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Important Differences Exist in Posterior Condylar Offsets in an Osteological Collection of 1,058 Femurs

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ABSTRACT

Posterior condylar offset (PCO) has important implications in total knee arthroplasty (TKA) function and design. In an osteological study of 1,058 femurs, we measured PCO using two separate techniques with a 3D digitizer. Measurements were standardized for the size of the femur. The medial PCO was greater than lateral PCO (32.6 mm vs. 31.2 mm, $P < 0.0001$). In 53% of individuals, the medial PCO differed between sides by more than 2 mm. Age did not affect standardized medial or lateral PCO. Compared with African-Americans, Caucasians had a larger standardized medial (1.3 mm vs. 1.2 mm, $P = 0.006$) and lateral (1.1 mm vs. 1.0 mm, $P = 0.004$) PCOs. The standardized medial (1.2 mm vs. 1.3 mm, $P = 0.073$), and lateral (1.1 mm vs. 1.1 mm, $P = 0.098$), PCO did not differ between men and women, respectively.

Total knee arthroplasty (TKA) has demonstrated good outcomes in terms of pain relief, range of motion, and subjective function but does not fully restore normal knee kinematics [1,2]. Posterior condylar offset (PCO) of the distal femur has recently received attention as one anatomic variable that may limit knee motion and potentially compromise stability following TKA [2–5]. As first defined by Bellemans et al [5], PCO is the maximum thickness of the posterior condyle projecting posteriorly to the tangent of the posterior cortex of the femoral shaft on a true lateral radiograph. This dimension may have profound consequences on the design, function, and outcome of TKA.

Although the anterior posterior (AP) dimension of the femur is assessed preoperatively and intraoperatively, little attention has been paid to PCO, which is not routinely measured. However, if PCO is not restored, impingement of the posterior aspect of the tibial insert against the posterior femur can limit flexion, cause pain, and affect long term function. Some authors have suggested medial PCO is greater than lateral PCO, however normative indices have not yet been established [6]. Related studies on femoral anatomical characteristics influenced by gender, race, and age have been reported with highly variable results. This has sparked significant interest in custom implant design, where outcome studies have been controversial [7–12].

The establishment of these definitive standards, as well as the recognition of any differences in PCO based on age, race and sex, may assist in efforts to restore native PCO in TKA, enhancing preoperative planning, implant selection, implant design, and computer-assisted surgery [12–14]. We therefore designed a study using a large osteological collection to answer the following questions: 1) Is medial PCO greater than lateral PCO? 2) Does PCO vary between an individual's contralateral knees? 3) How does PCO vary by age, race, and gender?

Materials and Methods

Specimens

Five-hundred and twenty-nine matched pairs of cadaveric femora (n = 1,058) from the Hamann-Todd Osteological Collection (Cleveland, OH) were analyzed. This collection contains over 3,000 complete, disarticulated human skeletons collected from the unclaimed dead of Cleveland area morgues between 1912 and 1938. The specimens were prepared by the Case Western Reserve University School of Medicine for anatomical dissection in the early 20th century, and were later donated to the museum. All soft tissues had been removed by boiling, and each bone was cleaned with brushes before being degreased with trichloromethane. Each specimen was catalogued for age, sex, and ethnicity in a large database which we utilized for our study. In order to study a population that might undergo TKA, we randomly selected specimens between the ages of 40 and 79 years at the time of death. We performed an a priori power analysis to ensure adequate numbers of race and gender. Average age for the 529 skeletons was 56 ± 10 years. There were 461 males and 68 females. There were 366 Caucasians and

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163 African-Americans. Specimens were excluded if sequelae from any confounding processes such as traumatic, rheumatologic, metabolic, or infectious conditions were identified.

Measuring Posterior Condylar Offset With a 3D-Digitizer

A MicroScribe 3-dimensional (3D) digitizer (Immersion Corporation, San Jose, CA) was used to capture coordinate measurements in millimeters (mm), creating a digital representation of each distal femur. The MicroScribe digitizer was capable of producing coordinate data for points in space in the X, Y, and Z planes based on the position of a telescopic stylus. It has a positional resolution of 0.13 mm, and a positional accuracy of 0.43 mm (mean values). Measurements were exported into a spreadsheet (Microsoft Corporation, Redmond, WA), and formulae were created to calculate the medial and lateral PCOs using the techniques mentioned below. All measurements were performed by a single author.

A surgical ruler (Zimmer Corporation, Warsaw, IN) and digital caliper (Mitutoyo America Corporation, Aurora, IL) were used to test to the reliability of the MicroScribe digitizer by calculating a Pearson product-moment correlation coefficient. One of the authors (DSW) assessed the intraobserver reliability by repeating measurements with 21 day separation. Interobserver reliability testing involved three authors (DSW, DFW and JJG) who performed blinded measurements using the same method within a two day period. Interobserver and intraobserver reliabilities for measurement of PCO were assessed with the intraclass correlation coefficient (ICC). Validity of the MicroScribe digitizer was very high ($r = 0.99$; $P < 0.0001$).

