In: Trabecular and Cortical Bone ISBN: 978-1-62808-766-6
Editor: V. Subramanium, M. Bhatnagar © 2014 Nova Science Publishers, Inc.

Chapter VI

Morphology of the Pelvis (Acetabulum) and Femur

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Abstract

Introduction: There are gender differences between male and female in morphology of the pelvis and femur. To confirm this finding, we studied the pelves and femurs in Department of Anthropology, Cleveland Natural History of Museum.

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Materials and Methods: The bones of 50 males and 50 females (total 200 hip joints) were selected from 3,300 skeletons in the museum at random under the following condition: the same distribution of age between the two groups, such as 5 (under 40), 5 (40-49), 15 (50-59), 15 (60-69), 10 (70 or more); and 20% of black in each age class of the groups. The notch acetabular angle was defined as an angle between a line connected the sciatic notch with the posterior acetabular ridge and a line connected both the posterior and anterior acetabular ridge. Each anteversion angle and inclination of the acetabulum, and antetorsion angle of the femur was also measured and statistically analyzed. The results were analyzed by unpaired *t*-test and considered *p* values of less than 0.05 to be significant. Femoral configuration, such as antetorsion of the femoral neck, neck shaft angle, medial offset of the femoral head, anterior bowing and lateral bowing of the femoral shaft was also examined in direct measurement and in radiographs.

Results: The shape of the anterior column of the acetabulum was classified in four types, such as straight, curved, angular, and irregular. Most of the pelves have the curved configuration (60.5%). The notch-acetabular angle was 88.4 ± 3.0° in male and 89.6 ± 3.8° in female ($p=0.013$). All of the angles were ranged within 90 ± 10°. The anteversion angle of the acetabulum was 18.5 ± 5.8° in male and 21.3 ± 7.1° in female ($p=0.002$). The antetorsion angle of the femoral neck was 9.8 ± 9.0° in male and 9.8 ± 8.0° in female ($p=0.954$). There were no correlations between the notch acetabular angle and the other angles ($r^2<0.08$). The neck shaft angle of the femur in neutral rotation was 123.2 ± 6.3° in male and 125.3 ± 5.4° in female ($p=0.014$). The neck shaft angle of the femur in derotation was 121.8 ± 6.1° in male and 123.8 ± 5.2° in female ($p=0.0158$). The medial offset of the femoral head in neutral rotation was 47.2 ± 6.4 mm in male and 41.9 ± 5.9 mm in female ($p<0.001$). The medial offset of the femoral head in derotation was 50.1 ± 5.3 mm in male and 44.3 ± 5.4 mm in female ($p<0.001$). The anterior bowing and lateral bowing of the femoral shaft was 10.3 ± 2.0° in male and 9.0 ± 2.4° in female ($p<0.001$).). The lateral bowing of the femoral shaft was 15.7 ± 8.7° in male and 10.1 ± 9.7° in female ($p<0.001$). There were three distinct femoral shaft configurations, such as lateral, double, and medial curve, of femoral shaft in neutral rotation, in anterior-posterior view.

Discussion and Conclusion: Dimensional differences of the pelvis and femur between females and males were significant with a wide variation within sexes. Most of acetabula had a non-straight acetabular ridge. Configuration of the ridge cannot be detected on standard radiographs nor intraoperatively. Measurement of anteversion angle is dependent upon the point of measurement along the acetabular ridge. Anteversion angle could easily be over-estimated in cases of non-straight anterior acetabular ridge. The notch acetabular angle had small standard deviations, such as 3.0° or 3.8°, and an extremely small range of 90 ± 10° in all of the cases.

Although female has slightly greater angle than male, the difference was only 1.2°. For the cases with posterior osteophyte of the acetabulum, this angle was decreased but more than 80°. In addition, this angle was not correlated with the other parameters. As a result, the notch acetabular angle was useful to identify the anteversion of acetabulum intraoperatively. Medial offset measurement assumes straight long axis of femur. Standard radiographs of hip include only proximal femur from which the long axis cannot be accurately determined. Offset measurement was influenced by rotation of femur. The actual amount of offset may be under-estimated on pre-operative radiographic assessment. Effect of lateral bowing on the apparent long axis of femur was a change of +3.5° varus. Similarly, bowing of the femur was found to be more complex than previously thought. In addition to anterior bowing, some femurs were found to have lateral and even medial bowing. Dimensional differences of the pelvis and femur between females and males were significant with a wide variation within sexes.

Introduction

It is useful to know the normal configurations of acetabulum and femur for clinical application, especially acetabular and femoral anteversion for proper implant positioning and to prevent dislocation in total hip arthroplasty. [2, 10] Adequate anteversion of the hip prostheses provides for a satisfactory functional range of motion. The point of measurement along a possibly curved or angular configuration seems to influence on the acetabular anteversion angle, since the acetabulum is not a simple hemispheric shape. Neither standard radiographs nor two-dimensional computed tomography (CT) scans allow for accurate determination of anatomic configuration [3] and, therefore, assuming acetabular wall configuration has some influence, accurate measurement of the anatomic anteversion angle cannot be determined. Three-dimensional CT scanning has potential for detection of variations in configuration, [1] although this technology currently is not used routinely nor is it cost-effective for routine use as a preoperative assessment tool to aid in intraoperative determination of anteversion. Despite the potential importance of acetabular ridge features, there have been no reports on how differences in anatomic structure influence measurement of acetabular anteversion.

A similar problem exists for accurate measurement of the medial offset of the femoral head. Offset measurement is greatly affected by femoral anteversion and bowing, neither of which can be appreciated adequately on two dimensional radiographs.

Accurate assessment is complicated by the fact that most patients with advanced osteoarthritis of the hip cannot internally rotate their hip on radiographs obtained preoperatively and therefore, the offset is influenced by the inability to attain the necessary derotation of the femur. Several studies of proximal femoral anatomy have regarded the femoral shaft as straight in the standard anteroposterior (AP) view. [8, 22, 25] It is well known that the femoral shaft has some anterior bowing and clinically other configurations have been seen.

The overall incidence of dislocation after primary total hip arthroplasty averages between 2% and 3%. [19] Several risk factors have been identified. There is a definite predilection in female patients with some studies reporting rates double that of male patients. [10, 12, 20, 29] Component positioning has been linked directly to incidence of dislocation. Fackler and Poss [6] reported a significant increase in postoperative dislocations when femoral offset was decreased by inserting the femoral component with a valgus neck shaft angle. Cup orientation is particularly critical. Lewinnek et al. [13] described a safe zone of acetabular component orientation as a lateral opening of 40°± 10° with anteversion of 15°± 10° to decrease the likelihood of dislocation after total hip arthroplasty. Surgical approach also can affect proper positioning of the acetabular component. For example, it has been shown that the surgeon tends to place the cup in 5° to 7° less anteversion with a posterior approach. [18] Positioning the patient in the lateral decubitus position during total hip arthroplasty can allow the pelvis to rotate forward and result in placement of the cup in a retroverted position. [19] Yet, despite all of these reports as to the importance of controlling the amount of anteversion, there have been no reports of how to measure anteversion in an accurate and consistent manner. External alignment guides have been shown to be helpful in reproducing abduction but inaccurate regarding anteversion of the acetabular component. [7] Recently a computer- assisted and image-guided system (HipNav, Center for Orthopaedic Research, Pittsburgh, PA) was developed and is being tested clinically for precise planning and placement of the acetabular component in total hip replacement surgery. [9] In total hip arthroplasty, it was extremely difficult to install the socket in coinciding with anteversion of acetabulum. Dr. D'Antonio suggested that the notch-acetabular angle was nearly equal 90. To confirm this finding, we studied the pelves and femurs in Department of Anthropology, Cleveland Natural History of Museum.

