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Variability in Distal Femoral Anatomy in Patients Undergoing Total Knee Arthroplasty: Measurements on 13,546 Computed Tomography Scans

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ABSTRACT

Proper mechanical and rotational alignment plays an important role in achieving the success of the total knee arthroplasty (TKA). The purpose of the present study was to retrospectively determine with computed tomography (CT) the distal femoral valgus angle (DFVA) and femoral rotation angle (FRA). Our cohort included 13,546 CT scans of patients undergoing TKA. The average DFVA was 5.7 ± 2.3° (range from 1 to −16°) with 13.8% of patients identified as outliers. The distal FRA angle average was 3.3 ± 1.5° (range from −3 to 11°) with 2.8% of patients identified as outliers. These data can be useful in making orthopedic surgeons aware of the variability of femoral anatomy. Using the same cutting angle may lead to malposition of the femoral component.

Proper limb alignment and implant positioning are important to the success of total knee arthroplasty (TKA) [1,2]. Incorrect mechanical alignment is related to early implant wear, implant loosening and instability of the prosthesis [3,4]. Alignment within a range of ±3° varus–valgus from the mechanical axis is desired and associated with better outcomes [1,2]. Although many studies reported the benefits of proper postoperative alignment on the outcomes of TKA, some clinical studies could not correlate proper alignment with a longer implant survivorship at long-term follow-up [5,6]. Despite the controversy on this topic, the standard surgical technique of TKA should aim to maintain proper alignment.

In order to have a postoperative proper alignment, conventional knee arthroplasty instrumentation typically aligns and places implants based on the population's average anatomy. In the TKA surgical technique, with intramedullary (IM) femoral alignment guides, the distal femoral resection is typically set at 5 to 7° from the anatomic axis in order to make the resection perpendicular (0°) to the mechanical axis of the femur. This technique is based on the average angle between the anatomic and mechanical axis of the femur, which is known to be 5 to 7° [7–9]. Numerous studies have documented the use of an IM guide leads to malalignment of the femoral component of greater than 3° in up to 20% of cases [10]. Additional studies have reported considerable variations in the distal femoral valgus angle (DFVA) between patients [8,11]. In outlier patients, using same cutting angles may lead to high incidence of malalignment.

Rotational alignment of the femoral component in TKA plays an important role in achieving varus–valgus stability and patellofemoral tracking [12]. To create the appropriate femoral component rotation, the posterior condylar axis, anteroposterior axis, and transepicondylar axis have been proposed [13,14]. High variability in the femoral rotational angle (FRA) associated with all techniques has been reported [13,15,16]. With the measured resection techniques, the femoral component is typically placed 3° externally rotated to the posterior condylar line. Distal femoral anatomic abnormalities may lead to rotational malalignment when the measured resection technique is used.

Frequently, surgeons do not assess the native distal femoral anatomy preoperatively, considering the average value in the nonarthritic population. Using the standard instrumentation guides for the distal femoral resections may lead to femoral component malposition and malalignment in cases that had anatomic variability in distal femur. The purpose of this study was to determine the DFVA and FRA in a large number of patients undergoing TKA in an effort to better

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understand both average femoral anatomy and the incidence of "outliers" in this arthritic population.

Material Methods

We analyzed 13,546 computed tomography (CT) scans of osteoarthritic patients undergoing TKA with patient-specific instruments using Amira visualization software (Visual Science Group, Burlington, MA, USA) and NX computer-aided design software (Siemens Corporation, Berlin, Germany). Sixty-one percent were female patients ($n = 8241$) and 39% were male ($n = 5305$). Limb alignment was identified as varus in 81% ($n = 11{,}021$) valgus in 19 % ($n = 2525$) with a range from 27 varus to 22° valgus. Average patient age was 65.4 ± 10.3.

All CT scans included the hip, knee, and ankle. Three-dimensional reconstructions were performed on each scan and key landmarks were identified in Amira and NX software. The DFVA (also termed the femoral mechanical–anatomical axis) was defined as the difference between the anatomic and mechanical axes in the coronal plane (Fig. 1). The hip center was defined as the geometric center of the femoral head as defined by a best-fit sphere. The mechanical axis was defined as the line connecting the hip center and knee center. The line connecting 2 middiaphyseal points defined the anatomic axis of the femur.

The angle between the posterior condylar axis and the epicondylar axis in the axial plane defined FRA (Fig. 2). The posterior condylar line was defined by two points, each on the most posterior surface of the medial and lateral condyles. The transepicondylar axis was also defined by two points, one point was on the medial epicondyle (sulcus) and one point was on the lateral epicondyle (prominence). All measurements were digitally measured using NX software.

