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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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## **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:* In this descriptive laboratory study 28 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 were measured by MRI. Results were compared among the 3 groups, and correlation between the angles was analyzed during motion.

*Findings:* The range of internal tibial rotation for the valgus group was significantly greater ( $P=0.017$ ) and the differences between the medial and lateral posterior tibial slope angles were also greater ( $P=0.019$ ). For the varus group, the “knee-in” angle was significantly greater ( $P=0.048$ ). 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.

***Keywords:***

Static knee alignment; Dynamic knee alignment; “Knee-in & toe-out”; Range of tibial rotation; Posterior tibial slope angle; Valgus; Varus

## **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 in 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 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 in 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 30cm 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 30cm 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.

### *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 Figure 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 1000Hz. 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), 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 (DKH Frame DIAS IV, Tokyo, Japan). The “knee-in” angle is schematically demonstrated in Figure 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-minute 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: 0.38T; repetition time: 2824ms; and echo time: 112ms) 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 edge of the tibial plateau (Lerner et al., 2003; Samukawa et al., 2009) (Fig. 2). Also calculated was the

proportion of internal and external TR to maximum TR that was a combined range of internal and external TR.

After conferring on a report by McLean, et al. (2010) it prompted the authors to repeat MRI on 4 participants' knees of the valgus group and 4 participants of the varus group, who agreed to undergo the additional scanning, in order to take into account any influence of the PTS angle on the range of TR. Consequently, MR images of the frontal, sagittal and horizontal planes of the knee were taken, followed by determination of the PTS angle (Fig. 3). Specifically, we determined the sagittal plane of the knee joint (Fig. 3C) as being on a level with the anteroposterior line along the intercondylar eminence on a horizontal plane (line OP, Fig. 3A) corresponding to the longitudinal axis of the tibia on a frontal plane (Fig. 3B). Following this, we obtained MR images of the tibial plateau on a sagittal plane (Figs. 3D and 3E) that was in parallel to the pre-determined sagittal plane (Fig. 3C) at a point of maximum anteroposterior diameter for each of the medial and lateral condyles of the tibial plateau (lines AB and CD, Fig. 3A) in parallel to the anteroposterior line along the intercondylar eminence on a horizontal plane of the tibial plateau. The PTS angle was defined as the angle between the perpendicular line OP (Fig. 3C) to the tibial longitudinal axis and the line connecting the anterior and posterior edges of the tibial plateau (Figs. 3D and 3E) at the

longitudinal axis of the tibial shaft that was equally divided on a sagittal plane (Fig. 3C) (Hashemi et al., 2010; Hashemi et al., 2008). Again, the ImageJ 1.45 was utilized to analyze the obtained images. The positive value demonstrated that the posterior edge of the tibial plateau was lower compared to its anterior edge. Also calculated was the difference in angles for the 2 groups that resulted from subtracting the amount of the medial PTS angle from the lateral PTS angle.

### *2.6. Statistical analysis*

One-way analysis of variance was employed for a comparison among the 3 groups, followed by Tukey-Kramer multiple comparison in the event of statistical significance. A Pearson's product moment correlation coefficient was used for the correlation analysis. F-test was carried out, followed by independent *t*-test or Welch's test for the comparison of the PTS angle between the valgus and varus groups. An alpha level of .05 was selected for statistical significance, using the SPSS version 11.9 (SPSS Japan Inc.) and the computer software Microsoft Excel 2010 for the data analysis.

## **3. Results**

### *3.1. Motion analysis (Table 2)*

As the landing knee became "knee-in", the following the lower limb joint pattern for

all 3 groups was demonstrated: the ankle was in dorsiflexion, pronation and abduction, the knee in flexion, varus and internal rotation, and the hip in flexion, adduction and internal rotation, respectively.

Variation in “knee-in” angle from IC to PK for the varus group was significantly greater than that for the valgus group ( $P=0.048$ ). The knee was in varus from IC onward for all 3 groups, and variation in varus angle from IC to PK for the valgus group was significantly greater than that for the varus group ( $P=0.047$ ). All 3 groups demonstrated internal TR with no statistical significance. The hip was in adduction and internal rotation on IC for all 3 groups, and the hip abduction angle for the varus group was significantly greater than that for the neutral group ( $P=0.036$ ). And variation in adduction angle from IC to PK for the varus group was greater than that for the valgus group with no statistical significance.

