Anthropometric Measurements of the Human Knee: Correlation to the Sizing of Current Knee Arthroplasty Systems

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Anthropometric Measurements of the Human Knee: Correlation to the Sizing of Current Knee Arthroplasty Systems

By Kirby Hitt, MD, John R. Shurman II, MD, Kenneth Greene, MD, Joseph McCarthy, MD, Joseph Moskal, MD, Tim Hoeman, MD, and Michael A. Mont, MD

Background: There is a paucity of data concerning the morphological dimensions of the distal part of the femur, the proximal part of the tibia, and the patella. The objective of this study was to analyze the exact anatomic data collected from a large group of patients undergoing total knee arthroplasty and to correlate the measurements to the dimensions of current prosthetic systems.

Methods: Eight different centers collected morphologic data from the distal part of the femur, the proximal part of the tibia, and the patella from 337 knees during total knee arthroplasty. Microcaliper measurements from templates and measuring guides were used to decrease intraobserver variation. The study included 188 women (209 knees) and 107 men (128 knees) who had a mean age of sixty-nine years. A characterization of the aspect ratio (the medial-lateral to anterior-posterior dimensions) was made for the proximal aspect of the tibia and the distal part of the femur. Known dimensions from six prosthetic knee systems were compared with the morphologic data.

Results: A wide variation in the aspect ratio for the femoral component was seen among the six different prosthetic systems. For women, there was a significant association between the component size and the amount of medial-lateral overhang, with larger sizes having more overhang ($p < 0.0001$). Although the femoral aspect ratio for the morphologic data showed higher ratios for smaller knees and proportionally lower ratios for larger knees, the designs showed little change in the aspect ratio. The tibial aspect ratio from the morphologic data showed a higher ratio for smaller knees and a proportionally lower ratio for larger knees. The Duracon component tracked the decline in aspect ratio fairly well, whereas the other brands either did not change with anterior-posterior dimension or actually increased (NexGen). Gender differences in the morphologic data were shown by the variable tibial aspect ratios. A comparison of the bone dimensions from the study data and the dimensions of the implants indicated that the smaller sizes were too small while the larger sizes tended to be too large. The average overall unresected patellar thickness was 23.7 mm.

Conclusion: The results of this study will allow manufacturers to make more appropriate determinations of the sizes and aspect ratios of components for use in total knee arthroplasty.

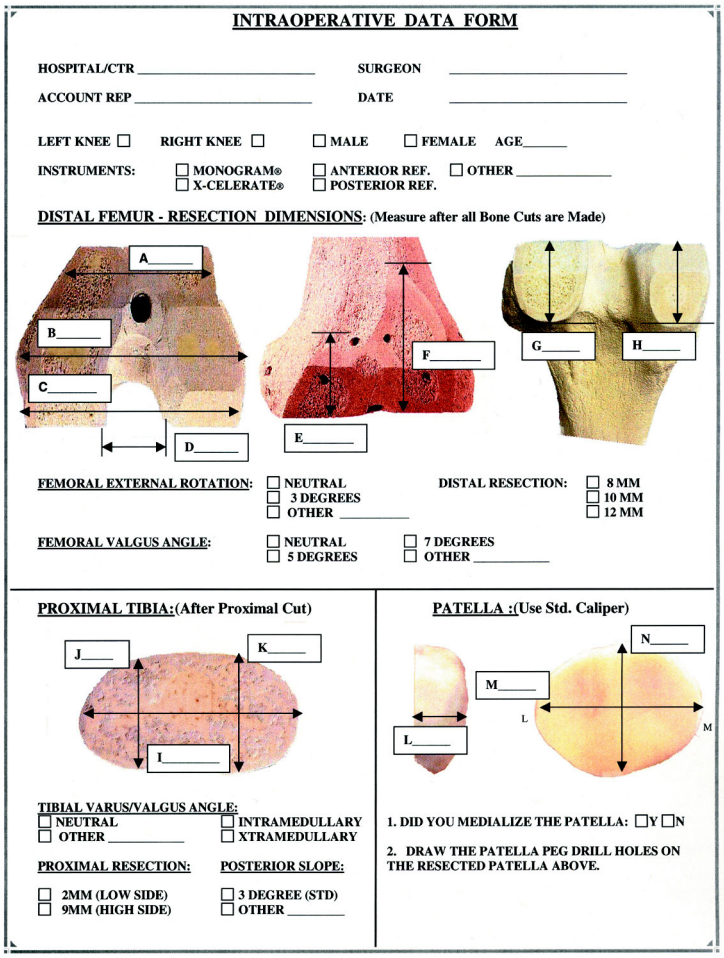
Early designs of total knee prostheses were limited in the number of sizes available to the surgeon. The evolution of the design and kinematics in total knee replacements led to improved sizing options to more closely duplicate patient anatomy. Proper implant sizing can help to avoid complications and maximize outcome. Surgeons must rely on prosthesis manufacturers to provide appropriately sized implants.

