The Female Knee: Anatomic Variations

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Abstract

Traditional knee implants have been designed “down the middle,” based on the combined average size and shape of male and female knee anatomy. Sex-based research in the field of orthopaedics has led to new understanding of the anatomic differences between the sexes and the associated implications for women undergoing total knee arthroplasty. Through the use of a comprehensive bone morphology atlas that utilizes novel three-dimensional computed tomography analysis technology, significant anatomic differences have been documented in the shape and size of female knees compared with male knees. This research identifies three notable anatomic differences in the female population: a less prominent anterior condyle, an increased Q angle, and a reduced medial-lateral:anterior-posterior aspect ratio.

In recent years, medical research has revealed a multitude of differences between men and women beyond the obvious variations in primary and secondary sex characteristics. The notion that women are not “little men” has been demonstrated in studies ranging from cardiovascular disease to depression to basic cellular metabolism. This study of sex-specific issues in medicine has extended to orthopaedics.1 Of current interest is the relationship of sex to fit and function in total knee arthroplasty (TKA).

The issue of female-specific knee characteristics is particularly relevant because, compared with men, women have a higher prevalence of knee arthritis, more severe accompanying symptoms, and greater functional disability. In unadjusted analyses for 2003 through 2005, physician-diagnosed arthritis among adults in the United States was estimated at 21.6% (46.4 million people) and was significantly more common in women than in men (25.4% versus 17.6%).2 The incidences of this condition, as well as the sex disparity, are likely to grow for two reasons. First is the dramatic increase in obesity, which disproportionately affects women; obesity contributes to the risk of arthritis.3 Second is the trend toward implanting knee prostheses in younger patients,4 who can expect to live longer, more active lives than did their predecessors.

Although women account for two thirds of all TKAs,5 there is evidence that this highly successful technology is underutilized in women, with a potentially adverse effect on quality of life and productivity. In a study of more than 48,000 Canadians aged 55 years and older, the number of individuals with the potential need for hip or knee arthroplasty was estimated to be 44.9 per 1,000 women and 20.8 per 1,000 men.6 The potential need for hip or knee arthroplasty was defined as the presence of severe symptoms and disability, with clinical and radiographic evidence of arthritis, as well as absence of contraindications to surgery. After adjusting for willingness to undergo the proce-
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**Historical Perspective**

Early in their development, total knee prostheses were simple mechanical devices that only roughly approximated the workings of the human knee. Before 1976, prostheses were available in few sizes, and no differentiation was made between devices for the left versus the right knee. By the early 1980s, it was recognized that these limitations compromised function and clinical results in many respects. Eventually, designers and manufacturers sought to more accurately accommodate the specifics of human anatomy and the spectrum of demography. Implant choices were expanded to a larger number of sizes, and asymmetric femoral components to improve patella tracking were introduced. The concept of modularity was eventually incorporated into implant design, allowing industry to provide the surgeon more latitude in fitting an implant to a specific anatomic situation without excessive inventory requirements.

By the 1990s, improved articulations and materials were introduced. Early in the 21st century, high flexion and minimally invasive surgical techniques further advanced clinical practice. Nonetheless, implant features continued to be based on anatomic data that represented a compromise of the differences recently recognized between male and female anatomy.

**Anatomic Variations Between Female and Male Knees**

For years, physicians have reported anatomic variations beyond mere differences in size between the knees of men and women. Hitt et al reported on morphologic data recorded on the distal femur, proximal tibia, and patella in 337 knees (209 female, 128 male) during TKA. The aspect ratio (the medial-lateral [ML] to anterior-posterior [AP] [ML: AP] dimension) was characterized for the proximal aspect of the tibia and the distal femur. These morphologic data were compared with known dimensions from six prosthetic knee systems. A wide variation in the aspect ratio for the femoral component was seen among the six systems. In addition, for women, there was a significant association \( P < 0.0001 \) between the size of the component and the amount that the component would overhang the medial or lateral margin of the femur, with larger sizes having more overhang. Although the femoral aspect ratio was higher for smaller knees and proportionately lower for larger knees, the implants studied showed little change in the aspect ratio. Sex differences in the morphologic data also were demonstrated by the variable tibial aspect ratios. Comparison of the bone dimensions from the study data and the dimensions of the implants indicated that, in the typical female patient, the smaller sizes were too small and the larger sizes tended to be too large.

In a related study, Chin et al performed intraoperative measurements of male and female distal femurs during primary TKA. Their data demonstrated that, independent of AP height for any given AP dimension, women tended to have a narrower ML dimension. The authors noted that these sex-based differences had important implications for femoral implant design.

The increased prevalence of patellofemoral symptoms and disease in the female population also has long been noted, and anatomic differences at the articulation have been documented. The quadriceps angle \( Q \) angle—the angle formed between the vectors for the combined pull of the quadriceps femoris muscle proximally and the patellar tendon distally—is, on average, greater in females than in males. Differences range from 2.7° to 5.8° when measured supine with the quadriceps relaxed and from 3.4° to 4.9° on standing.

**Two Distinct Patient Populations**

Mahfouz et al created a comprehensive bone atlas of femurs and patellas, using a novel, proprietary three-dimensional computed tomography analysis technology. The data were used to investigate the degree to which anatomic variation might be a potential source of adverse effects on some women undergoing TKA. The aim of the investigation was to quantify the anatomic sex differences. Significant anatomic shape differences were found in the typical female knee, including a less pronounced anterior condyle height and a distinct ML:AP aspect ratio, resulting in a more trapezoidal shape of the knee.