### 3.2. *The range of TR* (Table 3)

With the knee in a 30° flexed position the range of internal TR for the valgus group was significantly greater than that for the varus group ( $P=0.017$ ). There was no significant difference in the range of external TR between the valgus and varus groups. The proportion of internal TR to maximum (or combined) TR for the valgus group was significantly greater than that for the varus group ( $P=0.019$ ), and, similarly, the

proportion of external TR to maximum TR for the varus group was greater than that for the valgus group ( $P=0.019$ ).

### 3.3. *PTS angle* (Table 3)

There was no significant difference in the medial and lateral PTS angles between the valgus and varus groups. The difference in angles for the 2 groups resulting from subtracting the degree of the medial PTS angle from the lateral PTS angle was greater in the valgus group than in the varus group ( $P=0.019$ ). In addition, both the medial and lateral PTS angles in the valgus group were virtually the same, whereas there was a tendency for the medial PTS angle in the varus group to be greater than that for the lateral PTS angle.

### 3.4. *Correlations among the “knee-in” angle, hip adduction/abduction angle, hip rotation angle, varus/valgus angle, TR angle, range of internal TR and PTS angle* (Table 4)

There was a significantly negative correlation between the variation in the “knee-in” angle from IC to PK and the angle of internal TR at PK ( $R=-0.39$ ,  $P=0.038$ ). There was a significantly positive correlation between the variation in the “knee-in” angle from IC to PK and that of the angle of hip adduction from IC to PK ( $R=0.80$ ,  $P<0.001$ ), but a significantly negative correlation was yielded between the variation in the angle of

hip adduction from IC to PK and the angle of internal TR at PK ( $R=-0.52$ ,  $P=0.004$ ). Furthermore, there was a significantly positive correlation between the range of internal TR and the angle resulting from subtracting the medial PTS angle from the lateral PTS angle ( $R=0.90$ ,  $P=0.003$ ,  $n=8$ ). There was no significant correlation between the “knee-in” angle and valgus/varus angle at IC and PK with no correlation for variations from IC to PK.

#### **4. Discussion**

We found that the range of internal TR for the valgus group was significantly greater than that for the varus group as shown on the MR images. In addition, the values for the range of internal TR, when divided by those for the combined range of internal and external TR, were significantly greater in the valgus group than for those in the varus group, but these same computed values for the range of external TR were significantly greater in the varus group than for those in the valgus group. This means that the tibia inclined to gravitate to more internal rotation in the valgus group and external rotation in the varus group. This finding supports Hypothesis I.

In static alignment of the knee the varus group demonstrated a greater medial PTS angle compared to its lateral PTS angle. A positive correlation was demonstrated



between the range of internal TR and the difference in the lateral/medial PTS angles. This finding shows that the range of TR due to being in valgus or varus may be affected by a difference in the medial and lateral PTS angles due to the effect of valgus or varus in static alignment of the knee. As for the relationship between the range of TR and PTS angle, the greater the PTS angle, the more posteriorly the femoral epicondyles move (Giffin et al., 2004), and the greater the lateral PTS angle, the greater the internal TR. In contrast, due to the concave medial plateau geometry, the displacement of the femoral epicondyle is small (Kapandji, 1987). Consequently, external TR is less likely to increase, even though the lateral PTS angle increases, for an increase in the medial PTS angle shifts the tibiofemoral contact point anteriorly. This is accompanied by anterior shifting of the TR axis located on the medial tibial plateau, so that internal TR is restrained by the increased tension on ACL (Fig. 4) (McLean et al., 2010). From these findings, an increase in the lateral PTS angle may lead to an increase in internal TR, while an increase in the medial PTS angle restrains internal TR. Our varus group might have exhibited smaller internal TR compared to those in the valgus group because the former's lateral PTS angle was smaller than the medial PTS angle, while the medial and lateral PTS angles of the latter were almost equal. This finding is in agreement with a statement by Kendall et al. (1993) who have

demonstrated that, when in standing the knee is in varus, the tibia rotates externally, while the femur rotates internally and, when the knee is in valgus, the tibia rotates internally and the femur externally. These facts suggest that the tension of ACL during motion varies in individuals with valgus and varus in static alignment of the knee, even though the internal TR angle is similar.

