

Biomechanical Mechanisms Affecting Axial Tibial Rotations of the Knee after a Cruciate Retaining Total Knee Arthroplasty

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INTRODUCTION: Axial tibial rotation of the knee with flexion is recognized as a characteristic motion pattern that can affect the knee joint function. Asymmetric tibiofemoral joint articulation has been shown to result in axial tibial rotation. Numerous studies have reported that it is a challenge to restore normal axial tibial rotation using a contemporary total knee arthroplasty (TKA) despite various innovations have been proposed to improve the surgery. Our objective is to investigate the mechanisms that limit axial tibial rotations of TKA knees by comparing the tibiofemoral articular motions of normal and TKA knees during a weightbearing flexion. We hypothesize that contemporary TKAs cannot reproduce the asymmetric tibiofemoral articulations of normal knees and therefore cannot reproduce normal knee axial tibial rotations.

METHODS: Twenty healthy knees of 20 living human subjects and 11 patients with a unilateral CR TKA (NexGen CR Flex, Zimmer) were recruited in our previous studies. The testing protocols were approved by our institutional review board. Informed consent was obtained from each subject prior to test. Each normal knee was MRI scanned for reconstruction of a 3D anatomic model, including the femur, tibia and cartilage surfaces. Each subject performed a weightbearing flexion from full extension to maximal flexion and the knee motion was captured using a validated dual fluoroscopic imaging system (DFIS) (**Fig. 1a**). The 3D models of the normal knee or 3D CAD models of the TKA knee and the paired fluoroscopic images of the knee were input in a solid modeling software (Rhino, Seattle, WA) to reproduce the knee motions using a 2D-3D matching algorithm. The knee positions along the flexion path were represented by a series of models of either the normal (**Fig. 1b**) or the TKA knees (**Fig. 1c**). Articular contact points at each flexion position were defined using the centers of overlapping areas of the tibiofemoral cartilage surfaces for normal knees and of the tibiofemoral component surfaces for TKA knees. The knee kinematics was analyzed at every 15° flexion interval along the flexion path from 0° to 105°. Contact distances were calculated as the shortest distances in each flexion interval on both the medial and lateral femoral condyles and tibial surfaces. Axial tibial rotations were calculated using the differences between the medial and lateral articular distances of both femoral and tibial surfaces at each flexion interval. The data in flexion intervals were then added to calculate tibial rotations along the flexion path. For data analysis, the articular distances of the normal and TKA knees were compared at both the medial and lateral compartments. The axial tibial rotations due to articulations on the tibiofemoral articular surfaces were specifically compared at each flexion interval and along the flexion path. An ANOVA was used for data analysis. A significant difference was defined when $p < 0.05$.

RESULTS SECTION: At medial compartment, the articular contact distances of the normal knees were significantly longer than those of the TKA knees at flexion intervals up-to 60° of flexion ($p < 0.05$) (**Fig. 2a**). At high flexion interval of 90° to 105°, the articulation distance of the normal knees was significantly shorter than that of the normal knees. At lateral compartment, the articular contact distances of the normal knees were significantly shorter than those of the TKA knees at flexion intervals up-to 30° of flexion and at high flexion interval of 90° to 105° ($p < 0.05$) (**Fig. 2b**). The internal tibial rotation was $6.8 \pm 4.5^\circ$ for normal knees and $1.5 \pm 2.2^\circ$ for TKA knees at the flexion interval of 0°-15° (**Fig. 2c**). No difference in axial tibial rotations was found in flexion intervals beyond 45° of flexion. Total internal tibial rotations of the normal knees consistently increased with flexion and reached a peak of $18.4 \pm 7.8^\circ$ at 105° knee flexion (**Fig. 2d**). Total internal tibial rotations of the TKA knees also increased with knee flexion and reached $5.5 \pm 3.5^\circ$ at 75° of flexion, and slightly dropped at higher flexion angles. The TKA knees had significantly lower internal tibial rotation at each flexion angle than TKA knees (**Fig. 2d**).

DISCUSSION: This study investigated the mechanisms that limit axial tibial rotations of the knee after a CR TKA during a weightbearing flexion. While our previous studies found that the asymmetric articulations between the medial and lateral compartments resulted in internal tibial rotations with knee flexion, the data of this study revealed that the tibiofemoral articulations of the TKA knees were different from those of the normal knees. The TKA knees were actually less asymmetric in tibiofemoral articulations compared to the normal knees during flexion. Consequently, the axial tibial rotations of the TKA knees were significantly reduced compared to the normal knees along the flexion path. Therefore, future investigations should focus on improvement of tibiofemoral articulations of the TKA knees to restore normal axial tibial rotations of the knee.

SIGNIFICANCE/CLINICAL RELEVANCE: This study revealed the physiological mechanisms that limit the axial tibial rotations of the knee after a CR TKA. The data could be instrumental for future improvement of TKA designs and surgical implantation techniques to restore normal knee functions.

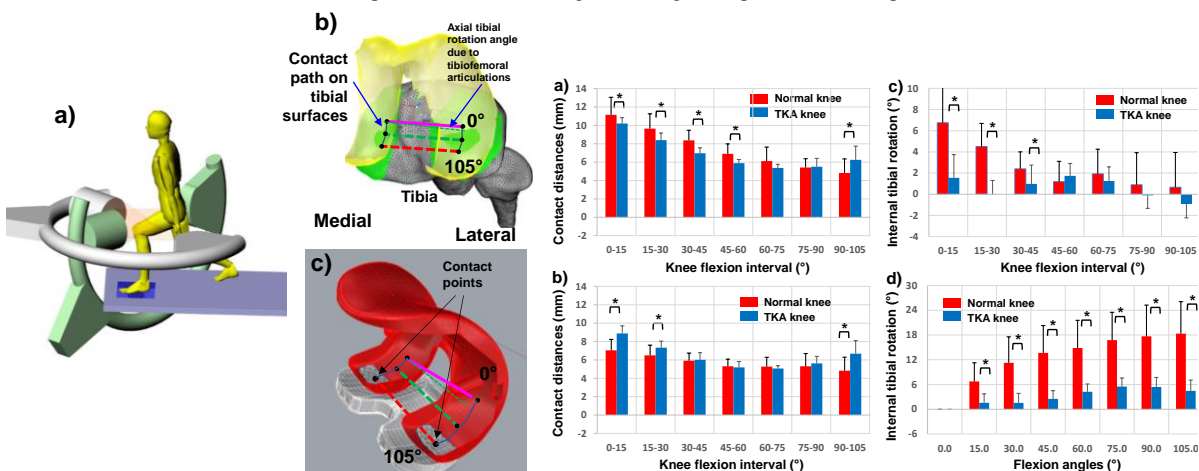


Fig. 1. (a) The dual fluoroscopic imaging system (DFIS) set up for measurements of knee joint positions during weightbearing flexion. (b) In-vivo normal and (c) TKA knee contact positions at different flexion angles along the flexion path reproduced using 3D models of the knee.

Fig. 2. Articular contact distances (Mean \pm SD) on the (a) medial and (b) lateral femoral condyles of the normal and TKA knees. Internal(+) and external(-) tibial rotations (c) at all flexion intervals and (d) along flexion path of the knee. A *** indicates that the data are significantly different between the normal and TKA knees ($p < 0.05$).