The patient's anatomy was categorized as an outlier if femoral valgus or rotation deviated more than 3° from the measure average. All data were collected and analyzed utilizing Microsoft Excel software (Microsoft Corporation, Redmond, WA). Data were analyzed using Anova analysis.

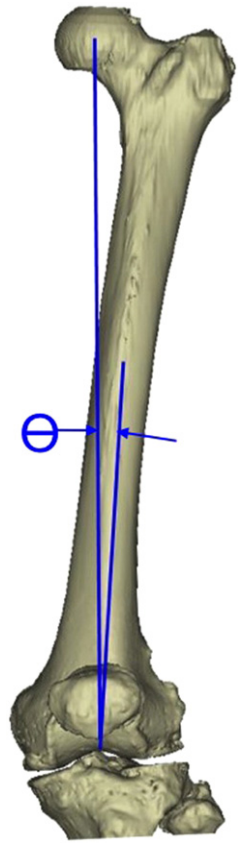

Fig. 1. Definitions of the anatomic axis, mechanical axis, and distal femoral valgus angle with the 3D reconstruction of the CT scan.

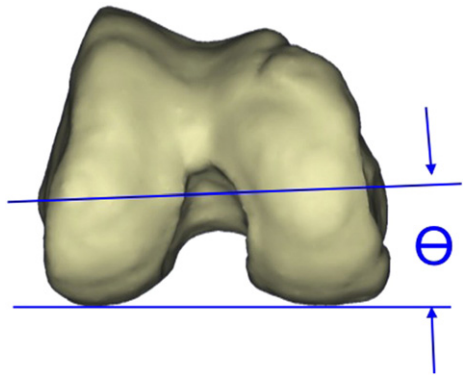

Fig. 2. The angle between the posterior condylar axis and the epicondylar axis in the axial plane define femoral rotation angle with the 3D reconstruction of the CT scan.

All engineers involved with this study were trained in the use of Amira software, NX software, and knee anatomy. CT scans, which we measured for our study, were used for the patient specific knee prosthesis. To assess reliability of the femoral mechanical axis and DFR measurements, a subsample of 11 engineers were identified to perform a repeat reading of CT scans. Engineers were blinded to the test. Six replicates were completed for 10 CT scans, for a total of 60 measures. All repeat measurements were ±0.1°, showing high reliability.

Results

The average DFVA was 5.7 ± 2.3° (range 1–16°). The average DFVA of the males was 5.82 ± 2.25° and females 5.65 ± 2.35°. The range of DFVA was 1° varus to 16° valgus (Fig. 3). Outliers in DFVA were identified in 13.8% of scans (Fig. 4).

The average distal FRA was 3.3 ± 1.5° (range 3° internal rotation to −11° external rotation) (Fig. 5). The average FRA for male patients was 3.1 ± 1.5° and the average FRA for females was 3.3 ± 1.5°. Outliers in femoral rotation were identified in 2.8% of scans (Fig. 6). All outlier data are shown in Table 1.

Discussion

This study demonstrated that the DFVA is highly variable in patients undergoing TKA. To our knowledge, this is the largest study designed to evaluate patients using modern CT scan data and accurate 3-dimensional (3D) computer modeling. CT is an excellent imaging

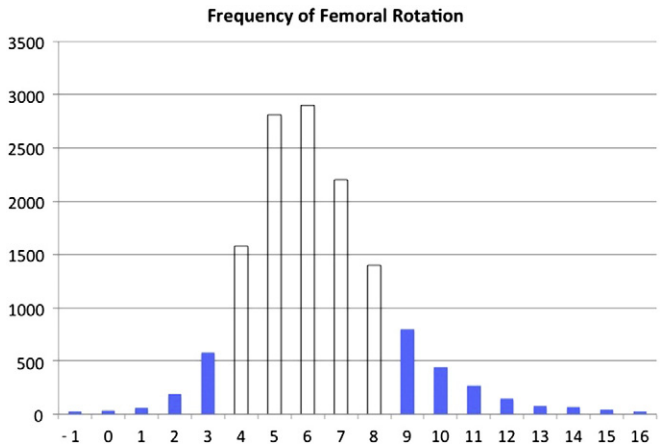

Fig. 3. The frequency of each value of distal femoral valgus angle is shown in the graphic. Outliers of the distal femoral valgus angles are shown with blue columns.