Items of measurements and evaluations in the study are listed in the table 1. The aims of the current study were to: (1) evaluate in detail the morphologic features of the pelvis and femur particularly for configuration of the acetabular anterior and posterior columns and the medial offset of the femoral head relative to the configuration of the femoral shaft; (2) evaluate any differences attributable to gender; and (3) determine whether there is any practical way to accurately assess acetabular anteversion intraoperatively either directly or indirectly.

Materials and Methods

This study was done in collaboration with the Department of Physical Anthropology at the Cleveland Museum of Natural History. The department houses the Hamann-Todd Osteological Collection, which was amassed between 1912 and 1938 by Drs. CA. Hamann and T.W. Todd of the Western Reserve University, Department of Anatomy, and it contains 3100 skeletons of the unclaimed dead of the Cleveland area. [17] Only normal pelves and femurs were included for this study. Specimens with osteoarthritis of the hip, evidence of previous trauma to the pelvis or femur, or skeletal disorders such as multiple epiphyseal dysplasia or osteogenesis imperfecta were excluded. Because gender differences were considered a primary objective of the study, the sample group consisted of 50 males and 50 females (total 200 hip joints) skeletons were selected from 3,300 skeletons in the museum.

The age and race distribution selected to be similar to the population having total hip arthroplasty in the United States. Specimens were selected randomly based on the following conditions: five were younger than 40 years, five were between 40 and 49 years, 15 were between 50 and 59 years, 15 were between 60 and 69 years, and 10 were 70 years or older. Twenty percent of the skeletons in each age group were from African-Americans (black). The average age was 57.9 ± 12.2 years (range, 28-82 years) for males and 57.5 ± 13.5 years (range, 18-82 years) for females. Two hundred normal femur and pelvis combinations (100 male, 100 female) were studied. All measurements were done by one author (MM). [14]

The individual bones (iliums, sacrums, and femurs) were stored in separate areas in the museum, and therefore required reconstruction for this study. The pelves were reconstructed using a thin clay (0.5 to 1.5 cm, proportional to the size of the pelvis) [27] and rubber bands. An anatomic frontal plane of the pelvis was defined by the anterosuperior iliac spines and by the pubic symphysis. This plane is nearly vertical during upright sitting, standing, and walking. [1, 16] In this study, the pelvis was laid on a flat glass table (craniograph) in a prone position so that the anterosuperior iliac spines and the pubic symphysis were in contact with the glass. The glass table was regarded as the anatomic frontal plane (Figure 1).

Table 1. Items for Pelvic and Femoral Measurements

<Pelvis (Acetabulum)>

- Acetabular ridge configuration
- Acetabular anteversion angle
- Notch acetabular angle

<Femur>

- Femoral shaft configuration
- Femoral anterior and lateral bowing angles
- Femoral anteversion angle
- Femoral neck shaft angle and medial offset

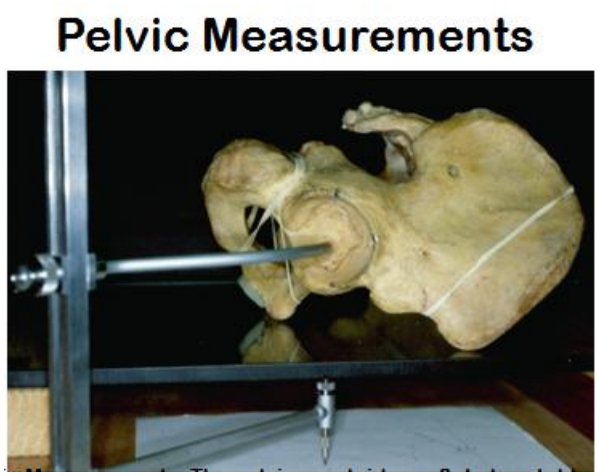


Figure 1. Pelvic Measurements. The pelvis was laid on a flat glass table (craniograph) in a prone position so that the anterosuperior iliac spines and the pubic symphysis were in contact with the glass. The glass table was regarded as the anatomic frontal plane.

The femur was placed on an osteometric board in the supine position so that the posterior aspects of the medial and lateral femoral condyles and the base of the femoral neck were in direct contact with the board (Figure 2).

Statistical Analysis

Statistical analyses for comparison of morphologic features between males and females were done using unpaired *t*-tests or chi square analysis. Comparisons from right to left femur were done using paired *t*-tests. Correlations between variables were calculated using the Pearson product moment coefficient of correlation (r).

The results were analyzed and considered p values of less than 0.05 to be significant. The statistical package used was Microsoft® Excel and its statistical software (Microsoft Corporation, Redmond, WA).

Pelvis (Acetabulum)

Morphologic Features

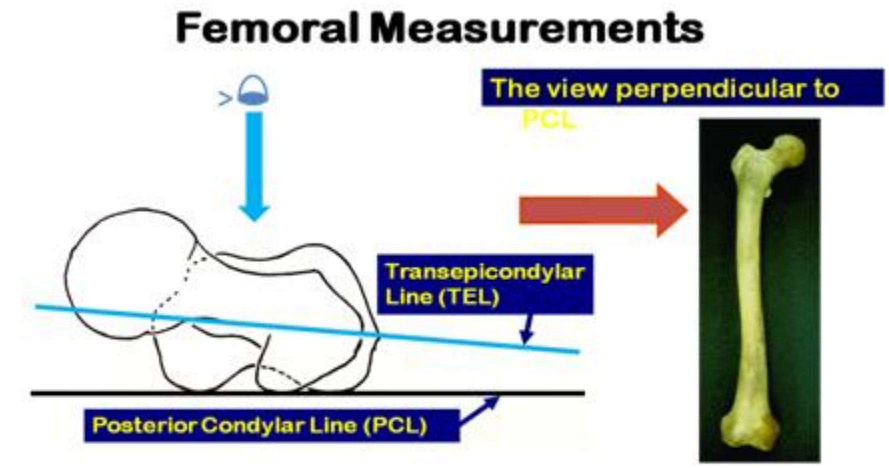
The shape of the anterior column of the acetabulum was classified in four types, such as straight, curved, angular, and irregular (Figure 3). Most of the pelves (121; 60.5%) had a curved configuration, 51 (25.5%) were angular, 19 (9.5%) were irregular, and nine (4.5%) were straight.

Of the 100 pelves examined, 51 had the same configuration of both anterior acetabular ridges and 49 had differing configurations from one side to the other.

There were no differences between genders regarding either breakdown of configurations seen (57 males and 64 females had curved configurations; $p = 0.087$) or side-to-side similarities or differences (29 male and 22 female pelves had the same configuration bilaterally; $p = 0.161$). All posterior columns were a simple hemicircle or straight classification.