**Female-Specific Knee Implant Design**

**Modified Anterior Flange**

Other research confirms that the female knee has a less pronounced anterior condyle height than does the male knee. The mean lateral condyle height for females is 10.1 mm, versus 10.9 mm for males (difference, 0.8 mm); the medial condyle
height is 5.1 mm for females and 6.4 mm for males [difference, 1.3 mm]¹⁹ (Figure 1). However, traditional knee arthroplasty uses a femoral knee component that replaces a woman’s knee with the same thickness of anterior condyle as a man’s, regardless how much bone is removed. This may result in a patellofemoral joint that feels tight or “overstuffed” after surgery and in limited postoperative range of motion.⁷,²⁰,²¹ In an implant designed specifically for women, the sulcus could be recessed and the anterior condyle height lowered, producing a thinner anterior condyle that more closely approximates the thickness of the original resected anterior condyle of the female patient.

**Increased Trochlear Groove Angle**

Women typically are shorter than men, with wider hips and a larger Q angle, causing their patellas to track at a wider angle over the distal femur.¹⁰,¹²,¹³,¹⁶,¹⁸ Traditional implant designs are typically sex-neutral, accommodating an average of female and male Q angles, which may not be ideal. This may contribute to patellar maltracking [a particular concern in women following TKA]¹⁴ and may require intraoperative adjustments. A relatively lateralized patellar sulcus, which replicates the distinct Q-angle difference by increasing the patellar sulcus angle of the implant by 3°, could enhance patellar tracking and reduce the need for lateral retinacular release (Figure 2).

**Modified ML:AP Aspect Ratio**

Data from the bone atlas¹³ clearly document the presence of two distinct patient populations (Figure 3) as well as differences in shape between the female and male distal femur. In addition to the finding that the female femur is narrower in the ML dimension compared with a male femur of the same AP dimension, the female femur was found to be more trapezoidal compared with the more rectangular shape of the male femur (Figures 4 and 5). As a result, when implant size is selected based on the measurement of the AP femoral height—the standard method for reproducing femoral geometry to reestablish appropriate kinematics—the traditional implant fre-
quently may be too wide (medial to lateral); the result is that the implant overhangs the bone medially and/or laterally. This can lead to soft-tissue irritation and may affect soft-tissue balancing.

Because the great majority of female distal femurs are trapezoidal, the most prevalent points of overhang tend to be seen distally and anteriorly (Figure 6). In such cases, the surgeon may be required to make intraoperative adjustments to compensate for the overhang.\(^{15}\) Narrowing the femoral implant mediolaterally for a given AP dimension would proportion the implant appropriately at various locations to fit the female knee shape more accurately. Such narrowing thus could compensate for this distinct sex difference.

**The Science of Femoral Mapping**

To address the issue of reducing overhang and to more accurately size the femoral component to reproduce the female anatomy, a unique method was devised to predetermine both the contour of a distal femur resected for a TKA and the fit of an implant on the resected bone (Figure 7). In this process, \(1\) the three-dimensional inner box shape of the traditional implant was determined; \(2\) the shape was extracted; \(3\) the shape was then unfolded, creating a two-dimensional profile; \(4\) the resection planes of the female bone were rendered in a two-dimensional profile and \(5\) were overlaid on the implant profile, indicating the areas where traditional implants overhang the female bone. Additional female datasets were then added to increase the statistical accuracy, and a two-dimensional female profile was created that, when folded into a three-dimensional shape, more accurately replicates the shape of the female bone. In this way, femoral mapping addresses implant variations relevant to a specifically female design.

**Summary**

Surgeons have long recognized the differences in male and female
knees, often making intraoperative adjustments on female patients to minimize patellofemoral complications. Such adjustments have the potential to adversely affect function and produce symptoms. A femoral implant designed specifically for women may lessen the need for intraoperative adjustments [eg, downsizing] to make the femoral component more accurately fit the female patient and may reduce the potential for subtle patellar maltracking and overstuffing of the patellofemoral joint.

Reproduction of the female knee anatomy using femoral mapping. A-C, The inner shape of a traditional implant is unfolded into a two-dimensional profile. D-F, The resection planes of the female bone are rendered two-dimensionally, overlaid on the profile of the traditional implant, and additional female datasets are then added. Arrows in panel E indicate where the traditional implant (shaded outline) overhangs the female bone. G and H, The resulting two-dimensional female profile replicates the shape of the female bone (inner shape in panel G). (Reprinted with permission from Zimmer, Warsaw, IN.)

Note From the Editor-in-Chief

There are no clinical studies to date reviewing and reporting the outcomes of women with sex-specific total knee arthroplasty. This preliminary report was written by Ms. Conley, an employee of the Zimmer Corporation, in conjunction with Dr. Rosenberg (an orthopaedic surgeon and chair of an advisory panel of the Zimmer Institute) and Dr. Crowninshield (a PhD and former senior vice president and chief science officer of the Zimmer Corporation), who are consultants for or receive royalties or have stock or stock options in the Zimmer Corporation. The material presented in the Journal of the American Academy of Orthopaedic Surgeons has been made available by the American Academy of Orthopaedic Surgeons for educational purposes only. This material is not intended to present the only, or necessarily best, methods or procedures for the medical situations discussed, but rather is intended to represent an approach, view, statement, or opinion of the author[s], which may be helpful to others who face similar situations.

References


