Evaluation of the 3-D, Weight-bearing Orientation of the Normal Adult Knee using Low Dose Radiation

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Introduction: Traditionally, the success of TKA was accepted to be dependent on obtaining a neutral, mechanical axis of the lower extremity, with positioning of the femoral and tibial components perpendicular to the mechanical axis in the coronal plane. However, up to 20% of patients remain “unsatisfied” following a TKA, and several studies have challenged the importance of a neutral, postoperative mechanical axis alignment on both the survivorship and function of modern TKAs.1,2

Recently, the concepts of constitutional varus and kinematic alignment have been introduced, which hypothesize that correction to a neutral mechanical alignment may not be “normal” for a significant proportion of the population, and that restoration of a patient’s native alignment and joint line obliquity will improve functional results.3,4 However, despite the emphasis placed on clarifying the importance of alignment in TKA, a limited amount of data exists studying anatomic variables and alignment in normal, asymptomatic adults. Furthermore, prior assessments have been limited by the use of 2-dimensional (2D) radiography (often on short films), in which rotational attitudes due to the degree of deformity or anatomic variations such as femoral bowing, can affect standard alignment measurements.

A new, low-dose radiation imaging technology has been introduced, allowing for the simultaneous acquisition of biplanar, standing, weight-bearing films, that can be rendered into a 3D image corrected for rotation. The purposes of this study were to obtain 3D, weight-bearing, full-length lower extremity images corrected for rotation in asymptomatic adults to establish 1) normative data of limb alignment and joint line orientation, 2) the degree of correlation between the lower extremities in the same subject, and 3) the capability of full-length 2D images to predict the alignment measured on 3D images corrected for rotation.

Methods: 100 subjects (200 lower extremities, average age 35 ± 11.5 yrs, 58% female), with no history of trauma, surgery, symptoms, or treatment, were prospectively recruited to receive weight-bearing, simultaneous biplanar imaging of both lower extremities. 3D images of the 200 lower extremities were created using parametric modeling and corrected for limb rotation, from which the hip-knee-ankle angle (HKA), mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA), anatomic mechanical axis (AMA), medial neck-shaft angle (MNSA), femoral, and tibial bow were measured. The HKA was used to categorize knees as varus (≤3°), valgus (≥3°), or neutral (0° ± 3°), and the mLDFA was used to determine whether joint line obliquity was present (≤87°or ≥93°) or absent (90° ± 3°).

Student’s t-tests were used to compare radiographic parameters between males and females (p<0.05=significant). Fischer’s exact tests were used to determine if the correlation between the two lower extremities of the same subject, for the HKA and mLDFA, was significant; and, if the 2D measurements correlated with the 3D, rotationally controlled measurements (p<0.05=significant). Cohen’s kappa coefficients (κ) were estimated to determine the degree of association, accounting for the probability of correlation simply by chance.

Results: The mean values for the radiographic parameters measured, for knees in neutral, valgus, or varus alignment are presented in Table 1. For measurements of the HKA in 200 knees, 70.0% were neutral, 19.5% were varus, and 10.5% were valgus. 32.1% of the male knees and 10.3% of the female knees were in a varus alignment, while 8.3% of the male knees and 12.1% of the female knees were in a valgus alignment. Joint line obliquity of ≥3° was present in 52.5% of all knees (45.2% of males, 57.8% of females). Only 31% of knees demonstrated both a neutral mechanical axis and mLDFA perpendicular to the femoral mechanical axis.

Male knees possessed a more varus mechanical alignment (-1.49° ± 2.87° versus 0.14° ± 2.34°, p<0.001), a more varus MPTA (87.43° ± 2.72° versus 88.75° ± 2.36°, p<0.001), and a more varus MNSA (127.33° ± 4.24° versus 128.94° ± 4.73°, p=0.01) versus female knees. However, the mean mLDFA was more valgus and oblique in female knees (86.73° ± 1.84° versus 87.2° ± 1.5°, p=0.04).

The agreement of one lower extremity to the other lower extremity in the same subject, for both the HKA and mLDFA, was statistically significant (p<0.001). With one knee in a neutral mechanical alignment, the likelihood of the other knee having a
neutral alignment was 84.1%. However, when one knee is in varus, there is only a 68.4% likelihood that the other will also be in varus, and when one knee is in valgus, there is only a 41.7% likelihood that the other knee will be in valgus (κ=0.48 - moderate agreement). If joint line obliquity is present in one knee, the other is 79.6% likely to also possess joint line obliquity; while if it is absent, the other knee is also 66.7% likely to be absent of joint line obliquity (κ=0.46 - moderate agreement).

Lastly, when the 2D image demonstrated a knee in neutral alignment, the corresponding 3D image is 92.9% likely to also be in neutral. This increases to an agreement between the 2D and 3D images of 100% for a 2D valgus alignment, but decreases to 75.6% for a 2D varus alignment (κ=0.77 - substantial agreement). When a 2D measurement indicates the absence of joint line obliquity, the 3D measurement has a 75.7% probability of also demonstrating the absence of joint line obliquity (κ=0.58-moderate agreement).

**Discussion:** A neutral mechanical axis and perpendicular joint line in TKA does not restore a patient’s native anatomy in 69% of knees. In addition, although a statistically significant association was present, there remains a considerable amount of variation between the two lower extremities in the same subject for both the overall mechanical alignment and the presence of joint line obliquity. Thus, it remains unclear how to reliably predict the native mechanical axis and joint line obliquity for patients who present with degenerative joint disease. Lastly, as expected, differences are present between the 2D and 3D images for the HK and mLDFA, especially in patients with a varus mechanical alignment. Therefore, whether rotationally controlled, 3D images are necessary to predict a patient’s true limb morphology remains in question.

**Significance:** A novel, low-dose imaging technology was used to obtain 3-D, weight-bearing images of asymptomatic, adult knees, demonstrating only 31% to have a neutral mechanical axis without joint line obliquity. This study is the first to provide 3-D, normative data of alignment and joint line obliquity in a large population of asymptomatic, adult knees.

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**References:**