Measurements

The acetabular anteversion angle was measured at the center of the acetabulum in a vertical plane to the glass table (horizontal plane) along the anterior to posterior ridges [15] (Figure 4). For acetabula that were not straight, the long axis of the anterior wall was converted to a straight line, and the midpoint then was established along that line (Figure 5).



PCL: Posterior Condylar Line, TEL: Transepicondylar Line.

Figure 2. Femoral Measurements. PCL was used for definition of neutral rotation of the femur in this study. The neutral rotation may be changed to slightly internal position, however, when TEL is used for definition of the neutral rotation. Femoral measurements were performed in the view perpendicular to PCL.

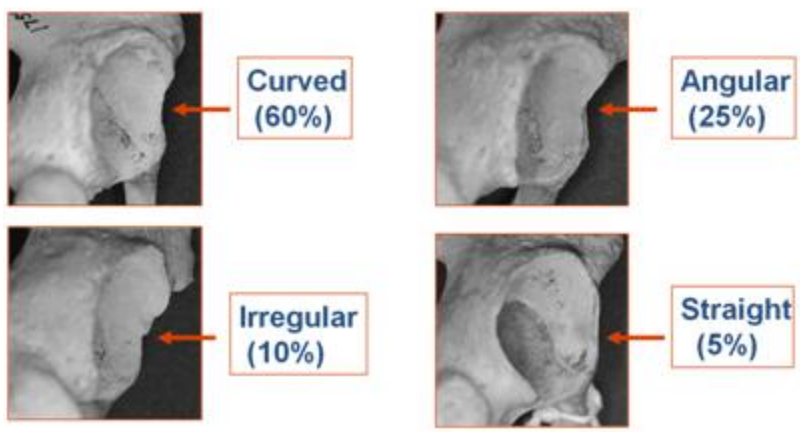


Figure 3. Anterior Acetabular Ridge Configuration was classified into four types: Curved (60%), Angular (25%), Irregular (10%), and Straight (5%). Posterior column was almost always curved or straight. There was no differences between genders as to ridge configuration. (Reproduced by permission from "Wolters Kluwer Health", Lippincott Williams & Wilkins publication: Maruyama, M., Feinberg, J. R., Capello, W. N., D'Antonio, J. A. The Frank Stinchfield Award: Morphologic features of the acetabulum and femur: anteversion angle and implant positioning. *Clin. Orthop. Relat. Res.* 393:52-65, 2001).

The notch acetabular angle was defined as an angle between a line connected the sciatic notch with the posterior acetabular ridge and a line connected both the posterior and anterior acetabular ridge. Because the line from the sciatic notch along the posterior acetabular ridge had an inclination, the notch acetabular plane is not horizontal (Figure 6).

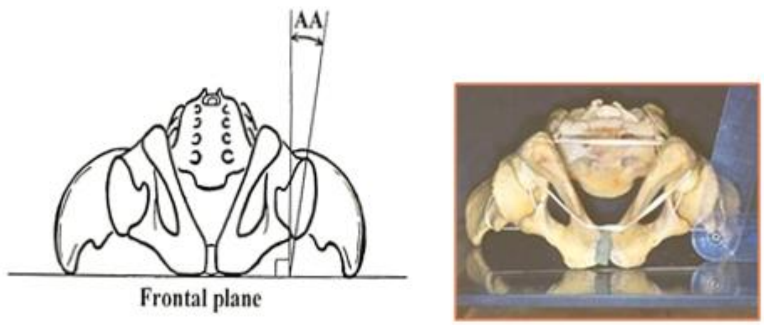


Figure 4. Acetabular Measurements: Anteversion Angle (AA). The pelvis was put on a flat glass table (craniograph) in prone position so that the anterior superior iliac spines and the pubic symphysis were contact to the glass. Thus, the glass table was regarded as the anatomic frontal plane. Acetabular anteversion angle (AA) was measured at the center of the acetabulum in a vertical plane to the glass table along the ridge.

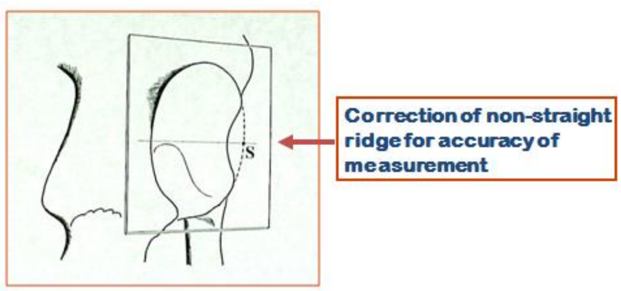


Figure 5. If correction was made in non-straight ridge for accuracy of measurement of anteversion angle, because most of the acetabulums were non-straight configuration, the anteversion angle varied (or decreased) by an average of 6.2^{o} based on the point of measurement along the anterior ridge for the non-straight anterior ridge.

Results

The anteversion angle of the acetabulum was measured as 19.9° ± 6.6° (range, 7°-42°). The corrected acetabular angle for the acetabula that were not straight was approximately 6.2° smaller than the uncorrected acetabular angle on average (Figure 5).

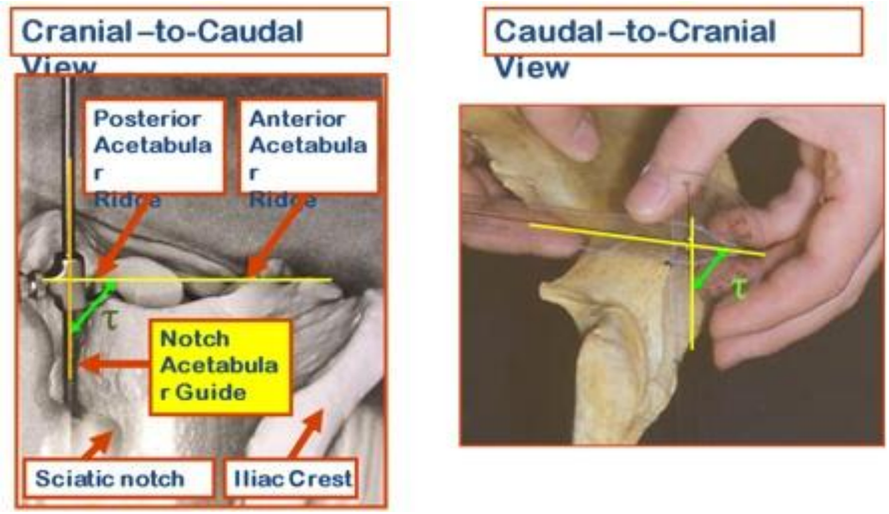


Figure 6. Notch Acetabular Angle (τ). The angle was created at the intersection of the line from the sciatic notch to the posterior acetabular ridge and the line from the posterior to anterior acetabular ridge. (Reproduced by permission from "Wolters Kluwer Health", Lippincott Williams & Wilkins publication: Maruyama, M., Feinberg, J. R., Capello, W. N., D'Antonio, J. A. The Frank Stinchfield Award: Morphologic features of the acetabulum and femur: anteversion angle and implant positioning. *Clin. Orthop. Relat. Res.* 393:52-65, 2001.)