The motion analysis of the single-limb-land task in our study demonstrated that variations in “knee-in” angle from IC to PK for the varus group was significantly greater than that for the valgus group, which is in agreement with the result of the study by Arai and Miaki (2012). The negative correlation between the variation in the “knee-in” angle from IC to PK and the angle of internal TR at PK demonstrate that “knee-in” and TR act in a kinetic chain, and the greater the internal TR, the smaller the variation in “knee-in” in this single-limb-land maneuver, which is also in agreement with the result of the study by Arai and Miaki (2012). However, the range of TR did not correlate with the angles of both internal TR and “knee-in”, hence rejection of Hypothesis II, although McLean et al. (2010) have found a positive relationship between PTS and movement. The reason for this rejection may be that movement is not only influenced by osteo-articular factors, but myo-ligamentous factors must also be considered in order to assess movement involving the range of TR and PTS angle.

The variation in hip adduction angle from IC to PK significantly correlated with that in “knee-in” angle from IC to PK and internal TR angle at PK. The hip joint has been found to adduct and internally rotate during “knee-in” in motion (Howard et al., 2011; Nyland and Caborn, 2004; Willson and Davis, 2008), and all of the participants in this study exhibited a similar tendency. Also in this study, the “knee-in” angle did not correlate with the angle of internal hip rotation, but did correlate with the hip adduction angle. This finding suggests that the “knee-in” angle may be influenced by the angle of hip adduction. A negative correlation was found between the angle of hip adduction from IC to PK and that of internal TR at PK, which suggests that the greater the internal TR angle, the smaller the hip adduction angle is.

A landing maneuver involves absorption of impact, and, during this period, successive movement occurs from the ankle to knee and from the knee to hip (Nyland and Caborn, 2004). In a single-limb-land task the landing leg receives a ground force, then the tibia rotates internally and shifts medially as the knee joint is flexed because the subtalar joint is pronated and abducted, and, then, the talocrural joint is dorsiflexed. Kapandji (1987) states that, as the tibia rotates internally with the knee in flexion, the posterior cruciate ligament and medial and lateral collateral ligaments become lax and ACL becomes strained. The tension produced by the stretched ACL in addition to the

movement of the tibia induces the femur into adduction and internal rotation, possibly resulting in “knee-in” during a landing maneuver.

The findings from this study demonstrated that “knee-in” took place due to internal TR and adduction and internal rotation of the hip joint, which was unrelated to the occurrence of either valgus or varus during the landing maneuver. “Knee-in” is frequently described as valgus in dynamic alignment of the knee because it resembles valgus on a frontal plane. However, in reality, movement that occurs with internal TR during “knee-in” is relative to the femoral movement, which simply does not take place on a frontal plane (Quatman and Hewett, 2009). In fact, in analyzing the movement of the knee one must acknowledge that “knee-in” and dynamic valgus are entirely different movements in addition to movements of the knee being also affected by those of the ankle and hip joints. Although we found no relationship among the range of TR, “knee-in” angle” and TR angle during the single limb land maneuver, the PTS angle, range of TR and “knee-in” angle differed due to varying static alignments of the knee. However, we believe that other anatomical factors may come into play regarding the interaction of movement and anatomical make-up. There has been a study (McLean, et al., 2010) that verified a correlation between movement and factors such as PTS. Thus, further studies will be required to elucidate whether or not valgus

or varus in static alignment of the knee contributes to risk factors for ACL injuries.