This study analyzed the exact anatomic data of a large group of patients undergoing total knee arthroplasty and compared the measurements with the dimensions of current total knee prosthetic systems.

Materials and Methods

Eight centers collected morphologic measurements from the distal aspect of the femur, proximal aspect of the tibia, and the patella of patients undergoing primary total knee arthroplasty. Patients were excluded from the study if the operation was not a primary knee replacement, if substantial bone loss and/or degradation requiring augmentation was involved, if the knee had a varus or valgus deformity of >15°, or if the patient did not have a fully developed skeletal system.

Morphologic data from the distal part of the femur and the proximal aspect of the tibia in 337 knees in 295 patients were analyzed. Two hundred and nine knees (62%) were in


INTRAOPERATIVE DATA FORM

HOSPITAL/CTR _____ SURGEON _____

ACCOUNT REP _____ DATE _____

LEFT KNEE ☐ RIGHT KNEE ☐ ☐ MALE ☐ FEMALE AGE_____

INSTRUMENTS: ☐ MONOGRAM® ☐ X-CELERATE® ☐ ANTERIOR REF. ☐ POSTERIOR REF. ☐ OTHER _____

DISTAL FEMUR - RESECTION DIMENSIONS: (Measure after all Bone Cuts are Made)

A_____ B_____ C_____ D_____ E_____ F_____ G_____ H_____

FEMORAL EXTERNAL ROTATION: ☐ NEUTRAL ☐ 3 DEGREES ☐ OTHER _____

DISTAL RESECTION: ☐ 8 MM ☐ 10 MM ☐ 12 MM

FEMORAL VALGUS ANGLE: ☐ NEUTRAL ☐ 5 DEGREES ☐ 7 DEGREES ☐ OTHER _____

PROXIMAL TIBIA: (After Proximal Cut)

J_____ K_____ I_____

TIBIAL VARUS/VALGUS ANGLE: ☐ NEUTRAL ☐ OTHER _____ ☐ INTRAMEDULLARY ☐ XTRAMEDULLARY

PROXIMAL RESECTION: ☐ 2MM (LOW SIDE) ☐ 9MM (HIGH SIDE)

POSTERIOR SLOPE: ☐ 3 DEGREE (STD) ☐ OTHER _____

PATELLA : (Use Std. Caliper)

N_____ M_____ L_____ L M

1. DID YOU MEDIALIZE THE PATELLA: ☐Y ☐N

2. DRAW THE PATELLA PEG DRILL HOLES ON THE RESECTED PATELLA ABOVE.

Fig. 1

Standardized intraoperative data form.

women, and 128 knees (38%) were in men. The mean age (and standard deviation) was 68 ± 9 years (range, forty-three to eighty-eight years) for the 188 women and 70 ± 11 years (range, thirty-two to eighty-nine years) for the 107 men.The mean age of all patients was sixty-nine years. Forty-two patients had a bilateral total knee arthroplasty performed in a sequential fashion during one operative setting. Patellar data were recorded for 177 patients (seventy-four men and 103 women). All measurements were recorded in millimeters with use of a sterilizable flat ruler, patellar caliper, femoral sizing template, tibial plateau template, and posterior condyle depth gauge. Standard accepted surgical procedures for total knee arthroplasty were used at the discretion of the participating surgeon. Monogram or X-celerate instrumentation from the Duracon total knee system (Stryker Howmedica Osteonics, Allendale, New Jersey) was used. A standardized protocol was followed in recording femoral, tibial, and patellar measurements after all cuts were made with use of the surgeon's preferred surgical technique (Fig. 1).

A characterization of the aspect ratio (the medial-lateral dimension divided by the anterior-posterior dimension × 100) was made for the tibia and