The acetabular anteversion angle of the acetabulum was 18.5 ± 5.8° in male and 21.3 ± 7.1° in female (*p=0.002*) (Table 2).

Table 2. Acetabular Anteversion Angle

19.9° ± 6.6° (range, 7 to 42°)

- Female : 21.3° ± 7.1°
- Male : 18.5° ± 5.8°

Greater in females (p = 0.002 < 0.05)

The notch acetabular angle was almost perpendicular, measuring 89.0° ± 3.5° (range, 77°-100°). The angle was 88.4 ± 3.0° in male and 89.6 ± 3.8° in female (*p=0.014*). Most of the angles were ranged within 90° ± 10° (Figure 7).

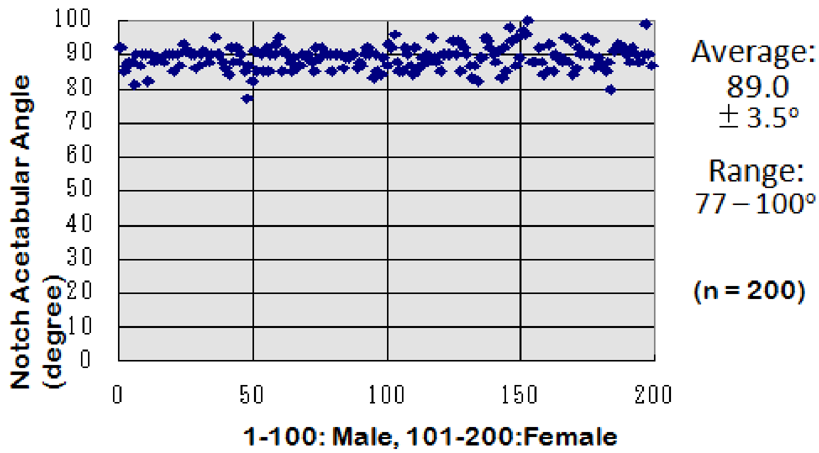


Figure 7. Notch acetabular angle was measured as an average of 89.0 ± 3.5° (range, 77-100°). The angle was 89.6 ± 3.8° in female and 88.4 ± 3.0° in male (p = 0.014). The angle is almost perpendicular to the face of the acetabulum and indicates anatomic anteversion.

There were no significant differences between right and left sides for males or females for any of the measured pelvic angles. There were no correlations between the notch acetabular angle and the other angles ($r^2<0.08$).

There were no significant differences found in the anteversion angle and the notch acetabular angle between younger (< 60 years) and older (≥ 60 years) group within each gender.

Clinical Applications

The notch acetabular angle (the angle created at the intersection of the line from the sciatic notch to the posterior acetabular ridge and the line from the posterior to anterior acetabular ridge) was measured in this study using a special tool that was placed between the sciatic notch and the posterior acetabular ridge. This notch acetabular angle has been used by two authors (JAD, WNC) to estimate the amount of acetabular anteversion necessary for accurate cup placement. With the patient in the lateral decubitus position and the surgeon on the anterior or abdominal side of the patient, the surgeon palpates using the index finger along a line from the posterior wall of the acetabulum to the greater sciatic notch.

A rod is placed parallel to the index and a mark is made on the posterosuperior aspect of the acetabulum using electrocauterization. The notch-acetabular angle, as determined in this study by direct bone measurement, had small standard deviations, such as 3.0° or 3.8°, and an extremely small range of almost 90 ± 10° in all of the cases. Although female has slightly greater angle than male, the difference was only 1.2°. For the cases with posterior osteophyte of the acetabulum, this angle was decreased but more than 80°. In addition, this angle was not correlated with the other parameters.

As a result, the notch-acetabular angle was useful to identify the anteversion of acetabulum intraoperatively. Therefore, because that line essentially is perpendicular to the plane of the face of the acetabulum, reaming for a hemispherical cup parallel to that line would result in placement of the cup in anatomic anteversion for that patient. However, if the surgeon wishes to place the acetabular component in increased anteversion, particularly when using a posterior approach, the direction of the reaming and insertion of the cup will be divergent from that line and will angle toward the top of the sciatic notch instead of the center of the iliac wing. A schematic drawing of how the desired anteversion angle is determined intraoperatively is shown in Figure 8 and 9. The fact that the notch acetabular angle was measured as nearly perpendicular in the 200 pelves in this study suggests that this angle is an accurate estimation of acetabular anteversion and that the use of this technique intraoperatively may aid the surgeon in determining more accurate placement of the acetabular component. Because an improperly angled cup is a recognized cause of dislocation, the incidence of dislocation after primary total hip arthroplasty may be reduced with use of this technique.

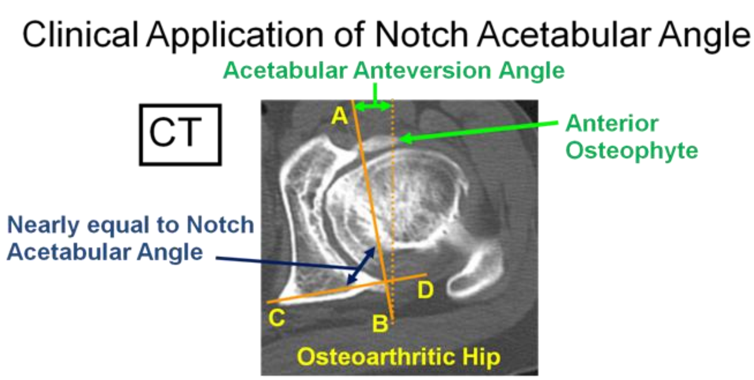


Figure 8. Notch Acetabular Angle in the Hip with osteoarthritis. Line AB indicates true acetabular anteversion. Although line AB cannot be often identified due to anterior osteophyte in case of osteoarthritic hip, line CD, which indicates nearly equal notch acetabular angle, is almost perpendicular to line AB.

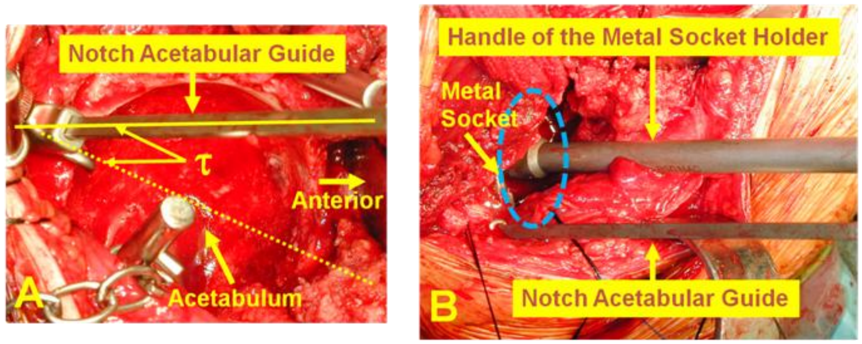


Figure 9. Surgical Application of Notch Acetabular Angle. A) Notch acetabular guide indicates the line from the sciatic notch to the posterior acetabular ridge. B) If the handle of the metal socket holder set parallel to the notch acetabular guide, the socket will be installed in the anatomically anteverted position, because the notch acetabular angle (τ) is almost perpendicular to the face of the acetabulum and indicates anatomic anteversion.

