Analysis of Tibial Rotation Using Magnetic Resonance Imaging

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# 1. INTRODUCTION

The knee joint is the largest joint in the human body and is capable of flexion-extension, varus-valgus, and internal-external rotation movements (Takeda et al., 1994). Together with the surrounding muscles, the ligaments of the knee play a key role in controlling the displacement of the tibia on the femur, and injury to these ligaments can cause joint laxity, or instability, leading to loss of joint control (Magee, 2002). The tibia rotates internally when the knee flexes and externally when it extends, a phenomenon known as "screw-home motion" (Hallen & Lindahl, 1966; Piazza & Cavanagh, 2000). The articular surfaces of the tibia and the femur are incongruent, enabling the two bones to move by differing amounts, guided by muscles and ligaments (Magee, 2002).

Two features common to previous studies that need to be addressed are that the observed angles of tibial rotation vary widely and the studies were difficult to generalize. One possible explanation is that the studies did not share a common definition of tibial rotation. In addition, tibial rotation was usually examined at angles close to terminal knee extension so as to confirm the existence of screw home motion and to determine the effects of injuries. Lastly, side-to-side differences are as yet undetermined even though this is considered essential information for clinicians wanting to see the effects of injuries and to regain tibiofemoral joint mobility.

Magnetic Resonance Imaging (MRI hereafter) is becoming an increasingly valuable tool for in vivo studies of musculoskeletal biomechanics, as it is a non-invasive means of obtaining precise anatomic and geometric information. To the best of our knowledge, MRI has never been used to measure tibial rotation in normal knees although previous researchers have compared the tibial rotation of pathological knees with that of intact knees (Czerniecki et al., 1988; Nagao et al., 1998; Brandsson et al., 2002; Georgoulis et al., 2003). Furthermore, most of

these studies examined tibial rotation when the knee position was close to fully extended. Although several studies have been conducted to determine tibial displacement on the femur at different knee angles of flexion (Iwaki et al., 2000; Logan et al., 2004), the degree of in vivo tibial rotation at different angles remains relatively undetermined.

As such, the purposes of this study were two-fold: to determine the angle of tibial rotation at different angles of knee flexion using MRI, and to identify any side-to-side differences.

## 2. METHODS

### 2.1 Subjects

Ten normal subjects (5 male and 5 female) were recruited for this study. The mean age was 19.9 ± 1.6 years old; mean weight was 55.9 ± 10.7 kg; and mean height was 162.3 ± 8.4 cm. The subjects had no previous histories of knee injuries or neurological disorders. Potential subjects were excluded if they had any general joint laxity or history of claustrophobia. All subjects were required to read and sign an informed consent form.

### 2.2. Test Procedure

The Sapporo Medical University Institutional Review Board approved this study.

Subjects lay in a supine position inside the MRI magnet on a specially-designed apparatus made of wood and plastic that allowed the examiner to set the knee flexion angles and also stabilized the femur and tibia (Fig. 1). The hip angle was fixed at 45 degrees, and knee flexion angles of 30, 60, and 90 degrees were chosen for measurement. The position of each subject on the MRI apparatus is shown in Fig. 2. Subjects were asked to relax during the

measurement, and the knee flexion angles were selected arbitrarily.

A clinical 1.5-T whole-body MR scanner (Magnetom Symphony, Siemens Medical Solutions, Erlangen, Germany) was used throughout this study. MR images were obtained using 3-dimensional true fast imaging with steady-state procession (FISP) with the following imaging parameters: TR 4.3 ms, TE 2.08 ms, matrix size 256 × 180, flip angle 55 degrees, slice thickness 3.0 mm, field of view 300 mm × 281 mm. Using a built-in body coil, 52 axial slices were obtained from each knee. The 60 s acquisition time included L-R directional phase oversampling to avoid wrap-around from the other knee. The tibial rotation angle was verified from MR Images, and the same radiologic technologist (A.Y.) took all the images. The anatomical reference points used in the present study (Fig.1) had previously been described and shown to be reliable (Lerner et al., 2003). The sagittal slices were reformatted from the set of 52 slices and the sagittal slice in which the top of the intercondylar notch of the femur first appeared was chosen. To monitor the rotation of the femur, the position of the slice was determined on the selected sagittal slice perpendicular to the longitudinal axis of the femur and crossing the distal femoral point. This slice was also reformatted from the set of 52 slices so as to define the line connecting the medial and lateral femoral points (c in Fig. 3) as an indicator of femoral line. Similarly, to monitor the tibial line, a line connecting the medial and lateral points on the posterior tibia was determined on the tibial aspect slice (f in Fig. 3), which was then reformatted from the set of 52 slices in respect to the longitudinal axis of the tibia and the position of the posterior condyle. The vector angle between the lines (c & f in Fig. 3) representing the rotational angle was then measured. A positive value was interpreted as the degree of internal rotation, and a negative value as the degree of external rotation.

