Clinical Biomechanics 28 (2013) 642–648

Contents lists available at SciVerse ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Influence of static alignment of the knee, range of tibial rotation and tibial plateau geometry on the dynamic alignment of "knee-in" and tibial rotation during single limb drop landing

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ARTICLE INFO

Article history:
Received 21 November 2012
Accepted 8 May 2013

Keywords:
Static knee alignment
Dynamic knee alignment
"Knee-in & toe-out"
Range of tibial rotation
Posterior tibial slope angle
Valgus
Varus

ABSTRACT

Background: Dynamic alignment of "knee-in & toe-out" is a risk factor for anterior cruciate ligament injury and is possibly influenced by static knee alignment, range of tibial rotation and tibial plateau geometry.
Methods: Twenty-eight healthy women were classified into valgus, neutral and varus groups based on static alignment of their knees. A 3-dimensional motion analysis was carried out for a single limb drop landing. The range of tibial rotation and posterior tibial slope angle was measured by MRI. Comparison among the 3 groups and correlation between the angles was analyzed during motion.
Findings: The differences between the medial and lateral posterior tibial slope angles were greater ($P = 0.019$), also range of internal tibial rotation for the valgus group ($P = 0.017$) and, for the varus group, the "knee-in" angle ($P = 0.048$). The "knee-in" angle correlated significantly with the tibial rotation angle ($R = -0.39$, $P = 0.038$), and the range of tibial rotation correlated with the variations between the medial and lateral posterior tibial slope angles ($R = 0.90$, $P = 0.003$).
Interpretation: The range of tibial rotation, posterior tibial slope and "knee-in" angle varied according to whether the knee was in valgus or varus with the range of tibial rotation dependent on the posterior tibial slope angle. The greater the "knee-in" angle became, the smaller the internal tibial rotation was, acting in a kinetic chain. The results suggest that static alignment of the knee may be utilized as a predictor for potential problems that occur during motion.

1. Introduction

Anterior cruciate ligament (ACL) injuries frequently occur in sports activities of young women college students during acute deceleration, cutting, and single-limb-land maneuvers (Arendt and Dick, 1995). In such circumstances the knee is fully extended or slightly flexed, and the limb is in a significant "knee-in" (apparent, but not true, valgus) position with the tibia rotating either internally or externally (Boden et al., 2000; Nagano et al., 2007; Olsen et al., 2004). Hewett et al. (2005), Kobayashi et al. (2010) and Krosshaug et al. (2007) analyzed dynamic alignment of noncontact ACL injury and found that "knee-in & toe-out" (or valgus with foot abducted) was the commonest dynamic alignment position for knee injury during a landing maneuver. Anatomically, valgus of the knee, internal tibial rotation (TR) and anterior tibial translation cause excess stress on ACL (Berns et al., 1992; Withrow et al., 2006; Zantop et al., 2007), so these joint movements may occur in the dynamic alignment of "knee-in & toe-out".

Static alignment of the lower limb is a risk factor contributing to ACL injuries in addition to dynamic alignment of the knee, and assessment of static alignment while standing enables investigators to predict a possible motion in action (Nguyen et al., 2011). In static alignment of the knee on a frontal plane, the knee is sharply shifted to "knee-in" position upon loading (Andrews et al., 1996), and ACL injuries may result because a large rotation occurs at the knee joint (Urabe, 1998). Moreover, the larger the tibio-femoral angle is (or larger the valgus is) on the frontal plane, the larger the Q-angle will be (Horton and Hall, 1989; Nguyen et al., 2009), which affects "knee-in" during motion. However, little evidence exists on the relationship between valgus/varus of the knee in static alignment and its effect on "knee-in" in dynamic alignment.

Arai and Miaki (2012) reported that individuals with valgus in static alignment of the knee showed a smaller "knee-in" angle during the single-limb-land task and a greater tendency for increased internal TR than for those with varus. Furthermore, "knee-in" and TR act in a kinetic chain, and the more externally the tibia rotates, the more "knee-in" increases (Arai and Miaki, 2012). However, the influence of valgus/varus during static alignment on "knee-in" and TR remains largely unknown. Patients with valgus/varus deformity show a greater range of TR than those without deformity, thereby demonstrating how the range of TR affects static alignment of the knee (Sun et al., 2009). However, individuals

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http://dx.doi.org/10.1016/j.clinbiomech.2013.05.003

with varus show greater external TR when the knee is extended than those with valgus (Cooke et al., 2000). Due to the geometry of the tibial plateau with its posterior slope and variations in angle on its medial and lateral aspects, valgus/varus occurs accompanied with a varying TR range (Cooke et al., 2000; Ries, 1995). Therefore, static alignment of the knee may be affected by range of TR even in normal individuals, and the angle of the posterior tibial slope (PTS) and range of TR affect “knee-in” and TR during motion.

The 2 hypotheses were as follows: Hypothesis I: the range of TR and PTS angle would vary according to the variations in valgus/varus of the knee in the position of static alignment; and Hypothesis II: the variations in the range of TR and PTS angle would influence the “knee-in” angle during motion. The purpose of this study was to elucidate the influence of static alignment of the knee, range of TR and geometry of the tibial plateau on “knee-in” and TR during motion.