< Femur>

Morphologic Features

There were three distinct femoral shaft configurations, such as lateral, double, and medial curve, of femoral shaft in neutral rotation, in anterior-posterior view (Figure 10). Of the 200 femurs, in a neutral rotation, 162 (81 %) had lateral bowing. Thirty-two (16%) had a double or S curve, and six (3%) had medial bowing.

All double or S curves had lateral bowing proximally and medial bowing distally. With the femur in the derotated position, 124 (62%) were classified as having lateral bowing, 32 (16%) with a double curve, and 44 (22%) with medial bowing. By rotating the femur from neutral to the derotated position, the direction of bowing in 38 (19%) femurs appeared to change from lateral to medial.

In the neutral and derotated positions, femoral shaft configuration differed between males and females with the females having a greater occurrence of medial bowing (six versus 0 in neutral rotation and 29 versus 15 in derotation; $p < 0.05$). All but six of the 100 specimens had the same configuration bilaterally in the neutral position, and all but 15 had the same femoral configuration in derotation.

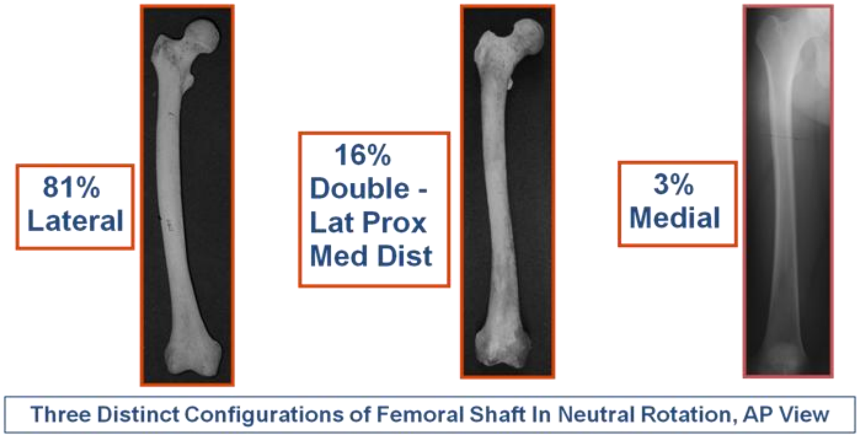


Figure 10. Femoral shaft configuration. Three distinct configurations of femoral shaft in neutral rotation, AP View, were determined. Most of the femora (81%) had the lateral bowing. The double curved femora, which were lateral proximal and medial distal, was observed in 16 %. The medial bowed femora were only 3 %. Shifting from neutral to derotation (commonly internal rotation) position, 38 (19%) femurs appeared to change from a lateral to medial bowing. (Reproduced by permission from "Wolters Kluwer Health", Lippincott Williams & Wilkins publication: Maruyama, M., Feinberg, J. R., Capello, W. N., D'Antonio, J. A. The Frank Stinchfield Award: Morphologic features of the acetabulum and femur: anteversion angle and implant positioning. *Clin. Orthop. Relat. Res.* 393:52-65, 2001).

Measurements

Femoral configuration, such as lateral bowing and anterior bowing of the femoral shaft, anteversion (or antetorsion) of the femoral neck, neck shaft angle and medial offset of the femoral head was also examined in direct measurement and in radiographs.

For consistency of measurement, the total length of the femur from the top of the greater trochanter to the base of the condyles was measured for each femur and then divided into tenths. The axis of the proximal femur (FPA) was set as a line connecting the midpoints of the mediolateral width of the femur at a distance of 2/10 and 3/10 from the top of the greater trochanter. The lateral bowing angle from the anterior-to-posterior view in neutral rotation (θ) was defined as an angle between FPA at the 2/10 and 3/10 positions and a line connecting the intersection of the neck and proximal femur axes and the center of the femoral condyles (Figure 11).

In the same manner, the lateral bowing angle from anterior to posterior in derotation was defined as the lateral bowing of the femur in the derotated position. Anterior bowing angle (δ), based on the lateral radiograph of the hip in the derotated position, was measured as the angle between the following two axes: a femoral axis at the proximal 2/10 and 3/10 lengths and a femoral axis at the 6/10 and 8/10 lengths (Figure 12).

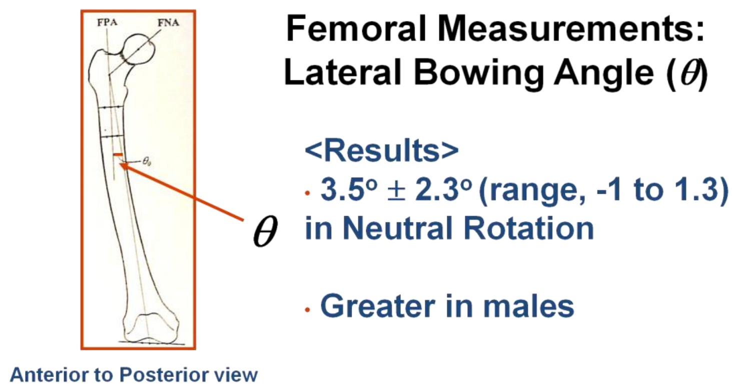


Figure 11. Lateral bowing angle (θ) was defined as an angle between proximal and long femoral shaft axis in AP view. The angle was measured as an average of $3.5^o \pm 2.3^o$ in neutral rotation and greater in males ($4.2^o \pm 2.3^o$ (range, 0 to 12) in males and $2.8^o \pm 2.1^o$ (range, -1 to 13) in females ($p = 1.5 \times 10^{-5}$). The angle was decreased in $1.5^o \pm 2.6^o$ in derotation. (Reproduced by permission from "Wolters Kluwer Health", Lippincott Williams & Wilkins publication: Maruyama, M., Feinberg, J. R., Capello, W. N., D'Antonio, J. A. The Frank Stinchfield Award: Morphologic features of the acetabulum and femur: anteversion angle and implant positioning. *Clin. Orthop. Relat. Res.* 393:52-65, 2001).

Femoral anteversion was defined based on the previous works of Billing [5] and Murphy et al. [21] The long axis of the femur (FLA) is the line defined by two points: the center of the knee (the center of the distal femoral metaphysis on a cross section through the femoral condyles), and the center of the base of the femoral neck (the center of the femoral diaphysis on a cross section through the base of the femoral neck). [14] The axis of the femoral neck (FNA) is the line defined by two points: the center of the femoral head, and the center of the base of the femoral neck. This axis bisects and passes through the midline between the anterior and posterior borders of the femoral neck. [14] In this study, neutral rotation of the femur was defined by the posterior condylar line (Figure 2). Direct bone measurement was done using a craniometer on the osteometric board for determination of the anteversion angle from the proximal (α) and distal (α_0) views (Figure 13, 14).

The reconstructed pelvis was combined with the femurs to recreate the hips so static radiographs could be obtained of all specimens. First, the right and left femurs were placed in neutral rotation and an AP radiograph was taken. Then both femurs were put in a position such that each femur was derotated (commonly internally rotated) around its long axis by the angle of anteversion from the distal view (Figure 14).

