knee joint. This study examines the effects of landing surface inclinations on knee kinematics during drop landing. Twelve recreational athletes performed five drop landings from an overhead bar with their feet 30 cm above three different surfaces: a flat surface, a 25° inversion surface, and a combined surface of 25° inversion and 25° plantarflexion. Three-dimensional kinematic data was collected using a seven-camera Vicon system. Selected knee kinematic variables were assessed using a one-way repeated measure analysis of variance ($p < 0.05$). Landing on the combined surface resulted in a significantly reduced knee flexion range of motion (ROM, 44.7°) compared to landing on the flat surface (51.3°) and, thus, may likely incur greater knee joint loading due to increased stiffness in the joint. In addition, landing on the combined surface produced a 41% increase in knee abduction ROM compared to the inversion surface. Landing with decreased knee flexion and increased knee abduction ROM may predispose the anterior cruciate ligament to larger strains, thereby increasing the risk of anterior cruciate ligament injury.

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1. Introduction

Lateral ankle sprains are the most common type of injury resulting from athletic activity and are often caused by landing on uneven surfaces.[1] Such landings are typically studied for their effects on the ankle joint only.[2] However, when landing, the body must decelerate rapidly and incurs a large force at the knee joint and the ankle joint. These forces cause the tibia to move anteriorly, which puts the anterior cruciate ligament (ACL) under an increased amount of stress.[3,4] Consequently, the most common non-contact mechanism for ACL injuries occurs when the center of mass is behind and away from the supporting ankle joint, resulting in an increased amount of stress. [3] Approximately 70% of all ACL injuries occur from non-contact events. [3]

Landing from a jump is one of the most frequent actions that results in ACL injury.[3,5] During a drop or jump, the center of mass is often away from the ankle joint—a position that may lead to ACL injury.[3,5] On impact, ground reaction forces can reach up to 3 to 14 times the body weight.[5] Most of these forces are absorbed by the lower extremities, causing stress on the joints, particularly the knee joint.[6] Landing technique can positively or negatively affect knee loading. Landing with a more extended knee (i.e. decreased knee flexion) is known to increase ground reaction forces. Every degree of decreased knee flexion upon landing correlates to a one percent increase in ground reaction forces.[5] It has also been observed that an increase in knee abduction is a significant predictor of increased ACL injury during the impact phase of jump landing.

Anterior tibial movement during the impact phase of landing is associated with an abduction torque about the knee joint that increases the stress on the ACL.[4] It is most likely that a combination of these movements— rather than a single event— may lead to ACL injury.

Landing on an uneven surface can be hazardous to the ankle joint and may also cause increased loading on the ACL. It is necessary to further investigate how common non-contact mechanisms of lateral ankle sprains may affect knee joint kinematics and what those subsequent changes may implicate for knee joint injury risks. This study was designed to examine the effects of landing surface inclinations on knee kinematics during drop landing. We hypothesized that landing on inclined surfaces will result in a reduced knee flexion range of motion (ROM) and an increased abduction ROM.

2. Method

Twelve healthy recreational athletes (age: 24.4 ± 4.2 years, height: 1.74 ± 0.09 m, mass: 71.4 ± 11.6 kg, 10 males and 2 females) were recruited from the University of Tennessee Knoxville campus as subjects for this study. The subjects had no history of serious lower-extremity injury and had no previous ankle sprains within the last six months. All test subjects were fully debriefed about the design of the experiment and signed an informed consent form delineating the risks of the study. The experimental protocol of the study was approved by the University of Tennessee's Institutional Review Board.

