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Location of the natural knee axis for internal–external tibial rotation

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ABSTRACT

Background: Rotating hinge and mobile bearing tray knee replacement designs utilize a single fixed axis for tibial rotation, yet there is little published information regarding the natural internal–external axis (IEA) for tibial rotation. Identifying the IEA should provide an opportunity for reproducing normal knee kinematics and maintaining the balance of forces in the soft tissues that help control rotation of the tibia.
Methods: The location and orientation of the IEA relative to the tibial plateau were calculated in 46 fresh frozen human cadaveric specimens using an instant center of rotation analysis at fixed knee flexion angles ranging from five degrees to 105°.
Results: IEA location ranged from 4.0 to 4.9 mm medial and 1.7 to 5.5 mm posterior to the center of the tibial plateau (from 5° to 105° of knee flexion). IEA orientation was reported relative to a reference axis perpendicular to the plane of the tibial plateau. In the frontal plane, the IEA was not significantly different from the reference axis from five degrees to 45° flexion, and 2.0° to 2.7° valgus to the reference axis from 60° to 105° flexion. In the sagittal plane, the IEA was not significantly different from the reference axis from 5° to 15° flexion, and 3.0° to 7.0° extended from the reference axis from 30° to 105° flexion.
Conclusions: The IEA moves posteriorly with increasing knee flexion on the tibial plateau. Placement of the IEA relative to the tibial plateau for a rotating hinge or mobile bearing tray implant may represent a compromise between design objectives for moderate and deeper knee flexion.
Clinical relevance: This study has relevance for future knee implant designs.

1. Introduction

It has been shown that, in its simplest form, relative motions between the tibia and femur occur about two independent fixed axes, one axis for flexion–extension and another for internal–external tibial rotation (IEA) [1,2]. While there have been numerous studies in the literature related to the natural flexion–extension axis of the knee [1–7], less attention has been directed towards finding the knee's natural IEA for tibial rotation [1,2].

Allowance for internal–external tibial rotation has been shown to be an important design feature of modern total knee replacements (TKR). Prior clinical experience with hinge-type implants utilizing a single fixed axis for flexion–extension was universally poor, with failures attributed to loosening at implant-bone interfaces due to rotational torque. This led implant designers to incorporate rotational freedom into subsequent designs. In contrast to modern fixed bearing designs, which allow unconstrained tibial rotation, two commonly used TKR implants incorporate a fixed internal–external axis (IEA) for tibial rotation. The rotating hinge prosthesis is used primarily for revision knee arthroplasty, after tumor resection, in knees with excessive varus–valgus deformities, and in selected cases where soft tissue stability is lacking [8–14]. In contrast, the mobile-bearing tray TKR is used for primary procedures in younger high-demand patients, with the goals of providing more rotational freedom at the articulating surfaces and larger load-bearing surface areas at metal-polyethylene interfaces which could theoretically lead to reduced wear [15–18].

Implant wear in TKR is a function of both the tibiofemoral component geometry and the materials at the bearing surfaces. Essner et al. [19] showed that implant design played a more significant role in knee wear reduction than bearing surface material, suggesting that design geometry has a first-order effect and should be addressed before materials. In that context, mobile-bearing knee replacements were designed to minimize wear and loosening complications associated with fixed-bearing designs by increasing surface congruity during maximum impact of the loading activity by allowing rotational relief of the components [16,17]. Buechel et al. [15] suggested that mobile-bearing TKR is, in most cases, superior compared with fixed-bearing TKR. Huang et al. [17] noted that fixed-bearing prostheses with low congruity may generate high contact stress leading to early failure of the polyethylene compared to a highly congruent mobile-bearing geometry, but their study showed no superiority in survivorship of the mobile-bearing design over that of fixed-bearing knees.

Incorrect placement of the implant's IEA relative to the knee's natural IEA could have important implications related to successful

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biomechanical function of these two implant designs. For example, rotation of the tibia about a non-optimal axis could affect patellar alignment and points of patellar contact within the femoral component trochlear groove, which in turn could be related to post-operative anterior knee pain. Improper placement of the implant's IEA could also affect the balance of forces in soft tissues (collateral ligaments and joint capsule) that help control internal–external rotation of the tibia. Finally, incorrect placement of the IEA in mobile-bearing designs could affect the relative amounts of polyethylene wear at articulating interfaces beneath the mobile-bearing tray and between the femoral component and superior surface of the mobile-bearing insert.

The objective of this study was to determine the location of the knee's natural IEA on the tibial plateau and its orientation relative to the plane of the tibial plateau during a series of cadaveric tests performed at fixed knee flexion angles.

2. Methods

Forty-six fresh-frozen human cadaveric knees were used for this study. This group included 17 right-left pairs (seven male and 10 female pairs). Of the remaining 12 unpaired knees, eight were male (seven right, one left) and four were female (three right, one left). The mean age of all specimens was 31 years (16 to 45 range). The tibia and femur were sectioned 12 in. from the joint line and potted in cylindrical molds of polymethylmethacrylate (PMMA). Each knee was tested manually for stability prior to testing.