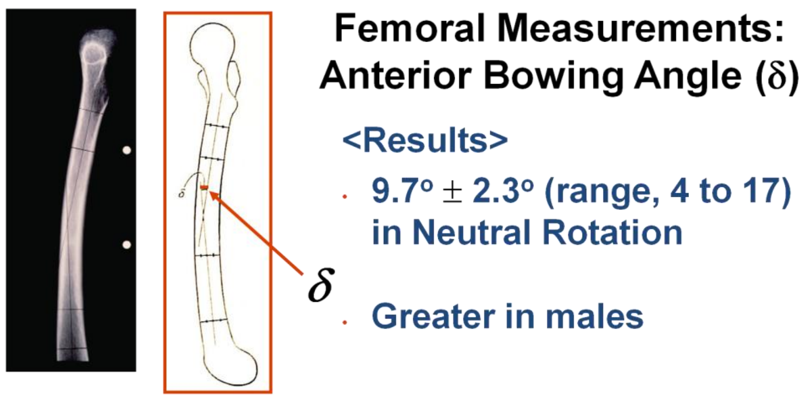
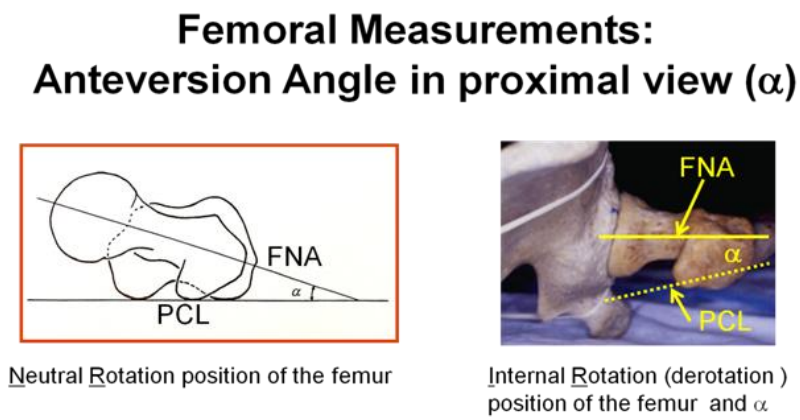


Figure 12. Femoral Measurements [Anterior Bowing Angle (δ)]: Anterior bowing angle (δ), based on the lateral radiograph of the hip in the derotated position, was measured as the angle between the following two axes: a femoral axis at the proximal 2/10 and 3/10 lengths and a femoral axis at the 6/10 and 8/10 lengths. The angle was measured as an average of $9.7^{o} \pm 2.3^{o}$ in neutral rotation and greater in males ($10.3^{o} \pm 2.2^{o}$ (range, 6 to 16) in males and $9.0^{o} \pm 2.4^{o}$ (range, 4 to 17) in females ($p = 5.7 \times 10^{-5}$). (Reproduced by permission from "Wolters Kluwer Health", Lippincott Williams & Wilkins publication: Maruyama, M., Feinberg, J. R., Capello, W. N., D'Antonio, J. A. The Frank Stinchfield Award: Morphologic features of the acetabulum and femur: anteversion angle and implant positioning. *Clin. Orthop. Relat. Res.* 393:52-65, 2001.)

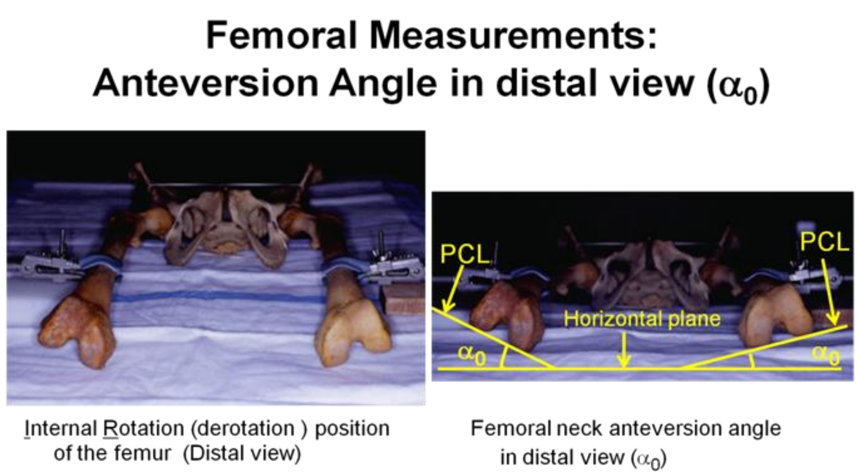
Anteroposterior and lateral radiographs were taken in this derotated position. The tube was set on the pubic symphysis with a tube-to-film distance of 47.5 inches.

Radiographic magnification was corrected by comparing the actual with the radiographic diameter of the femoral head. The following dimensions were measured from the radiographs: the femoral neck shaft angle (λ) based on the AP radiograph in neutral and derotated positions (Figure 15), and the medial offset of the femoral head based on the AP radiograph in the neutral and derotated positions (Figure 16).



FNA: Femoral neck axis, PCL: Posterior condylar line.

Figure 13. Femoral Measurements. Femoral neck anteversion angle in proximal view (α) was defined as an angle between FNA and PCL. FNA was parallel to horizontal plane in derotation (commonly internal rotation (IR)) position. Shifting from neutral rotation (NR) to derotation (commonly internal rotation (IR)) position, 38 (19%) femurs appeared to change from a lateral to medial bowing.



PCL: Posterior condylar line.

Figure 14. Femoral Measurements. Femurs were set in derotation (commonly internal rotation (IR)) position. Femoral neck anteversion angle in distal view (α_0) was defined as an angle between FNA and PCL.

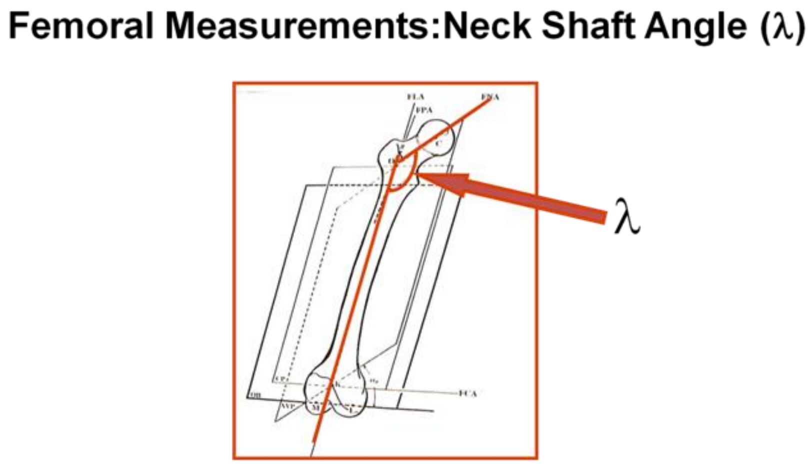


Figure 15. Femoral neck shaft angle was defined as an angle between femoral neck axis and long femoral shaft axis and measured by direct bone measurement. (Reproduced by permission from "Wolters Kluwer Health", Lippincott Williams & Wilkins publication: Maruyama, M., Feinberg, J. R., Capello, W. N., D'Antonio, J. A. The Frank Stinchfield Award: Morphologic features of the acetabulum and femur: anteversion angle and implant positioning. *Clin. Orthop. Relat. Res.* 393:52-65, 2001).