2. 3. Data analysis

A repeated-measures analysis of variance (ANOVA) was used to ascertain any differences in the amount of tibial rotation at 30, 60, and 90 degrees of flexion. In the presence of a main effect, a post hoc test (Fisher's PLSD test) was then used to determine differences in the angle of tibial rotation at the 3 angles of knee flexion. A paired t-test was also conducted to compare sides within each individual and to test for any systematic side-to-side differences. Pearson's correlation coefficient was used to compare the side-to-side differences of the rotational angles. Analyses were performed using Statview 5.0 software (SAS institutes Inc, Berkley, CA). A p-value of less than 0.05 was set as the significance level.

## 3. RESULTS

The tibial rotation angles at 30, 60, and 90 degrees of knee flexion are shown in Fig. 4. There was little difference in tibial rotation among the 3 angles of knee flexion ($p=0.40$-$0.92$). The descriptive results of tibial rotation at 30, 60, and 90 degrees of flexion are shown in Table 1. The tibia was rotated internally throughout the three angles of flexion. The tibial rotation relationship between the right and the left legs is determined in Fig. 5 and there was a significant correlation among the 3 angles between the right and the left sides ($r=0.40$, $p<0.03$).

## 4. DISCUSSION

Although morphological studies on the shape and congruence of the tibia and femur have been conducted (Iwaki et al., 2000), the nature of tibial rotation in normal subjects is not well understood, with many researchers having used measurements obtained at close to terminal extension to see if the tibia rotates externally with knee extension, an effect known as screw-home motion (Hallen & Lindahl, 1966; Todo et al., 1999; Iwaki et al., 2000; Piazza &

Cavanagh, 2000; Logan et al., 2004). Specifically, previous researchers did not sufficiently describe how the tibial rotation measurements were conducted, either by failing to adequately define tibial rotation or use consistent measurement points, or both. With this in mind, the present study was designed to examine the nature of the congruence between the tibia and the femur at a greater range of flexed knee positions (30, 60, and 90 degrees) and to clearly describe how to measure tibial rotation.

The results of this study show that the tibia was rotated internally and that there was little difference in rotation among the 3 angles. The present research confirms that the tibia rotates internally when knee flexes (screw home motion). Other tissues around the knee did not significantly affect tibial rotation at those 3 angles.

The presence of pathologies can be identified in a variety of ways, but bilateral symmetry in the internal-external rotation of the tibia has not yet been reported. Previous studies that have used a clinical testing apparatus to look for side-to-side differences in the range of tibial rotation in the right and the left knees are nearly identical (Shoemaker & Markolf 1982; Lusin & Gajdosik, 1983; Samukawa et al., 2007). A significant side-to-side correlation was found in the present research. The limited number of subjects in this study, and the low correlation coefficient make it difficult to determine whether side-to-side differences actually exist or not. Further investigations are needed before any conclusions can be made.

Our purpose-built apparatus allowed both the knee and hip angles to be fixed, something none of the previous studies mention. The length of the muscles around the knee, especially quadriceps, hamstrings, IT-band, and popliteus, have previously been found to change the knee kinematics depending on position, possibly affecting the angle of tibial rotation (Kwak et al., 2000; Ferrari et al., 2003). Therefore, we tried to limit these effects as much as possible by using a special apparatus to fix the knee and hip joint flexion angles.