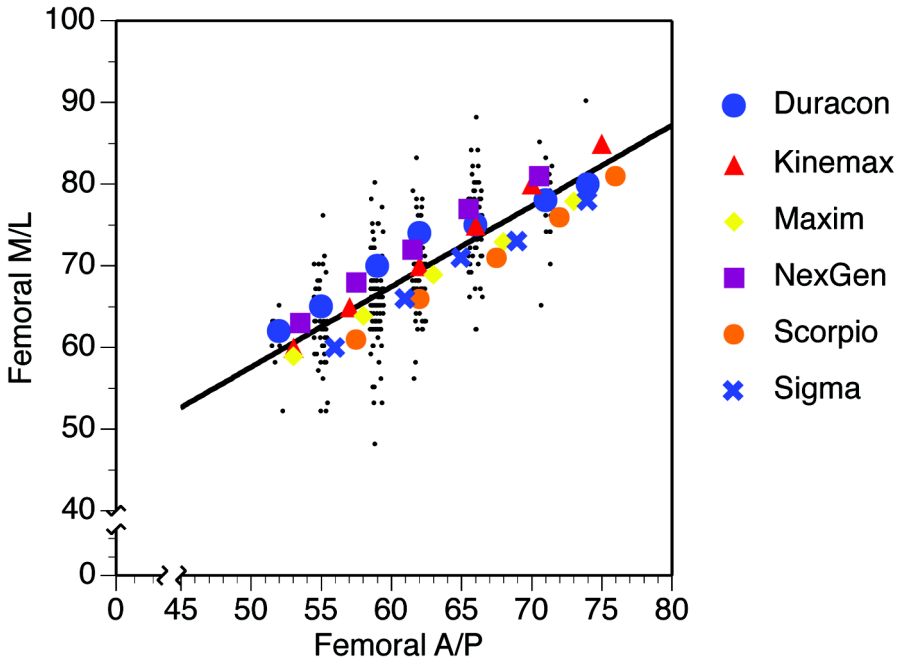


Fig. 2

The femoral medial-lateral (M/L) measurements versus the anterior-posterior (A/P) measurements (mm) for 337 knees, showing close approximation of the implant size to the morphologic data.

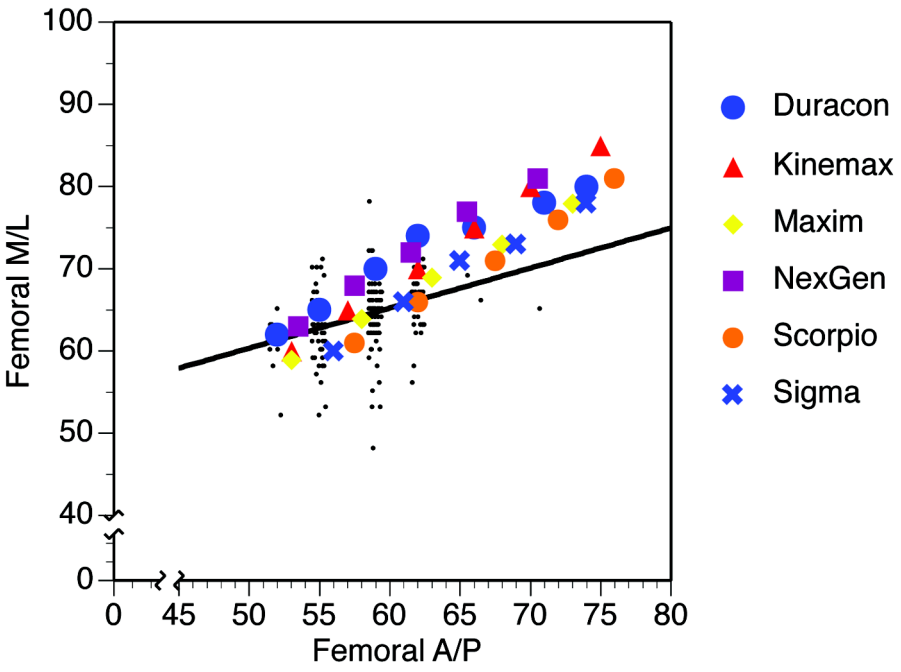


Fig. 3
The femoral medial-lateral (M/L) measurements versus the anterior-posterior (A/P) measurements (mm) for 209 knees in women. The medial-lateral overhang increased as the implant size increased.