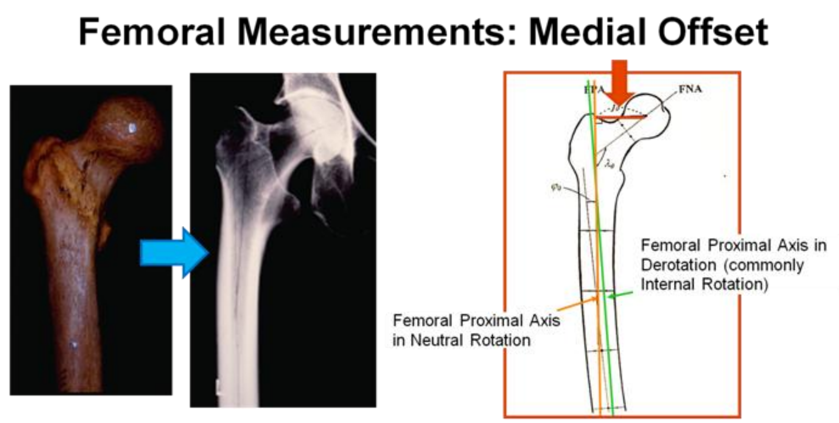


Figure 16. Medial offset of the femoral head was defined as a distance between the center of femoral head and the proximal femoral shaft axis. The offset was determined both in neutral rotated femur and in derotated femur (commonly internal rotation) on the A-P radiograph.

Results

The lateral bowing of the femoral shaft was 15.7 ± 8.7° in male and 10.1 ± 9.7° in female (*p<0.001*). If the lateral bowing angle from anterior to posterior (θ) measured ± 2° or less and the femur had minimal lateral bowing, more females than males had straight femurs (38 versus 16, respectively; *p<0.001*). The anterior bowing angle of the femur (δ) averaged 9.7° ± 2.3°, with males averaging approximately 1.3° more anterior bowing than females as measured on the lateral radiograph (*p<0.001*) (Table). The anterior bowing and lateral bowing of the femoral shaft was 10.3 ± 2.2° in male and 9.0 ± 2.4° in female (*p<0.001*). The anteversion (antetorsion) angle (α) of the femoral neck was 9.8° ± 8.5° (range, -15° to 34°) from the proximal view (9.8 ± 9.0° in male and 9.8 ± 8.0° in female (*p=0.954*)) and α_0 11.6° ± 9.1° from the distal view with no difference between males and females. There was no significant correlation between either the anterior or the lateral bowing angles and the anteversion angle (Table 3).

Table 3. Femoral Anteversion Angle

α : 9.8° ± 8.5° (range, - 15 to +34°)

- Female : 9.8° ± 8.0° (range, - 12 to +34°)
- Male : 9.8° ± 9.0° (range, - 15 to +30°)

α_0 : 11.6° ± 9.1° (range, - 30 to +34°)

- Female : 12.2° ± 7.8° (range, - 5 to +34°)
- Male : 11.1° ± 10.3° (range, - 30 to +34°)

No significant difference between males and females
No correlation with anterior or lateral bowing angles

The femoral neck shaft angle (λ) averaged 124.2° ± 6.0° in neutral rotation and 122.8° ± 5.7° in derotation (mainly internal rotation) on radiographic assessment.

The neck shaft angle of the femur in neutral rotation was 123.2 ± 6.3° in male and 125.3 ± 5.4° in female (*p=0.014*). The neck shaft angle of the femur in derotation was 121.8 ± 6.1° in male and 123.8 ± 5.2° in female (*p=0.0158*).

Females had a more valgus femoral neck-shaft angle on radiographic assessment than males in neutral and internal rotation. ($p < 0.05$) (Table 4).

The medial offset of the femoral head was significantly larger when measured in internal rotation versus neutral rotation (47.2 ± 6.1 mm versus 44.6 ± 6.7 mm, respectively; $p < 0.0001$). The medial offset of the femoral head in neutral rotation was 47.2 ± 6.4 mm in male and 41.9 ± 5.9 mm in female ($p < 0.001$). The medial offset of the femoral head in derotation was 50.1 ± 5.3 mm in male and 44.3 ± 5.4 mm in female ($p < 0.001$) (Table 5). The medial offset on the radiograph was influenced greatly by the anterolateral bowing of the proximal femoral shaft and anteversion of the femoral neck, because FPA by the bowing and FNA by the anteversion were changed in neutral and derotated position.

Table 4. Femoral Neck Shaft Angle

124.2° ± 6.0° (range, 107 to 141°) in neutral rotation

- Female : 125.3° ± 5.4°
- Male : 123.2° ± 6.3° ($p < 0.05$)

122.8° ± 5.7° (range, 106 to 140°) in derotation

- Female : 123.8° ± 5.2°
- Male : 121.8° ± 6.1° (p < 0.05)

Greater in females (Females had more valgus)

Discussion

Dimensional differences of the pelvis and femur between females and males were significant with a wide variation within sexes. Most of acetabula had a non-straight acetabular ridge. Configuration of the ridge cannot be detected on standard radiographs nor intraoperatively. The variations in configuration of the anterior acetabular wall and in bowing of the femur provide the information that affects the accuracy of the current methods of measurement of acetabular and femoral anteversion. The posterior acetabular ridge almost always forms a simple semicircle.

Table 5. Medical Offset of the Femur

47.2 ± 6.1 mm (range, 32 to 65 mm) in derotation

- Female : 44.3 ± 5.4 mm (range, 32 to 63 mm)
- Male : 50.1 ± 5.3 mm (range, 36 to 65 mm)

($p = 8.0 \times 10^{-13} < 0.05$)

44.6 ± 6.7 mm (range, 28.5 to 64.5 mm) in neutral rotation

- Female : 41.9 ± 5.9 mm (range, 28.5 to 61.5 mm)
- Male : 47.2 ± 6.4 mm (range, 30 to 64.5 mm)

($p = 6.2 \times 10^{-9} < 0.05$)

Greatly influenced by the anterolateral bowing of the femur as well as the anteversion of the femoral neck.

However, the anterior ridge either is curved, angular, straight, or irregularly configured (Figure 12). Because of these variations, measurement of anteversion angle is dependent upon the point of measurement along the anterior acetabular ridge. Anteversion angle could easily be over-estimated in cases of non-straight anterior acetabular ridge. In the anatomic model, the anteversion angle varied by an average of 6.2° when non-straight anterior ridges were converted to a straight configuration, therefore, the anteversion angle is dependent on the point of measurement along the ridge (Figure 3). This finding is important because the configuration of the anterior acetabular ridge is not discernible on a standard two dimensional radiograph nor is it possible to discern intraoperatively through palpation because of soft tissue, the presence of osteophyte, or both. Because greater than 95% of the 200 acetabula in this study had non-straight anterior ridges, had they undergone total hip arthroplasty, the amount of acetabular anteversion easily could have been missed to estimate in these cases depending on the point of determination along the acetabular walls intraoperatively. The presence of osteophyte, in particular those along the anterior acetabular ridge, could result in an over-estimation of the notch acetabular angle.