Determining the Most Reliable Method to Measure PCO

In order to determine the most reliable way to measure PCO in a cadaveric specimen, two separate protocols were compared: 1) The first technique was adapted from Bellemans et al [5] which referenced PCO 10 cm from the most distal aspect of the femur. 2) In the second technique, measurements were taken along the anatomic transepicondylar axis (TEA) and measured from the deepest point of the intercondylar fossa along the TEA, as has been similarly reported in studies utilizing MRI [6,15]. For both measuring techniques, a virtual TEA was created by determining the most medial and lateral aspects of the femoral condyles. The digitizer was walked along the posterior condyles in the same xy coordinates coplanar with the virtual TEA (black line in Fig. 1). The most posterior aspects of the medial and lateral distal femur were found by measuring the maximal AP (z-plane) distance between this line and the virtual TEA at the medial and lateral posterior condyles (M and L in Fig. 1). The intraobserver reliability was greater than 0.95 for medial and lateral PCOs when using the 10 cm method, yet was below 0.66 when using the intercondylar fossa technique. Similarly, the interobserver reliability was greater than 0.91 for medial and lateral PCOs when using the 10 cm method, however, was below 0.70 for the intercondylar fossa technique. Therefore, the Bellemans method was determined to be more reliable; the definitive calculations are reported from measurements taken at 10 cm. Results for both techniques are presented in Table 1.

Bellemans' Method (Technique 1)

Using the Bellemans method (technique 1), the AP (z-plane) distance between these local maxima and the medial/lateral center of the posterior cortex 10 cm from the most distal portion of the femur was calculated (light blue line in Fig. 2) to be PCO. Additionally, the AP diameter at the center of the femur was measured 10 cm proximal to the most distal aspect of the femur. Using this process, measurements were standardized to the patient's femoral size by dividing the actual PCO by the AP diameter of the femur.

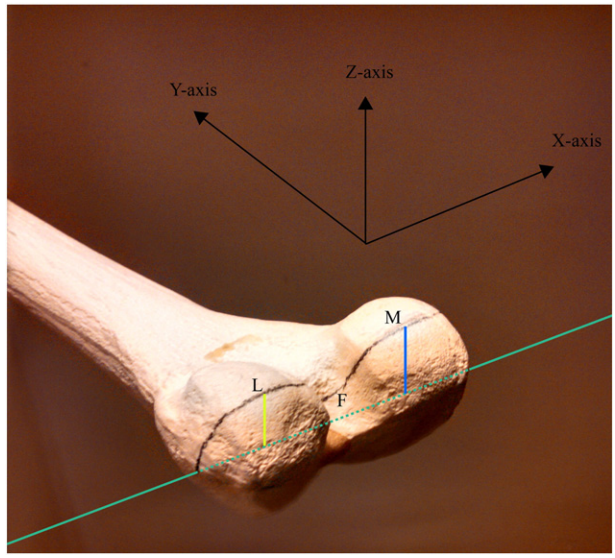

Fig. 1. Establishing the virtual TEA. For both measuring techniques, the most medial and lateral aspects of the distal femur were found. A virtual TEA was established by calculating a straight line between these two points (green line). The digitizer stylus was walked along the posterior aspect of the distal femur (solid black line) in the same xy plane as the virtual TEA. The height of posterior condyles was recorded in the z-dimension by taking the relative maxima at points L and M. In measuring technique 2, the most anterior portion (deepest part of the intercondylar fossa) was found (point F). In this technique, the medial and lateral PCOs were calculated by the vertical distances between points F and points M and L, respectively. For measuring technique 1, the z-coordinate at the center of the posterior cortex 10 cm from the most distal aspect of the femur was subtracted to calculate M and L as shown in Fig. 2.

Intercondylar Fossa Method (Technique 2)

For the intercondylar fossa method (technique 2), the maximum condylar height was determined by walking the digitizer stylus along the same xy coordinates as the virtual TEA (black line in Fig. 1) to find the relative maximum condylar heights (points M and L in Fig. 1). The difference between points M, L, and the deepest point of the fossa coplanar to the virtual TEA (point F in Fig. 1) was calculated to be the medial and lateral PCOs, respectively. The AP diameter was also measured (medial and lateral condylar heights). Standardized measurements were taken by dividing the actual PCO values by the respective condylar heights.

Statistical Analysis

SPSS Statistics 22.0 (IBM Incorporated, Armonk, NY) was used for all data analysis. The descriptive statistics of the medial and lateral PCOs were first analyzed using actual measurements, and then by using measurements standardized to the AP diameter of the femoral diaphysis or the AP condylar height, as described above. A Pearson product-moment correlation was performed to determine the effects of age on PCO. An independent samples t-test was used to compare the medial and lateral PCOs between groups based on sex and race. A paired-samples t-test was performed to assess differences in the medial and lateral PCOs based on laterality (left femur versus right femur in the same individual). Significance was set at alpha <0.05. All outliers (top and bottom 5%) were re-examined by the primary author to ensure accuracy in reporting. Continuous variables are reported as mean $\pm$ standard deviation, where appropriate.

Results

The average medial PCO was 32.6 ± 3.8 mm, and the average lateral PCO was 31.2 ± 4.1 mm, representing a statistically significant difference ($P < 0.0001$). When these values were corrected for the size of