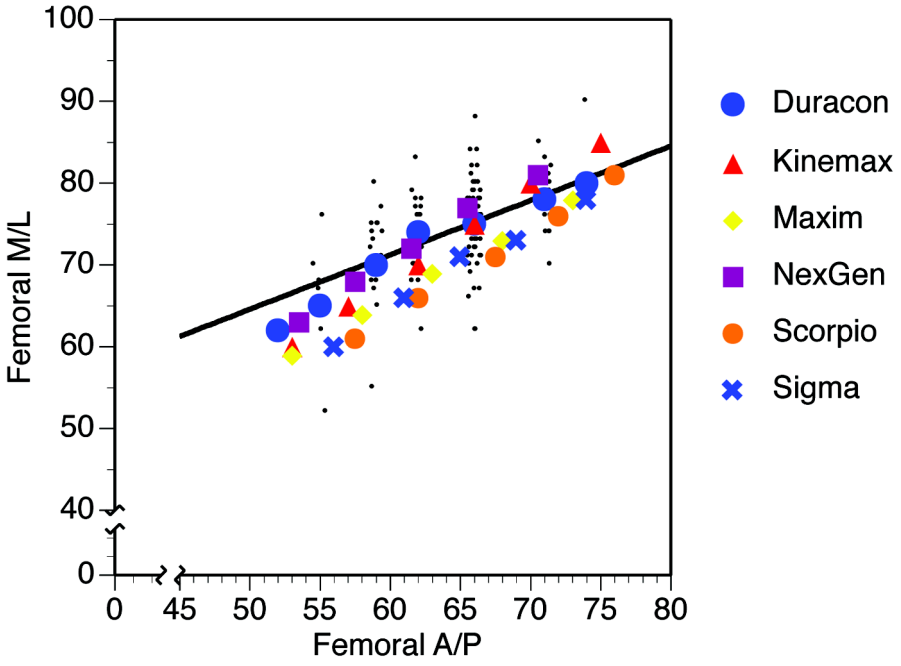


Fig. 4
The femoral medial-lateral (M/L) measurements versus the anterior-posterior (A/P) measurements (mm) for 128 knees in men, showing a trend toward a smaller medial-lateral dimension for a given anterior-posterior dimension.

femur. For the femur, this aspect ratio was compared with six prosthetic systems: Scorpio, Kinemax, and Duracon (Stryker Howmedica Osteonics); NexGen (Zimmer, Warsaw, Indiana); Maxim (Biomet, Warsaw, Indiana); and Sigma (DePuy-Johnson and Johnson, Warsaw, Indiana). On the femoral side, the implant size that most closely approximated the anterior-posterior dimension, after appropriate sizing and bone cuts were made, was chosen for comparison. As the anterior-posterior size is determined from anterior or posterior referencing as part of the procedure, attempts were made to compare medial-lateral dimensions from implants with similar anterior-posterior dimensions. Tibial medial-lateral and anterior-posterior data measurements were compared with five prosthetic systems. The tibial aspect ratio versus the anterior-posterior measurement was evaluated and compared with five implant designs. The anterior-posterior dimension of the tibia was determined as an average of the anterior-posterior measurements on the medial and lateral plateaus. Data from men and women were separated out and compared with those from current systems to evaluate gender differences. A microcaliper was used to measure the thickness of the patella before and after resection. Medial-lateral and inferior-superior patellar dimensions were determined.

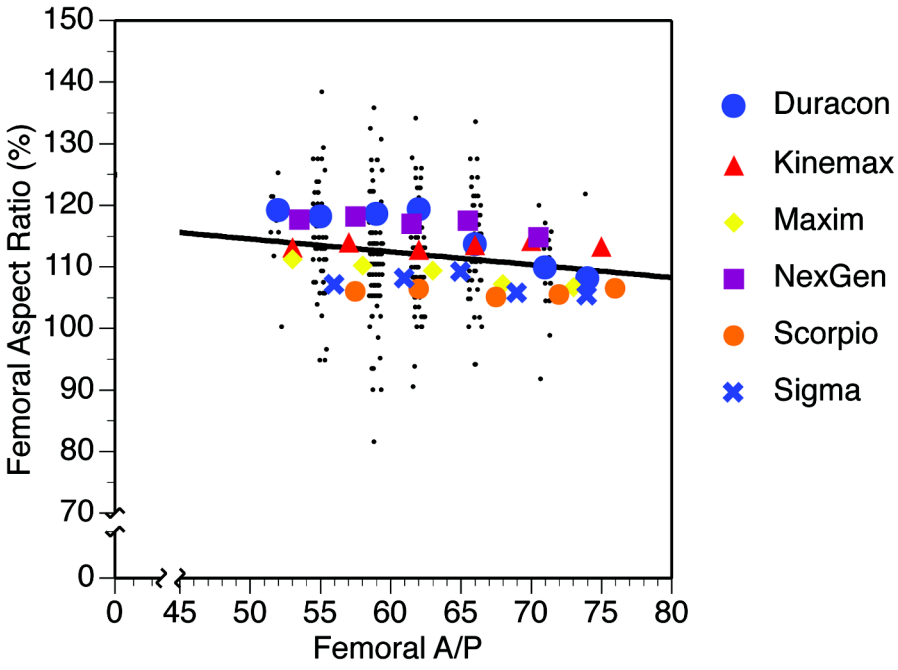


Fig. 5
The femoral aspect ratio versus the anterior-posterior (A/P) measurements (mm) for 128 knees in men, showing a higher aspect ratio for smaller knees and a proportionally lower ratio for larger knees.