Medial offset measurement of the femoral head is measured based on the assumption that the long axis of the femur is straight. Because standard radiographs of the hip usually only include the proximal femur, measurements that are taken have only the proximal femur from which the long axis cannot be accurately determined. Noble et al. [23] and Preininger et al. [24] defined the medullary axis using the proximal femur as a line passing through the midpoints of the medullary canal at 20 mm proximal and distal to the canal isthmus. However, because other authors [4, 26] described changes in the medullary canal with aging and osteoporosis, the extracortical borders were used to define the femoral axes in this study. The amount of offset was influenced by rotation of the femur seen on the radiograph because of femoral anteversion with the value of the offset in derotation significantly larger than in neutral rotation. Therefore, the actual amount of offset may be underestimated on pre-op radiographic assessment. Derotation of the femur was useful in negating the effect of the femoral anteversion; however, it often is not possible to position the patient with end-stage hip arthritis who has yet to have surgery in a derotated position. Therefore, the amount of offset may be underestimated on the standard radiograph, obtained preoperatively. Medial offset also was found to be influenced by not only the anteversion of the femoral neck but also by the anterolateral bowing of the femoral shaft.

Effect of lateral bowing on the apparent long axis of femur was a change of +3.5° varus. Similarly, bowing of the femur was found to be more complex than previously thought. In addition to anterior bowing, some femurs were found to have lateral and even medial bowing. The long axis of the proximal femur was altered depending on rotation attributable to the bowing. It is known that the femur has an anterior bowing of the shaft. The current authors, however, described an average lateral bowing of approximately 13° with 81 % of femurs having lateral bowing. The effect of lateral bowing on the apparent long axis of the femur was a change toward varus of 3.5° in neutral rotation and 1.5° in the derotated position. In the current study, the lateral bowing angle was measured based on neutral rotation as determined from the posterior condylar line. However, if neutral rotation were to be determined from the transepicondylar line, then the lateral bowing angle possibly could appear decreased. Clinically, the effect of lateral bowing would mean that an implant placed in apparent neutral alignment, as determined by viewing the radiograph of the proximal femur, actually would be in slight varus regarding the true long axis of the femur in the majority of cases (Figure 9-A). It is not known whether this slight varus positioning could affect the longevity of the implant adversely although varus orientation of the stem led to increased failure with the Charnley low friction arthroplasty. [11]

Some differences were found between morphologic features of male and female pelves and femurs. The acetabular anteversion angle was greater in females, which is similar to the reported findings of others. [15, 16] No gender differences were found relative to amount of femoral anteversion, and no correlation was found between acetabular and femoral anteversion angles, which is in agreement with previous reports. [3, 28] Males had a significantly greater medial offset of the femoral head and greater anterior and lateral bowing of the femoral shaft. In neutral rotation, medial bowing of the femur was seen in six females and no males.

Proper component positioning in total hip arthroplasty relative to the amount of acetabular and femoral anteversion is important in preventing postoperative dislocation. Although this orientation is critically important, it is extremely difficult to assess intraoperatively. Even with proper acetabular component positioning, excessive anteversion or retroversion of the femoral component can lead to component dislocation. [6] Furthermore, the most common error in femoral malpositioning is excessive anteversion. [6] The most important factor in minimizing the rate of dislocation under the surgeon's control is positioning of the components in total hip arthroplasty. [18]

We previously described the study of 200 pelves and femurs with morphologic details. [14] In particular, four distinct configurations of the anterior acetabular ridge were identified and the influence of these configurations on the accuracy of anteversion angle measurement was shown. Similarly, bowing of the femur was found to be more complex than previously thought. In addition to an anterior bow, femurs were found to have a lateral bow, and in some cases and depending on rotation, this additional bow appeared to be medial.

Detailed measurements of dimensions revealed differences between males and females and between younger and older females, which may help to explain the increased incidence of dislocation after total hip arthroplasty in females. These results have implications relative to implant design in that normal anatomy has a wide variation of configurations, and therefore one implant design may not be adequate for all cases.

In particular, differences in male and female anatomy regarding anteversion angles may indicate that either different implants or different guidelines for implant positioning are needed.

Furthermore, it was shown that hip rotation influences critical measurements used in implant positioning. The use of the notch acetabular angle as an indirect estimate of acetabular anteversion may be a useful tool to decrease the incidence of dislocation after primary total hip arthroplasty.

The results of this anatomic study may explain why component positioning relative to anteversion is so difficult. On the acetabular side, the anteversion angle is influenced greatly by the point of measurement and configuration of the anterior acetabular ridge. The anteversion angle, when measured with the above considerations, differed significantly between males and females.

On the femoral side, the complexity of the bowing of the femoral shaft could influence femoral component positioning relative to anteversion and medial offset. Long femoral axis (FLA) is not differed by rotation for measurement of medial offset, it may be ideal to use this axis (FPA). The anterior and lateral bowing angles differed significantly between males and females, and these angles differed depending on the rotation of the hip.

We usually take three-dimensional CT scanning for the patients with osteoarthritis of the hip joint (Figure 17).

The next stage of this morphologic study might be evaluation of variations in configuration of normal and pathologic bone by using three-dimensional CT scanning.

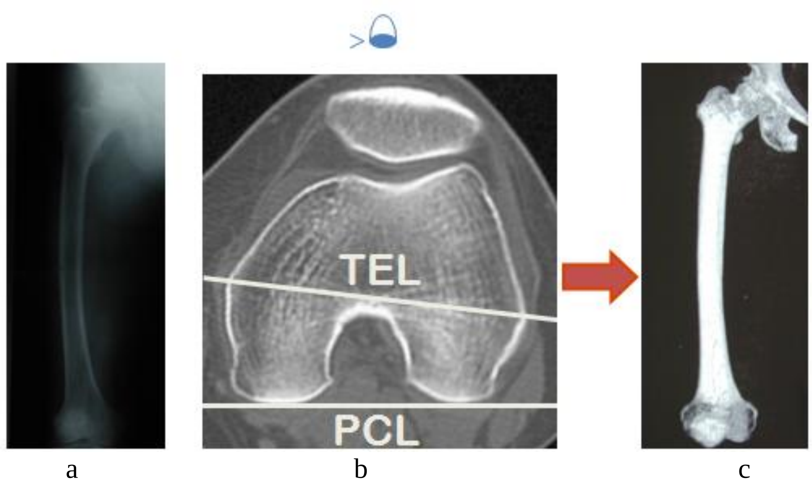


Figure 17. It is difficult to take a radiograph in neutral rotation perpendicular to PCL clinically (a). By using 3-dimensional computer tomography (3-D CT), it may be easy to evaluate femoral configuration in neutral rotation perpendicular to PCL (b and c).

Acknowledgments

The authors thank Bruce Latimer, PhD, Curator, and Lyman M. Jellema, Collections Manager, Department of Physical Anthropology, Cleveland

Museum of Natural History, for their excellent assistance and contribution for this study.

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