A seven-camera motion analysis system (240 Hz, Vicon Motion Analysis Inc. Oxford, UK) was used to obtain three-dimensional (3D) kinematics of both knees during testing. Subjects had rigid tracking retro-reflective marker clusters attached to both legs on the shanks, thighs, and pelvis and individual retro-reflective markers on the lateral, medial, proximal, and distal heel for tracking 3D kinematics during the motion trials (Figure 1). Anatomical markers were placed bilaterally on the lateral and medial femoral epicondyles, iliac crest, greater trochanter, lateral and medial malleoli, and the fifth and first metatarsal heads (Figure 1). Two force platforms (2400Hz, American Advanced Technology Inc., Watertown, MA, USA) were used to collect ground reaction force data in order to establish initial ground contact, defined as the onset of a force value in excess of 10 Newtons. The subjects performed a drop landing on a customized trapdoor platform, which contained a ball-point-joint surface that collapsed on contact (Figure 1). The trapdoor was

used to initiate a tilt of a 25° inversion or a combination of 25° inversion and 25° plantarflexion on the right foot of the subject (Figure 2). A flat platform was used for the left side during all trials. The trapdoor platform and flat platform were attached to the respective force platforms via double-sided tapes.

During the test session, each subject was given standardized lab running shoes (Adidas Noveto, Herzogenaurach, Germany) and asked to perform a five-minute warm up by running on a treadmill. Next, the subject practiced the drop landings from 30 cm in each landing condition in order to familiarize themselves with the conditions and prevent risk of injury. The anatomical and tracking reflective markers were then placed onto the subject accordingly. A static trial was then recorded as the subject stood still on the flat platforms. For the dynamic trials, the subjects initiated their own drop landing from an overhead bar positioned so that the feet were 30 cm above the landing platforms (Figure 2). The height of the bar was adjusted via an electrical hoist. While performing the landings, the subject was asked to land naturally and avoid overly stiff or soft landing positions of the knee joint. The subject then performed five successful drop landings in each of the three conditions, which were not randomized due to safety concerns. If the subject did not land normally or could not maintain balance upon landing, the trial was deemed unsuccessful and repeated.

The kinematic data were analyzed using the Visual3D biomechanics analysis suite (4.0, C-Motion, Inc., Germantown, MD, Figure 3). Marker data were filtered using a low-pass, fourth-order Butterworth filter at 12Hz. The 3D kinematic variables for the knee were calculated using Visual3D. Critical events and values were determined by customized computer programs (VB_V3D and VB_Table, MS VisualBasic 6.0).

The conventions of the 3D kinematic angles were defined by the right-hand rule and computed with a Cardan X-Y-Z rotation sequence in the Visual3D Software. Knee flexion, internal rotation, and knee abduction were deemed positive. Only data collected during the landing phase was analyzed. The landing phase was defined as the time from the initial contact to 350 ms afterwards. The landing phase for the left foot (flat surface) began at initial contact of the foot with the surface. The landing phase for the two inclined surfaces began when tracking marker placed on the trapdoor began its vertical velocity. The selected knee-kinematic variables were assessed by using a one-way repeated measures analysis of variance ($p<0.05$, SPSS 22, IBM Corp., Armonk, NY, USA).

3. Results

There was an increase in knee flexion ROM when comparing the inversion surface to the combined surface, but no difference was found between these two surfaces and the flat surface (Table 1). Similarly, the combined surface showed decreased maximum knee flexion angles compared to the inversion surface and the flat surface. The abduction ROM was smaller in the combined surface, compared to the inversion surface. No significant differences in peak abduction were seen between any of the surfaces.

4. Discussion

This study examined how landing on altered surface inclinations affects knee joint kinematics. We hypothesized that landing on the inclined surfaces would result in a decrease in knee flexion ROM and an increase in abduction ROM. The findings of this study supported our hypothesis.

The lower extremity joints are tasked with reducing and controlling the downward momentum that is obtained during landing from free fall. The combined landing condition (25° plantarflexion and 25° inversion) resulted in 14% less knee flexion ROM and 11% less peak knee flexion compared to the inversion surface, respectively. This resulted in increased lower limb stiffness during landing. Landing with the knee closer to full extension has been found to push the tibia anteriorly, putting the ACL at a greater risk of injury.[3] It is known that ground reaction forces increase by one percent for every degree the knee joint becomes more extended upon landing, thereby causing increased knee loading and more stress on the ACL upon ground impact.[3]

The combined surface also induced a 41% increase in knee abduction ROM compared to the inversion surface. However, there was no significant difference between the combined and flat surfaces. Links between increased knee abduction and the related increases in ACL strain have been established by numerous in vitro and in vivo studies.[4] Thus, the increase in knee abduction during the impact phase of jump landing is a key predictor of ACL injury.[3] Knee abduction during landing is caused by the abduction torques about the knee joint that can cause anterior tibial translation, as well as increased loading on the ACL.[4] This is commonly demonstrated in sports such as basketball, volleyball, and football when an athlete jumps in the air for the ball and lands on an opponent's foot.[2] The combination of these two predisposing factors intensifies ACL strain, making the knee joint significantly more vulnerable when landing on a combined plantarflexion and inversion surface.