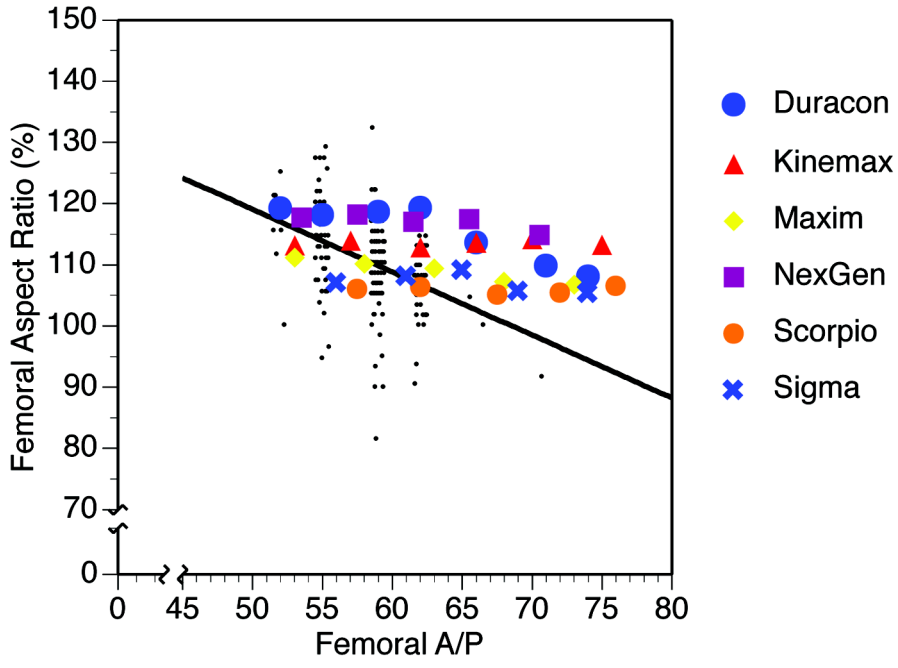


Fig. 6
The femoral aspect ratio versus the anterior-posterior (A/P) measurements (mm) for 209 knees in women.

In analyzing the data, best-fit lines were calculated with use of least-squares regression. The dimensions are summarized as the mean and standard deviation. The differences between the component medial-lateral and the femoral medial-lateral dimension were assessed with use of the Student t test. Comparisons of dimensions between men and women were made with use of the two-sample t test. A p value of <0.05 indicated a significant effect.

Results

Femur

For women with the Duracon component, there was a significant association between the component size and the amount of overhang, with larger sizes having more overhang. The average component overhang was +4.9 ± 4.5 mm (range, –8 to +22 mm) for women ($p < 0.0001$) and –0.1 ± 5.0 mm (range, –13 to +15 mm) for men ($p < 0.79$). This finding was consistent with those for the different designs. While the medial-lateral and anterior-posterior measurements closely approximated the morphologic data for all knees (Fig. 2), the femoral components for women tended to be too large for a given anterior-posterior measurement, with the most overhang in the larger sizes (Fig. 3). In men, the prosthetic designs tended to be smaller than the morphologic data in the medial-lateral dimension for a given anterior-posterior measurement (Fig. 4). The femoral aspect ratio for the morphologic data showed a higher ratio for smaller knees and a proportionally lower ratio for larger knees. The six designs showed little change in the aspect ratio with the anterior-posterior dimension (Figs. 5 and 6).

Of the forty-two patients who had a bilateral arthroplasty, different sized femoral components were used in thirteen (31%).

Tibia

The tibial aspect ratio from the morphologic data showed a higher ratio for smaller knees and a proportionally lower ratio for larger knees. The tibial aspect ratio for all knees versus the anterior-posterior dimension showed that as the