There were several potential limitations to this study. First, the resolution of the MRI images was very limited. The imaging protocols adopted in this study (acquisition time was 60 seconds) were referred to from previous studies (Incavo et al., 2003; Lerner et al., 2003). Ideally, scan times should be as short as possible to minimize subject anxiety. As less complicated sequences require less scan time, they are considered to cause less discomfort. Second, bone shape and/or gender-specific differences may exist. This study did not examine either possibility, but the potential for such differences should be emphasized. Furthermore, as only Japanese subjects participated in the study, the possibility of ethnic differences cannot be disregarded. Third, a conventional MRI apparatus with limited chamber space was used in this study, and the extended position of the knee was not reported on because the hip angle was fixed at 45 degrees of flexion to minimize the effect of different muscle lengths.

## 5. CONCLUSION

This study, in which new MRI techniques were developed to allow the measurement of tibial rotation angles in normal subjects at 30, 60, and 90 degrees of knee flexion, contains several important new findings. Firstly, the tibia was shown to rotate internally relative to the femur in all 3 positions. The relative relationship between the tibia and the femur changes very little over the three flexion angles. Secondly, tibial rotation angles between the right and the left sides were significantly correlated ($r=0.40$, $p<0.03$).

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Table 1
Descriptive statistics for measurement of tibial rotation at 30, 60, and 90 degrees of knee flexion.

| Knee flexion angles | 30 degrees | | 60 degrees | | 90 degrees | |
|---|---|---|---|---|---|---|
| | Right | Left | Right | Left | Right | Left |
| Mean (deg) | 4.3 | 7.1 | 7.2 | 7.2 | 5.4 | 5.6 |
| S.D. (deg) | 10.9 | 4.5 | 6.6 | 4.2 | 4.6 | 5.6 |
| Median | 6.0 | 7.0 | 7.0 | 7.0 | 4.0 | 4.5 |
| Minimum (deg) | -19.0 | 1.0 | -1.0 | -1.0 | 1.0 | -1.0 |
| Maximum (deg) | 15.0 | 14.0 | 19.0 | 14.0 | 15.0 | 18.0 |

“-” values meant tibia was externally rotated. The tibial rotation angles were internally rotated throughout the three angles of flexion.