Some limitations exist in this study. Manual fixation of TR during MRI scanning may have prevented a consistent rotatory moment, consequently, causing a confounding effect on the reading for the TR measurement. However, our result can be justified as it was very similar to those of a Mouton et al's (2012) study in which the range of TR was measured with application of a consistent moment within the limit of pain. Further, reflective skin markers may have caused a mismatch of movement between the skin and underlying bones, which could have resulted in a measuring error for the knee and hip angles. However, we considered this limitation to be negligible because the amount of variation was relative. In addition, the angles at IC and PK were expressed in absolute values and would have had a minimal effect on our results, for in this study there was a positive correlation between the variation of "knee-in" angle and TR angle at PK, which was in agreement with that of Arai and Miaki (2012).

## **5. Conclusion**

The results of this study revealed that the PTS angle and range of TR varied according to valgus or varus on static alignment of the knee. The individuals with valgus were found to have a larger variation in the lateral PTS angle compared to

medial PTS angle and also a larger internal TR compared to those with varus. Although variations in “knee-in” angle in valgus or varus were apparent on static alignment of the knee, the PTS angle and range of internal TR angle during the single-limb-land task did not affect the “knee-in” and tibial rotation angles.

### **Conflict of interest statement**

Both authors contributed significantly to the study and manuscript preparation, and neither of them demonstrate any conflict of interest regarding this submission.

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## Figure captions

**Fig. 1.** Positions for the attachment of the reflective markers (A and B) and the definition of the “knee-in” angle (C). A spherical reflective marker was placed bilaterally on the anterior superior iliac spine, posterior superior iliac spine, thigh, lateral epicondyle, crus, lateral malleolus, calcaneal eminence and head of the 2nd metatarsal according to a Plug-in-gait marker set. The “knee-in” angle was defined as the outer angle between the line from the thigh marker to the lateral epicondyle marker and the one from the lateral malleolus marker to the lateral epicondyle marker, which was subtracted from  $180^\circ$  and projected on a frontal plane.

**Fig. 2.** Determination of the range of tibial rotation (TR). A, Caudo-cephalic view of the horizontal cross-section of the femur at maximal internal TR. B, Caudo-cephalic view of the horizontal cross-section of the tibia at maximal internal TR. C, Caudo-cephalic view of the horizontal cross-section of the femur at maximal external TR. D, Caudo-cephalic view of the horizontal cross-section of the tibia at maximal external TR. 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 edge of the tibial plateau. The broken line on B is parallel to the line on A, and the angle between the 2 lines on B is the range of tibial internal rotation. The broken line on D is parallel to the line on C, and the angle between the 2 lines on D is the range of tibial external rotation.

**Fig. 3.** Measurement of the PTS angle. Image A shows the tibial plateau on a horizontal plane with line OP equally dividing the intercondylar eminence, and lines AB and CD are in parallel with line OP at a point of their largest anteroposterior diameters of the medial and lateral tibial slopes. Image B shows the tibia on a frontal plane with a line equally dividing the tibial shaft on the longitudinal axis of the tibia. Image C shows the tibia on a sagittal plane and a vertical line equally dividing the tibial shaft, which corresponds to the longitudinal axis of the tibia represented in Figure 4B. Line OP is perpendicular to the longitudinal axis of the tibia. Image D shows an image of line AB represented in Figure 4A. The angle between OP and AB is the PTS angle with line OP being parallel to line OP represented in Figure 4C. Image E shows line CD represented in Figure 4A. The angle between OP and CD is the PTS angle with line OP being parallel to line OP represented in Figure 4C.

**Fig. 4.** The relationship between the TR axis and internal TR. With internal TR, the tibia's rotation axis on the medial tibial plateau shifts anteriorly (as demonstrated on schematic illustrations A to B), causing further forward shifting of the rotational trajectory, so that internal rotation is restrained by the increasing tension on ACL. A, A cephalo-caudal view of the tibial plateau: trajectory of the ACL attachment during TR around its own axis when the PTS angle is small; B, a cephalo-caudal view of the tibial plateau: trajectory of the ACL attachment during TR around its own axis when the PTS angle is large.

### **Table captions**

#### **Table 1**

Mean ( $\pm$  SD) physical characteristics of the participants for the 3 groups.

PW/FL, proportion of pelvic width to femoral length

#### **Table 2**

Mean ( $\pm$  SD) variations in the "knee-in" angle from initial contact to peak "knee-in" ( $^{\circ}$ )

and angles at initial contact (°) and peak “knee-in” (°) for the 3 groups.