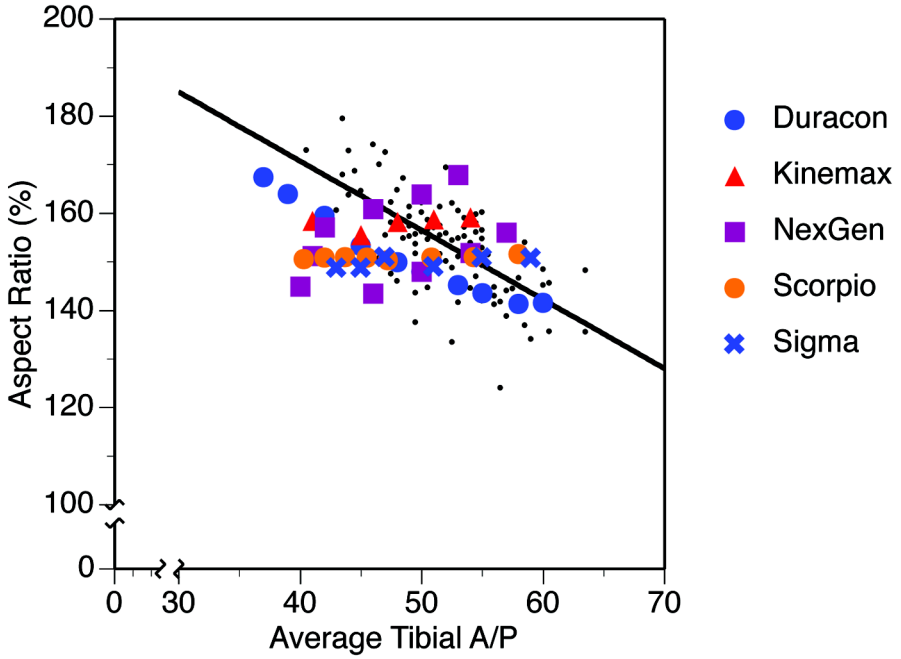


Fig. 7
The tibial aspect ratio versus the anterior-posterior (A/P) measurements (mm) for 128 knees in men, showing a higher aspect ratio for smaller knees and a proportionally lower ratio for larger knees.

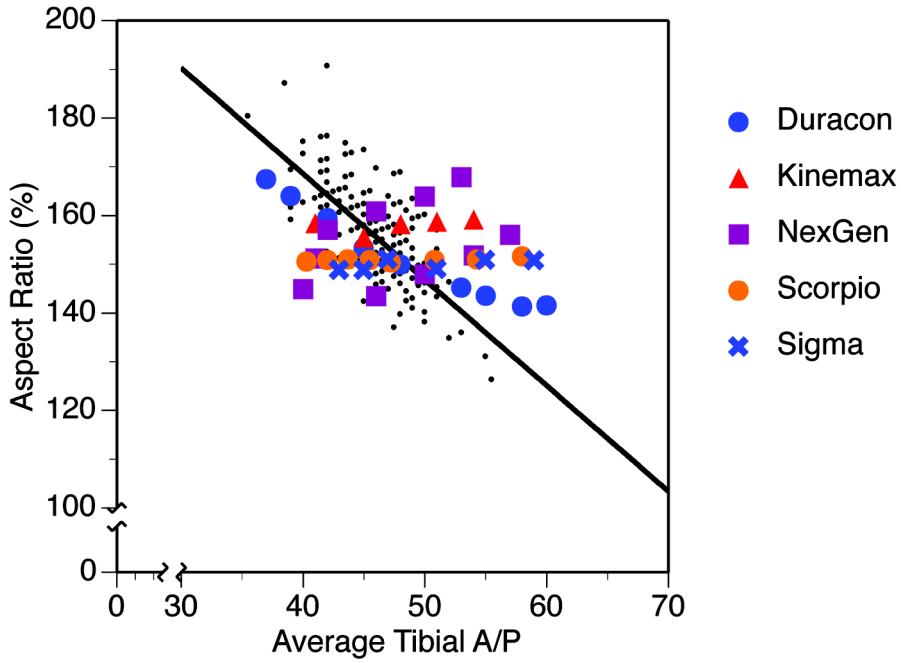


Fig. 8
The tibial aspect ratio versus the anterior-posterior (A/P) measurements (mm) for 209 knees in women.

anterior-posterior dimension increased, the aspect ratio decreased. The Duracon component tracked the decline in the aspect ratio fairly well, whereas the other brands either did not change with anterior-posterior dimension or actually increased (NexGen). The tibial aspect ratio from the morphologic data showed differing slopes for men and women. The majority of sizes available from the designs in this study revealed undersizing of the tibia in men compared with that in women (Figs. 7 and 8).

Evaluation of the medial-lateral to anterior-posterior dimension of the morphologic data with the prosthetic designs showed that the smaller implant sizes were too small. Likewise, the larger implant sizes tended to be larger than the morphologic data. The Duracon design most closely followed the morphologic data but was consistently smaller throughout the sizes (Fig. 9).

The absolute value of the difference in tibial anterior-posterior measurements indicated that the medial plateau was larger than the lateral plateau by a mean of 5.2 ± 3.1 mm for men and 4.3 ± 3.1 mm for women.

Of the forty-two patients with a bilateral knee replacement, nine (21%) had different sized tibial components.