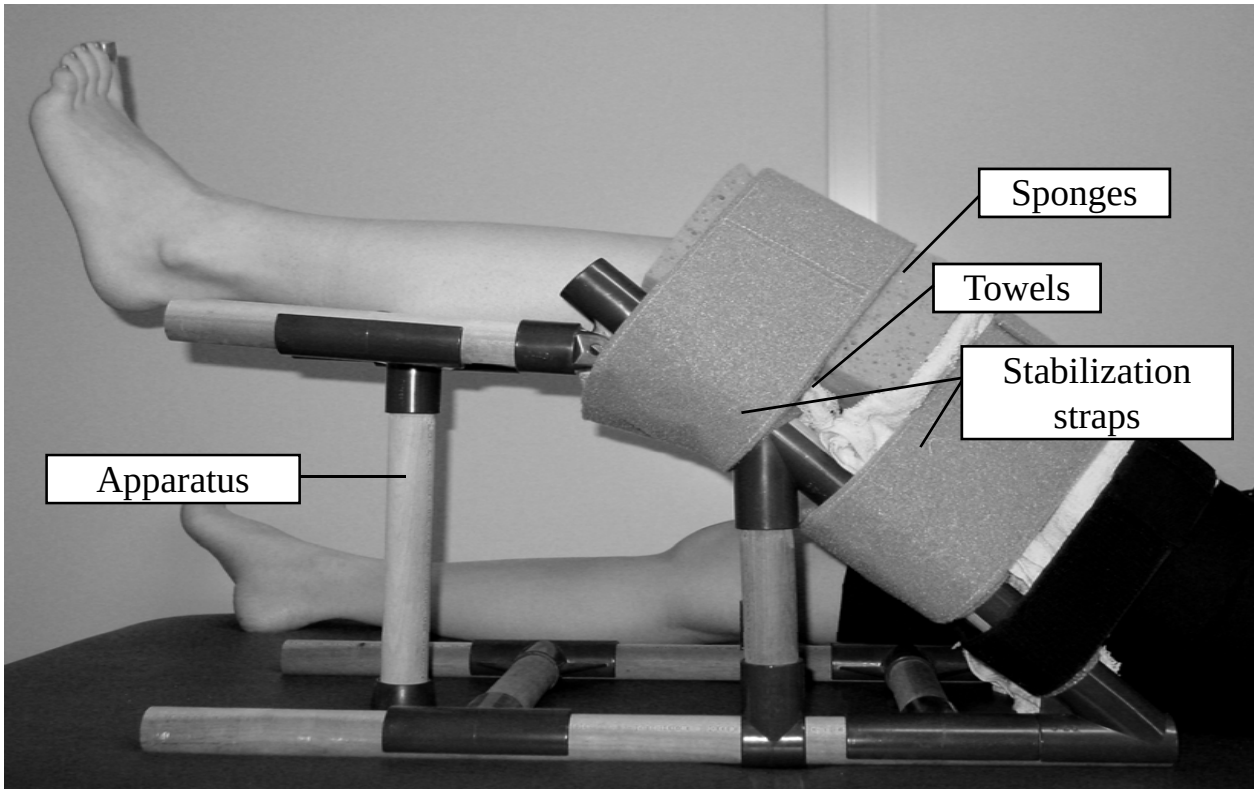


Fig. 1. Position of subject when measuring tibial rotation.


Fig. 2. Position of subject when measuring tibial rotation in MRI.