The femoral pot was clamped in a custom-built apparatus with the knee inverted (patella facing down; Figure 1). Full extension was defined as the angle between the femoral and tibial pots that resulted when a two newton meters extension moment was applied to the knee [20,21]. The distal end of the tibia was supported by a roller bearing mounted on an extension shaft attached to the distal end of the tibial pot, with the roller bearing resting on a horizontal plate. This configuration allowed unconstrained tibial rotation, while permitting anterior–posterior (AP), medial–lateral (ML), and proximal–distal (PD) motions of the distal tibia relative to the femur as the knee was manually flexed about the axis of the test apparatus (Figure 1). When the femoral fixture was ideally positioned, the tibia would remain relatively motionless (exclusive of the screw-home tibial rotation) as the femur was flexed about the axis of the test apparatus. That is to say, coupled motions of the tibia relative to the femur (AP, ML, and PD translations of the tibia) were minimized as the knee was flexed from 0° to 90°. This test apparatus and specimen alignment procedure have been used in prior knee studies from our laboratory [20,21].

To define the IEA, markers were established at two different levels of the tibia (Figure 2). At level 1 (along the periphery of the tibial plateau) four two millimeters screws were inserted at the transition from articular cartilage to bone. These screws were placed on the medial tibial plateau at the most anterior and most posterior points to define the AP depth of the plateau, and at the most medial and most lateral points (anterior to the collateral ligaments) to define ML width of the plateau. The medial, anterior, and lateral points were used to define a plane at the tibial plateau (Figure 2), and a line perpendicular to that plane was used as a reference axis for all subsequent descriptions of IEA orientation. At level 2 (approximately 20 cm distal to the plateau on the circumference of the tibial PMMA potting cylinder), posterior, medial, and lateral points were etched into the acrylic surface. A coordinate measuring machine, with a positional accuracy of 0.02 mm (Faro Gage, FARO Technologies Inc., Lake Mary, FL), was used to digitize the 3D coordinates of all markers during testing.

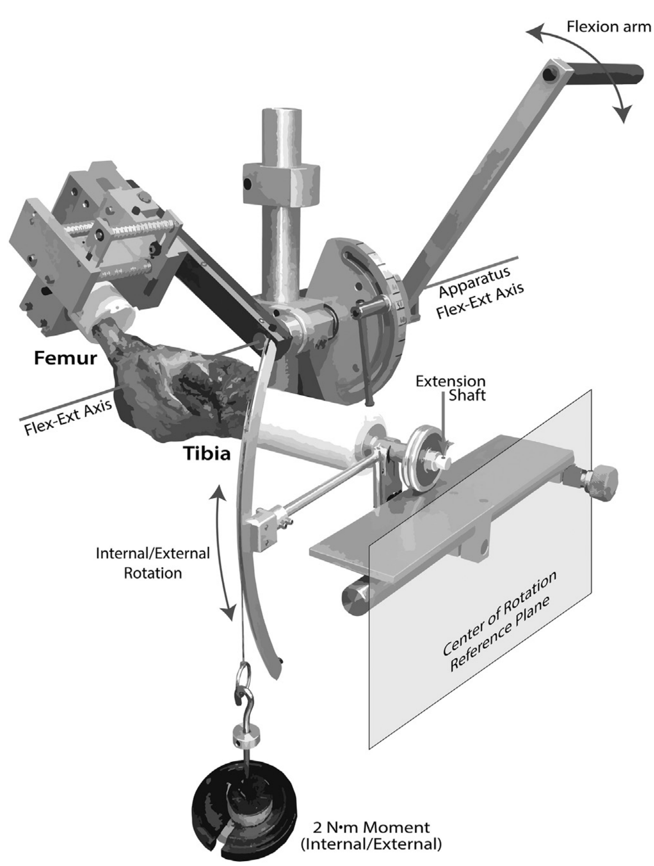

Figure 1. Test apparatus used to determine the IEA by applying 2 newton meters internal and external torques to the tibia.

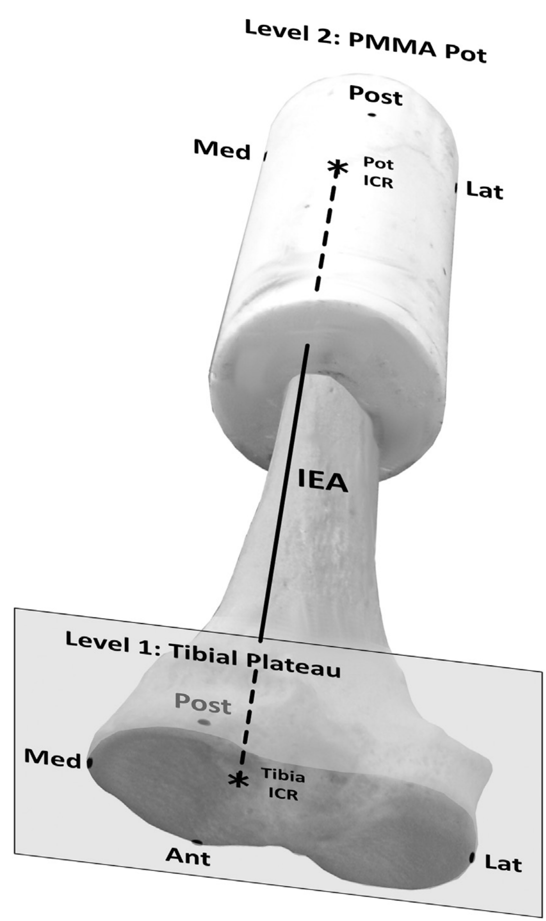

Figure 2. The plane of the tibial plateau was defined by medial, anterior, and lateral markers at level 1. The ICRs calculated at levels 1 and 2 were used to define the IEA.

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