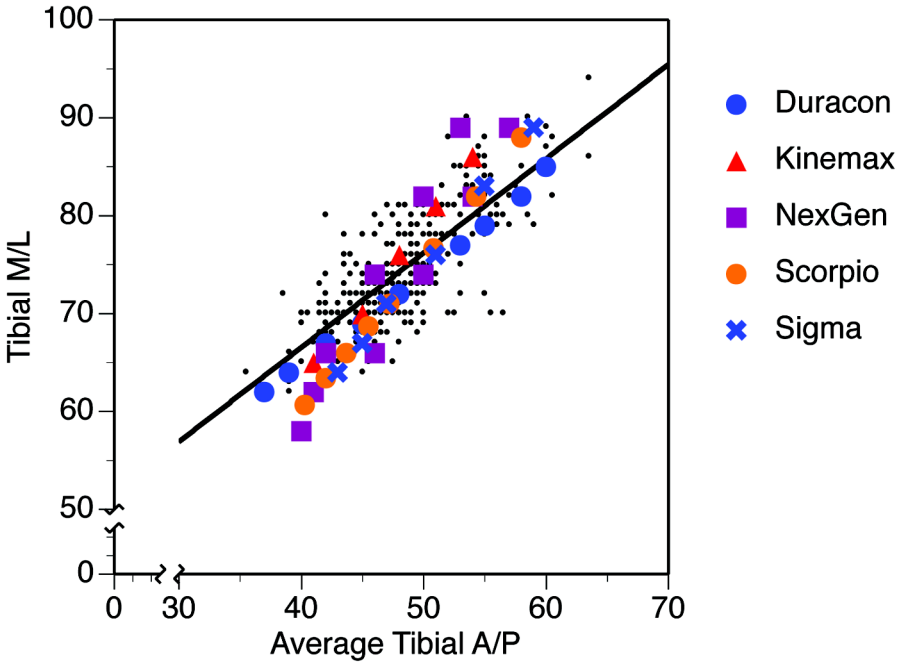


Fig. 9
The tibial medial-lateral (M/L) measurements versus the anterior-posterior (A/P) measurements (mm) for 337 knees. The smaller sizes of implants were too small and the larger implants tended to be larger than the morphologic data.

Patella

The overall average unresected patellar thickness for 177 knees was 23.7 mm. The average unresected patellar thickness was 25.3 mm for men and 22.5 mm for women. The medial-lateral and inferior-superior dimensions of the patella from the morphologic data for men and women are presented in Figures 10 and 11.

Discussion

Surgeons who perform arthroplasties must rely upon the prosthesis manufacturer to provide appropriately sized implants. There is a paucity of literature pertaining to the effects of improperly sized implants on patient outcome. Medial or lateral overhang on the femur or tibia could result in soft-tissue irritation and affect balancing efforts. Undersizing of either component could leave exposed cancellous bone, which could be a source of increased bleeding into the knee in the immediate postoperative period and may permit increased osteolysis from wear debris with longer follow-up. While the direct effects of these sizing concerns have been presumed to be minimal[1], no report has specifically addressed this issue, as far as we know.

The effect that alignment and implant position have on patellofemoral biomechanics has been previously reported[2]. Undersized or overhanging femoral components could lead to altered soft-tissue tensioning and altered patellofemoral stresses. The present study did not specifically address the dimensions of the patella after bone preparation as it relates to existing implants. Because eccentric placement of the patella toward the medial facet is often necessary to allow for improved tracking, complete coverage of exposed bone is often not possible. Dimensions are provided from the data to assist implant manufacturers in evaluating current and future designs. Multiple patellar sizes may be necessary to allow adequate remaining patellar bone without overstuffing the patellofemoral joint especially in women. As the average unresected patellar thickness was 22.5 mm, an 8 to 10-mm-thick patellar prosthesis may be required to maintain a minimum of 10 to 12 mm of remaining patellar bone.

The debate over the most appropriate geometry of the tibial tray continues. Although some authors have reported substantially better fit for asymmetric tibial components[3,4], Incavo et al.[5] reported that the tibial coverage was improved with symmetric designs. None of the these studies took into account the possibility of the gender difference in aspect ratio, which was shown in this

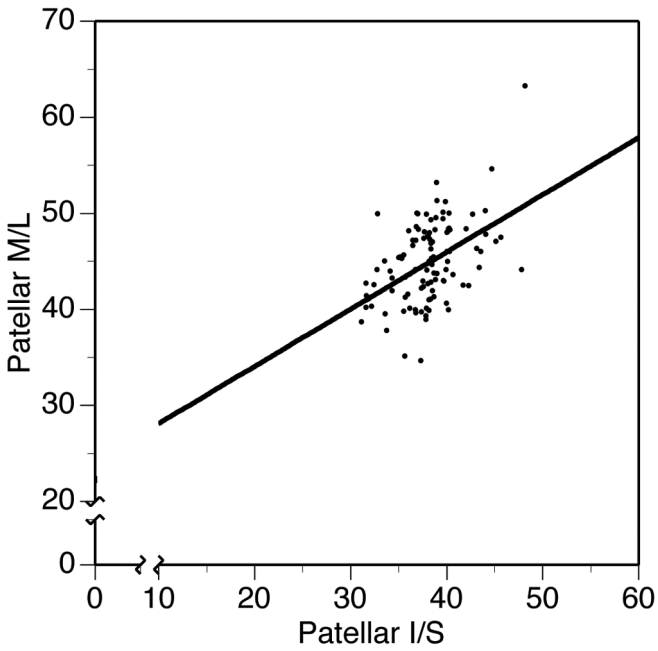


Fig. 10
The patellar medial-lateral (M/L) measurements versus the inferior-superior (I/S) measurements (mm) for 128 knees in men.