2. Methods

2.1. Participants

Seventy-eight women students attending the University of Kanazawa were screened for testing of their knee alignment while standing with only oral informed consent required. An assessment was carried out to define whether the knees were in varus, valgus or neutral. This procedure involved measurement of the distance between the medial malleoli and that between the femoral medial epicondyles, followed by dividing each of the values by the crus length, resulting in degree of varus or valgus. This assessment resulted in 49 women with varus, 15 with valgus and 14 in neutral, respectively. Twenty-four women out of 49 with varus and 7 out of 15 with valgus exceeded the median degree of varus or valgus and met the criteria for participating in this study, as so did 14 ‘neutral’ women. However, this resulted in only 28 of these individuals signing the written consent form to participate in the study. Accordingly, 10 women with varus were allocated to the varus group, 7 women with valgus to the valgus group and 11 of the ‘neutral’ women to the neutral group. The physical characteristics of the participants are shown in Table 1.

The Medical Ethics Review Board of the University of Kanazawa approved this study. All participants demonstrated no medical history of any orthopedic condition or disease of either lower limb.

2.2. Testing procedure

In order to perform a single limb drop landing each participant in the 3 groups was instructed to stand on the non-dominant leg on a 30 cm high platform with the toes reaching the edge, to place their hands on the iliac crests and to face forward to prevent trunk rotation. The dominant and non-dominant legs were not to touch. The non-dominant leg was selected for landing because noncontact ACL injuries in women are likely to occur to the non-dominant leg (Brophy et al., 2010). The non-dominant leg was defined in this study as the one that would not kick a ball (Borotikar et al., 2008). They, then, performed the single-limb-land task with the non-dominant leg onto the ground reaction force plate. They were to land on the non-dominant leg with the heel on a line that was 30 cm away from the front of the platform and to remain standing still with the foot in any position. The participants performed 10 practice trials, followed by test trials. Test trials were judged a failure when the dominant leg touched the ground, their trunk swayed excessively or their pelvis tilted. Test trials were repeated until they successfully completed 8 perfect test trials.

Table 1
Mean (±SD) physical characteristics of the participants for the 3 groups.

	Valgus group (n = 7)	Neutral group (n = 11)	Varus group (n = 10)
Age (years)	20.4 (0.5)	22.7 (4.0)	21.0 (0.5)
Height (cm)	160.9 (5.4)	158.6 (3.6)	161.0 (8.3)
Mass (kg)	60.7 (5.6)	51.9 (5.3)	49.7 (8.9)
Degree of valgus or varus (%)	9.8 (4.5)		10.2 (2.2)
PW/FL (%)	63.3 (3.7)	64.4 (6.2)	64.8 (6.1)

PW/FL, proportion of pelvic width to femoral length.

2.3. Motion analysis

A 6-camera high-speed (250 fps) motion analysis system (Vicon-Mx; Vicon Motion Systems, Oxford, UK) was used to record a single limb drop landing. Spherical reflective markers were placed according to a Plug-in-gait marker set, and the positions of attachment are shown in Fig. 1. During the single-limb-land maneuver, the ground reaction force was recorded through a force plate (9286AA, Kistler, Tokyo, Japan) at a sampling rate of 1000 Hz. Cameras and the force plate were synchronized with a trigger switch.

2.4. Data processing and analysis

Mean values for the 8 successful test trials were taken as the representative values. The following 6 angles were measured: “knee-in” (peak “knee-in” or PK) or “knee-out” (positive values corresponded to “knee-in”), varus or valgus (positive values corresponded to varus), knee flexion or extension (positive values corresponded to flexion), TR (positive values corresponded to internal rotation), hip adduction or abduction (positive values corresponded to adduction), and hip internal or external rotation (positive values corresponded to internal rotation). These angles were calculated on initial contact (IC) with the force plate to PK as well as variations in angle from IC to PK. Regarding the measurement for “knee-in”, the positional information obtained from the markers by the motion analysis system was converted to a text file and entered into 3-D motion analysis software (Frame DIAS IV, DKH, Tokyo, Japan). The “knee-in” angle is schematically demonstrated in Fig. 1C.

2.5. The range of TR and posterior tibial slope (PTS) angle

In order to prepare for measurement of TR the knee was scanned in a supine position by MRI (APERTO Eterna; Hitachi Medical Corp., Tokyo, Japan). Two anatomical positions were established for scanning: the hip and knee joints were in 30° flexion, together with the knee in either maximum external or internal rotation. First, the participant's lower limb was placed on a foam polystyrene rest and the thigh was fixated with towels and belts to maintain the hip and knee in 30° flexion. Next, the lower limb was scanned while being manually fixated within the limit of pain by one investigator (TA) in a position of either maximum external or internal rotation of the tibia. At the same time, the other investigator (HM) fixated the thigh to prevent movement of the hip joint. This was followed by taking 22 horizontal sliced images during a 1-min period from the distal end of the femur to the proximal end of the tibia for each anatomical position in a sequence of T2 weighted images (magnetic field strength: 0.38 T; repetition time: 2824 ms; and echo time: 112 ms) using a bony coil. Then, the frontal plane from these 22 slices was determined in order to identify the patella, medial and lateral epicondyles, intercondylar fossa, tibial medial and lateral condyles and tibial tuberosity. For analysis of the obtained images we utilized image analysis software (ImageJ 1.45, National Institutes of Health, Maryland, USA). For image analysis of the femur, the most distal image was selected from among the sequential images in which both the medial and lateral condyles were in approximation at the uppermost level of the intercondylar fossa and, similarly for the tibia, the most proximal image with a clear outline of the tibial plateau was selected. The range of TR was defined as the angle between the tangential line from the posterior edge of both the femoral condyles and the tangential line from the posterior