Upon landing, simultaneous activation of the hamstring and quadriceps muscles can protect the knee joint against anterior tibial translation.[3] Hamstring contraction compresses the knee joint, which can relieve the strain on the ACL with anterior tibial translation.[3] This co-contraction can also act to reduce abduction ROM.4 A deficit in muscular strength or a delay in hamstring activation can result in increased anterior tibial translation upon impact.[3,4] Safer landing patterns can be adopted by athletes to reduce the risk of ACL injury, especially since most ACL injuries are non-contact in nature.[4] Training plans targeting improved lower extremity movements, muscular strength, and muscle recruitment can be implemented to reduce injury risk. Also, prophylactic knee braces have been developed to limit anterior translation of the tibia relative to the femur to decrease strain on the ACL.[7] These designs include a rigid lateral component that can protect the knee joint against harmful knee abduction movements while allowing for knee flexion.[7]

A major limitation of this study was that the landing surface conditions could not be randomized due to safety concerns. Additionally, the movable surface of the trapdoor platform induced impact vibrations upon contact, precipitating noise in the signals of the force platform for the two inversion conditions. This rendered the force platform signals unusable in estimating joint loading. While we cannot say with certainty that landing with a stiffer knee will cause a tear in one's ACL, this study does show that landing on the combined inclined surface causes kinematic changes that may lead to increased joint force in the knee and result in increased ACL strain.

	Flat	Inversion	Combined
Flexion ROM (°)	51.3 ±1.0	51.5 ±1.6	44.7 ±2.3*
Peak Flexion (°)	73.7 ±2.6	72.1 ±2.5	64.5 ±2.9*#
Abduction ROM (°)	2.8 ±.96	3.1 ±.83	4.7 ±.76*
Peak Abduction (°)	2.8 ±1.7	2.5 ±1.7	3.1 ±1.3

*significant difference from the inversion surface (p<.05)

#significant difference from the flat surface (p<.05)

Tab. 1: Knee kinematic variables during landing on three different surfaces: mean±STD.

Fig. 1

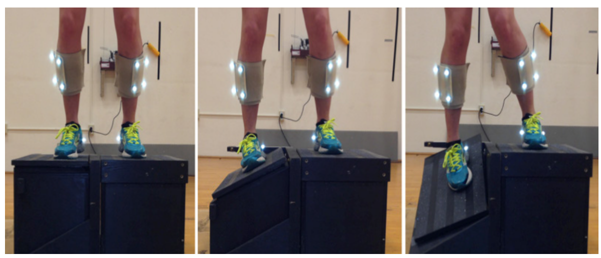

Fig. 2

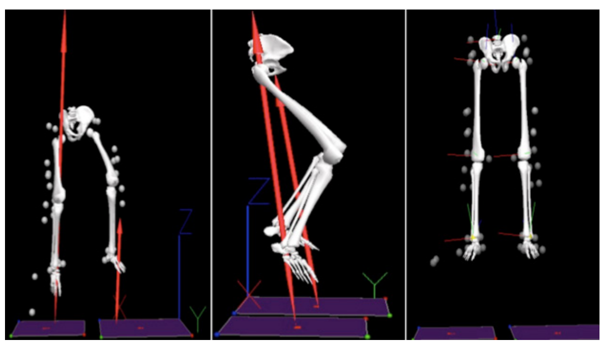

Fig.3

Fig.1: Subject in drop landing condition

Fig. 2: The three surface conditions of interest (flat landing surface (left), 25° inversion surface (middle), and combined 25°- inversion and 25° plantarflexion (right)).

Fig. 3: 3D representative model of lower extremity.

Footnotes

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