IC, initial contact; PK, peak “knee-in”; <sup>a</sup>*P*=0.048 (vs. valgus group); <sup>b</sup>*P*=0.047 (vs. valgus group); <sup>c</sup>*P*=0.036(vs. neutral group)

### **Table 3**

Mean (± SD) range of TR with the knee in 30° flexion (°) and proportion of rotation to maximum rotation for the 3 groups and mean (± SD) PTS angle (°) for the valgus and varus groups.

TR, tibial rotation; PTS, posterior tibial slope; <sup>a</sup>*P*=0.017 (vs. valgus group); <sup>b</sup>*P*=0.019 (vs. valgus group); <sup>c</sup>*P*=0.019 (vs. valgus group)

### **Table 4**

Correlations among the parameters. The parameters consisted of the following: 1) “knee-in” angle; 2) hip adduction/abduction angle; 3) hip rotation angle; 4) varus/valgus angle; 5) tibial rotation angle; 6) range of internal tibial rotation; and 7) difference between the lateral and medial PTS angles. The number of participants for parameters 1 to 6 was 28 and that for parameter 7 was 8. The sections for analyses were as follows: 1) angle at IC; 2) angle at PK; and 3) variations in angle from IC to



PK.

PK, peak “knee-in”; IC, initial contact; PTS, posterior tibial slope



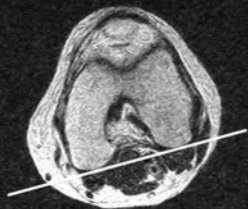
**A**



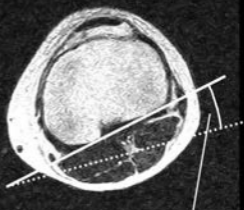
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**C**

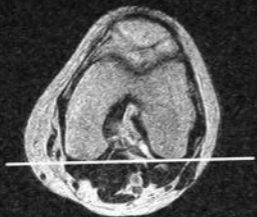


**A**



Range of internal TR

**B**

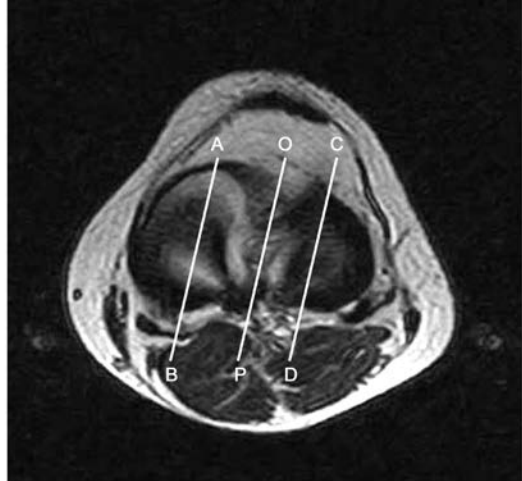


**C**



Range of external TR

**D**



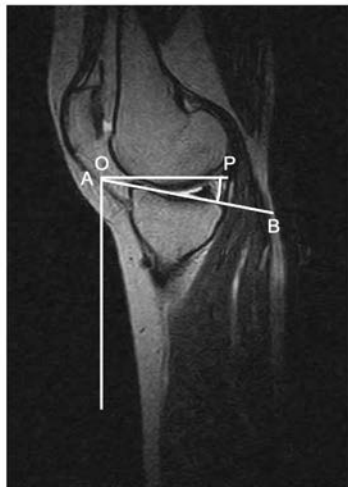
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B