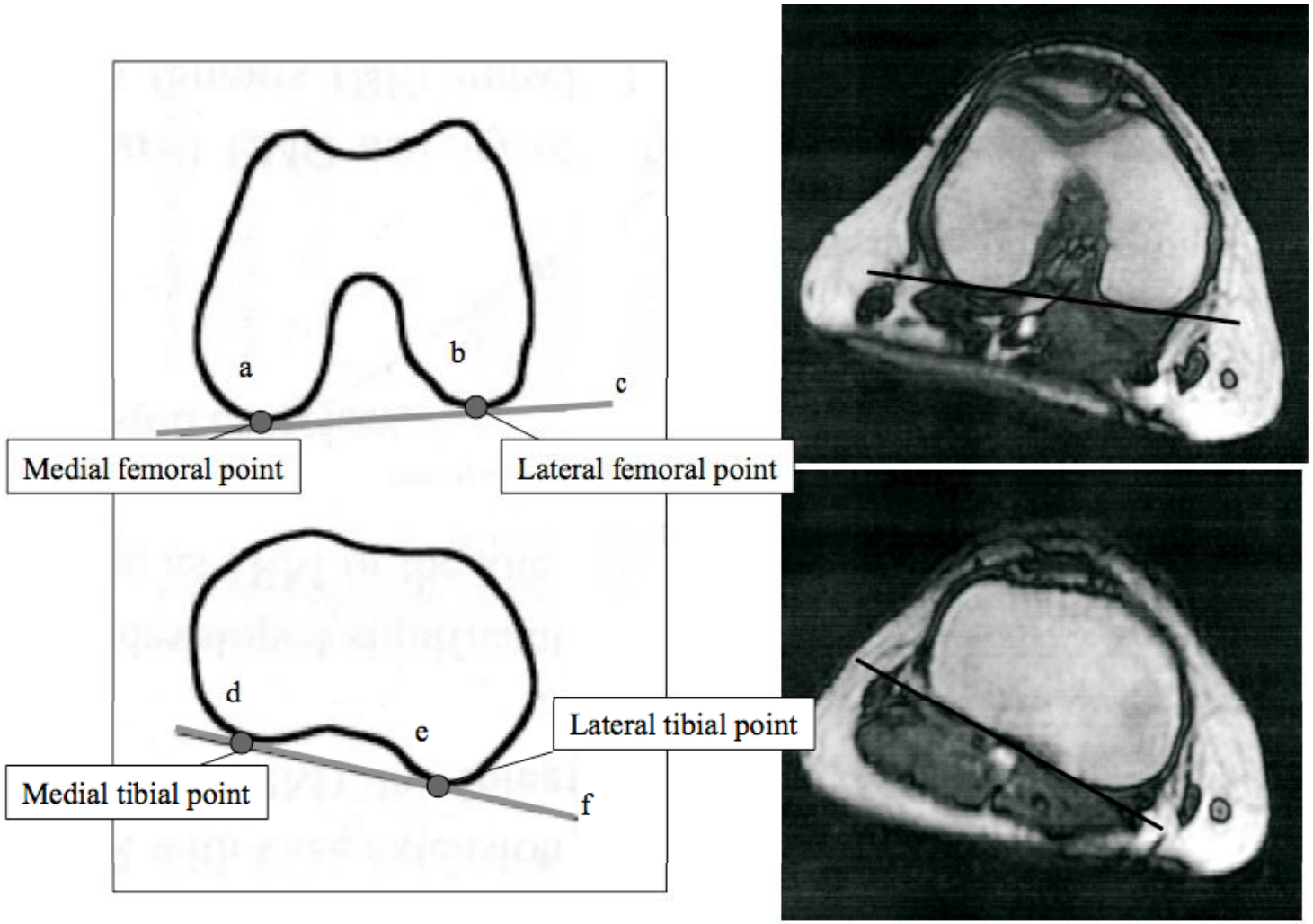


Fig. 3. Establishment of anatomic reference points for this measurement. The angle of tibial rotation was defined as the angle formed by the line c and the line f.

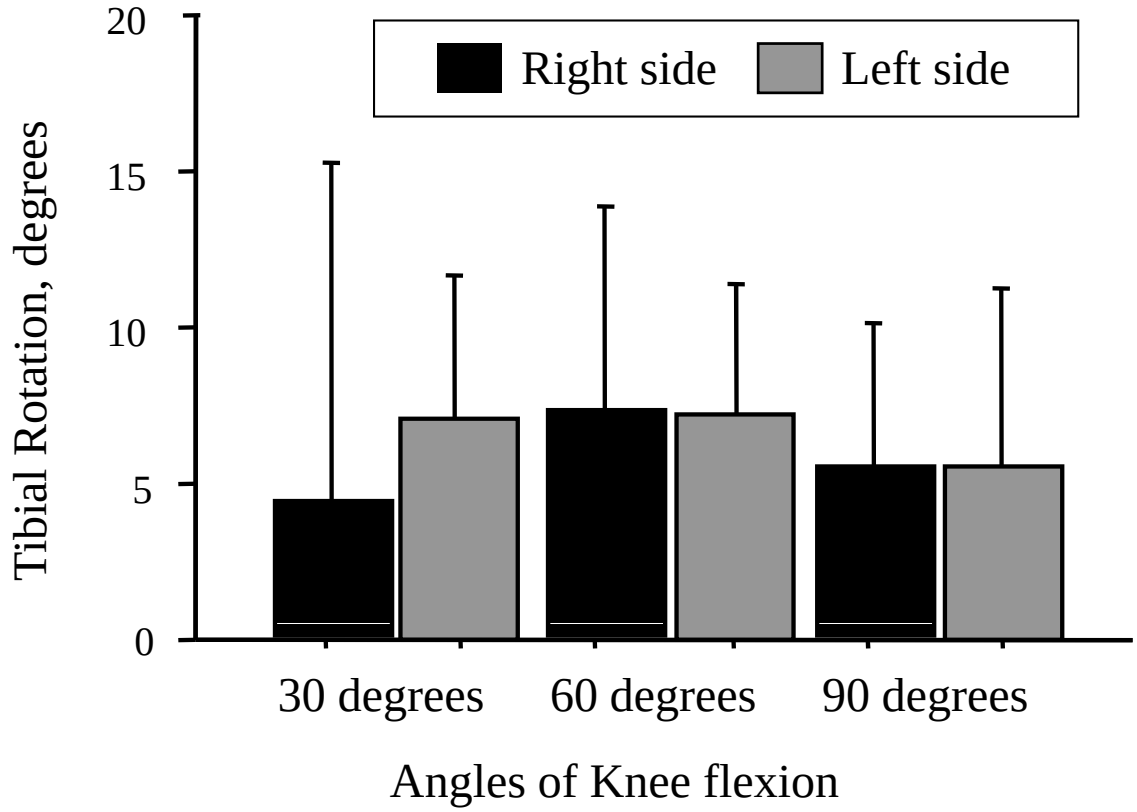


Fig. 4. Tibial rotation at 30, 60, and 90 degrees of knee flexion. Error bars indicate SD. No significant differences of tibial rotation were found between the right and the left sides (p=0.40-0.92).