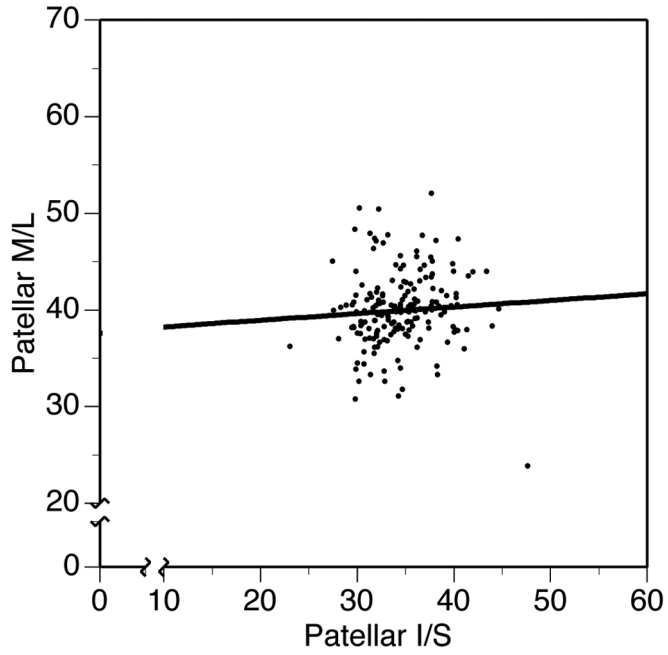


Fig. 11
The patellar medial-lateral (M/L) measurements versus the inferior-superior (L/S) measurements (mm) for 209 knees in women.

study. The dimensions of the cut proximal part of the tibia in men and women are different as shown by the variability of the aspect ratio. Mensch et al.[6], in a cadaveric and radiographic study, reported that the lateral condylar width was smaller than the medial tibial condylar width by 3 mm, with a greater difference seen in larger knees. Our study confirmed that the lateral tibial condyle is smaller than the medial tibial condyle by an average of 4.3 mm in women and 5.2 mm in men.

A marked variation was seen among the designs with respect to the aspect ratios of the implants and the study data as it related to the tibia. The morphologic data supported a decreasing aspect ratio as the anterior-posterior dimension of the plateau increased, but a majority of the implants had a relatively constant aspect ratio and, in one case, the ratio actually increased.

Like the present study, other studies have found that women have generally narrower femora than do men when the anterior-posterior dimension is adequate[6-9]. Seedhom et al.[8], in a radiographic and cadaveric study that evaluated sizing for knee prostheses, supported the idea that the required femoral component size should be based on the medial-lateral dimension of the femoral condyle. While this would avoid medial-lateral undersizing or overhang, the effect on flexion-extension balancing techniques would negate any potential benefits. Previous studies have used uncut bone in their evaluation[6,8,9], whereas our study data were based on direct measurements between current prosthetic dimensions and the dimension of the prepared bone. Manufacturers should consider gender-specific implants or decrease the medial-lateral dimension as it relates to a given anterior-posterior dimension to prevent component overhang in women. We believe that slight component undersizing in the medial-lateral dimension in men is better tolerated than is femoral overhang in women.

Surgeons who perform bilateral total knee arthroplasty need to be cognizant of the prevalence of component size asymmetry. The prevalence of asymmetrical femoral sizing in the simultaneous total knee arthroplasties in our study was 31%, which is higher than the 6.7% reported by Brown et al.[10] and emphasizes the need to size each knee independently when bilateral simultaneous or staged procedures are performed. A one-size tibial difference was seen in 21% of the knees. The depth of tibial resection can account for this difference even with identical surgical techniques. Like the femur, the tibia should be sized independently to provide the best coverage of the proximal aspect of the tibia and to avoid soft-tissue impingement.

In conclusion, some total knee prosthesis dimensions in current designs differ from actual knee morphology. This study is the first, to our knowledge, to evaluate the morphologic dimensions of the knee after bone preparation for prosthetic replacement. These dimensions better reflect the sizing necessary to reproduce the normal anatomy. These anthropometric data may be used as a guideline for future prosthetic designs. ■

Corresponding author:
Kirby Hitt, MD
Scott and White Clinic, 2401 South 31st Street, Temple, TX 76508. E-mail address: khitt@swmail.sw.org

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