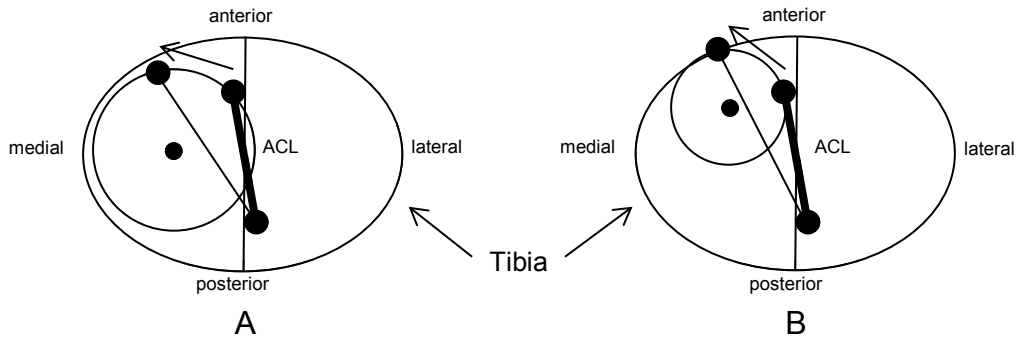
C



D



E



**Table 1**

	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)

**Table 2**

	Angles at IC			Angles at PK			Variations from IC to PK		
	Valgus group	Neutral group	Varus group	Valgus group	Neutral group	Varus group	Valgus group	Neutral group	Varus group
"knee-in"	2.8(2.5)	2.8(2.1)	0.6(2.1)	4.3(7.6)	10.6(6.3)	9.2(5.7)	1.5 (6.4)	7.8 (6.1)	8.6 (4.6) <sup>a</sup>
<i>Knee</i>									
varus/valgus	0.1(3.4)	0.9(2.9)	3.8(4.9)	13.4(8.9)	8.4(5.6)	10.0(10.3)	13.4 (6.2)	7.4 (4.5)	6.3 (6.5) <sup>b</sup>
<i>Knee</i>									
flexion/extension	9.2(3.1)	11.5(3.4)	11.2(3.8)	44.5(7.0)	47.8(5.2)	49.1(4.4)	35.3 (6.1)	36.3 (4.4)	37.9 (4.9)
tibial rotation	6.4(3.6)	4.4(4.7)	5.4(4.5)	15.0(5.5)	12.7(4.9)	13.9(5.2)	8.6 (5.5)	8.4 (4.5)	8.5 (5.4)
<i>Hip</i>									
adduction/abduction	-7.9(3.3)	-6.4(3.7)	-10.4(3.3) <sup>c</sup>	1.4(7.3)	4.9(4.3)	3.2(5.6)	9.3 (4.3)	11.2 (4.3)	13.6 (4.4)
hip rotation	-1.9(8.6)	1.5(9.4)	-5.0(11.9)	14.9(9.4)	14.0(9.1)	12.0(9.4)	16.8 (9.1)	12.6 (5.3)	17.0 (6.0)

**Table 3**

Range of TR with the Knee in 30° Flexion			
	Valgus group	Neutral group	Varus group
Internal rotation	16.2 (3.0)	12.3 (4.3)	10.2 (4.5) <sup>a</sup>
External rotation	7.7 (4.7)	12.3 (7.3)	12.4 (4.5)
Maximum rotation	23.9 (4.9)	24.6 (7.1)	22.6 (4.8)
Internal rotation /Maximum rotation (%)	69.6 (15.6)	51.9 (17.2)	45.4 (16.8) <sup>b</sup>
External rotation /Maximum rotation (%)	30.4 (15.6)	48.1 (17.2)	54.6 (16.8) <sup>b</sup>
PTS Angle			
	Valgus group (n=4)		Varus group (n=4)
Lateral	12.0 (4.9)		8.2 (3.2)
Medial	11.5 (3.7)		15.2 (3.6)
Lateral minus medial	0.5 (2.2)		-7.0 (4.2) <sup>c</sup>



**Table 4**

	Variation in hip adduction/abduction angle	Angle of tibial rotation at PK	Range of internal tibial rotation	Difference between the lateral and medial PTS angles
Variation in “knee-in” angle	$R=.80$ $P<.001$	$R=-.39$ $P=.038$	$R=-.49$ $P=.22$	$R=.65$ $P=.079$
Variation in hip adduction/abduction angle		$R=-.52$ $P=.004$	$R=-.42$ $P=.30$	$R=.675$ $P=.066$
Angle of tibial rotation at PK			$R=.19$ $P=.65$	$R=-.46$ $P=.25$
Range of internal tibial rotation				$R=.90$ $P=.003$