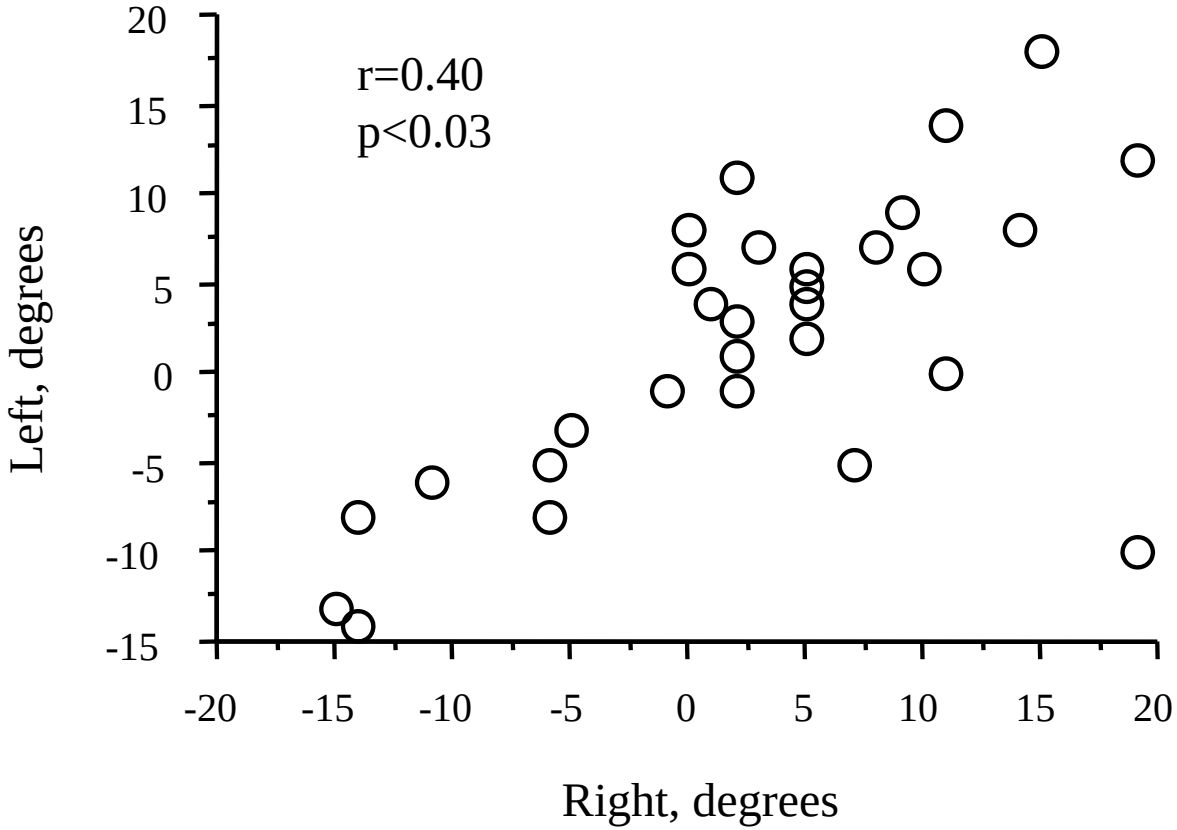


Fig. 5. The side-to-side comparisons of tibial rotation. A significant correlation was found between the right and the left sides (r=0.40, p<0.03).

Table 2

The side-to-side comparisons of tibial rotation.

| Knee flexion angles | r | p-value | 95%CIs | |
|---|---|---|---|---|
| | | | Lower | Upper |
| 30 degrees | 0.30 | 0.41 | -0.41 | 0.70 |
| 60 degrees | 0.67 | 0.03* | 0.09 | 0.92 |
| 90 degrees | 0.47 | 0.18 | -0.23 | 0.85 |

* significance level $p<0.05$