Tibial Base Design Factors Affecting Tibial Coverage After Total Knee Arthroplasty: Symmetric Versus Asymmetric Bases

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Introduction:
Proper axial alignment of the tibial base is critical for a successful Total Knee Replacement (TKR) outcome. Clinical studies have shown that mal-alignment of the tibial base leads to knee stiffness and patellofemoral complications.[1,2] Base rotation is typically achieved by aligning the base between the medial third and medial border of the tibial tuberosity.[3,4] Alternative techniques, such as allowing the trial base and insert to self-align to the femoral component through a functional range of flexion, also minimize rotational mismatch between the femur and tibia.[5,6]

The clinical benefits of asymmetric versus symmetric tibial bases have been debated since the first asymmetric bases were introduced into the market in the 1980's. Proponents of asymmetric designs claim improved coverage of the cut tibial surface, particularly posterior medially, which hypothetically may reduce the risk of tibial subsidence. More recently, proponents of asymmetric tibial bases have claimed an additional benefit, namely improved rotational alignment of the asymmetric base accomplished by rotating the base to maximize tibial coverage. Despite multiple decades of clinical use, neither of these claims have been substantiated in the clinical literature.

Proponents of symmetric base designs reference the strong clinical performance of modern cemented symmetric tibial bases. Revision rates associated with tibial subsidence in the literature for cemented symmetric bases are rare. A clinical series of early revisions reported by Fehring et al. found that less than 3% of revisions within 5 years of implantation were due to aseptic loosening of the tibial component.[2] Furthermore, proponents contend that symmetric bases offer flexibility in the placement of the base on the tibial surface without the risk of excessive implant overhang that may cause soft tissue irritation. This is beneficial to surgeons who establish their base rotation by flexing the knee through a functional range of motion while allowing the base to float on the resected tibial plateau, ensuring the tibial articulating surface is aligned with the femoral component.[5] From a hospital efficiency perspective, implant and instrument inventory is also decreased with symmetric bases, as compared to left/right asymmetric bases.

Despite their differences, those on either side of the debate agree that maximizing tibial coverage and optimizing tibial rotational alignment are keys to ensuring the long term function of total knee replacement. Both sides also agree that other design factors, including the number of tibial component sizes and the shape, influence the tibial coverage attained by a knee system.[7] Proponents of Rotating Platform (RP) knee designs highlight the potential benefit of decoupling tibial alignment and tibial coverage, allowing the two factors to be optimized independently in an RP design. To understand the influence of tibial base design factors on tibial coverage, the current study assessed the ability of five modern base designs (Fig. 1), including symmetric, asymmetric, fixed bearing (FB), and RP designs, to maximize coverage of the tibial plateau across a large patient population.

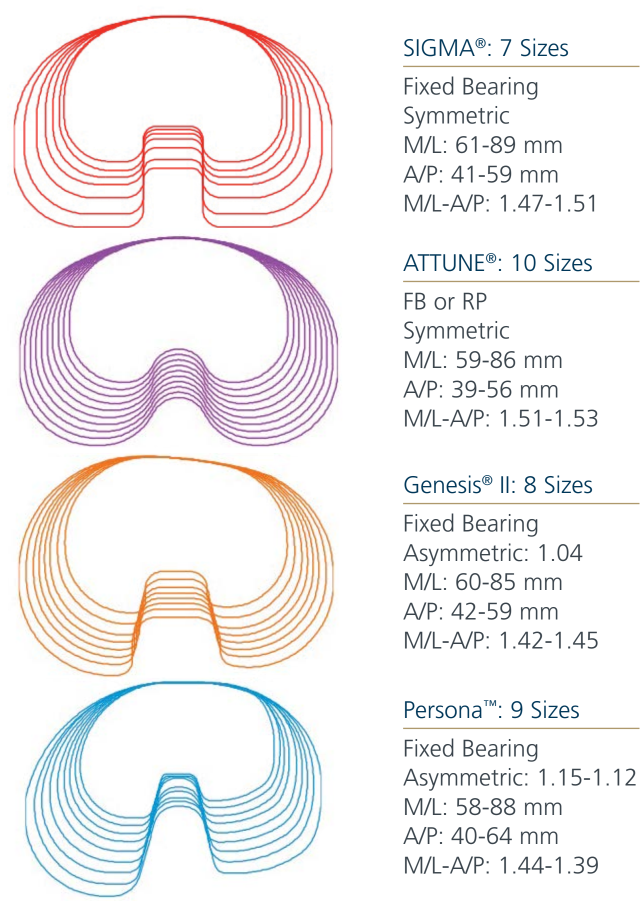


Figure 1: Tibial base designs analyzed in this study

Methods:

The fit of five different systems was assessed in this analysis (Fig. 1). The first base (SIGMA® Fixed Bearing System, *DePuy Synthes Joint Reconstruction**, Warsaw, IN) was symmetric with 7 sizes. The anterior periphery of the base was rounded and the posterior aspect of the base had flat sections along the posterior plateau. The second base (ATTUNE® Fixed Bearing System, *DePuy Synthes Joint Reconstruction*, Warsaw, IN) was symmetric with 10 sizes. It had an anterior aspect similar to the SIGMA System, but the posterior aspect of the base had a refined shape to reduce the potential for posterior lateral corner overhang (Fig. 2).

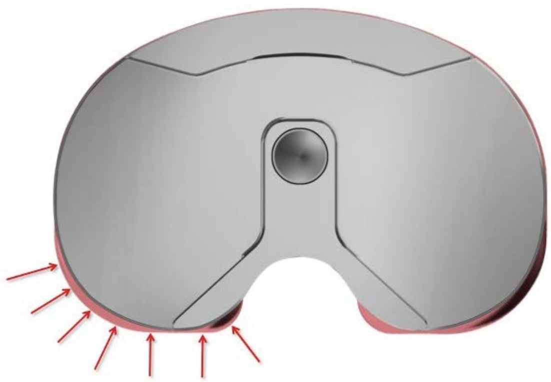


Figure 2: Overlay comparison of the ATTUNE Knee tibial base with the SIGMA Knee tibial base (in red), highlighting the refined shape of the posterior aspect of the ATTUNE Knee tibial base.

The third base (ATTUNE Rotating Platform System, *DePuy Synthes Joint Reconstruction,* Warsaw, IN) was the same as the second base, but designed to interface with a rotating platform insert, enabling rotation of the base relative to the articulating surface of the insert. The fourth base (Genesis® II, Smith & Nephew, Inc. Memphis, TN) had 8 sizes with an asymmetric profile. The medial plateau was about 4% longer in the anterior-posterior (A/P) dimension than the lateral plateau. The fifth base (Persona™, Zimmer, Inc. Warsaw, IN) had 9 sizes, also with an asymmetric profile. The medial plateau was 12%-15% longer in the A/P dimension than the lateral plateau, depending on the base size.

Lower limb computed tomography scans were collected from 14,791 Total Knee Arthroplasty (TKA) patients and each tibial bone was segmented. Virtual surgery was performed with an 8 mm tibial resection (referencing the high side) made perpendicular to the tibial mechanical axis in the frontal plane with 3° posterior slope. The tibial base was aligned transversely to the medial third of the tibial tubercle. An automated algorithm placed the largest possible base on the resected plateau, optimizing the medial-lateral (M/L) and A/P placement of the base to minimize base overhanging the tibial bone while maximizing coverage of the plateau. The rotating platform base was given an extra degree of freedom in the optimization, allowing the base to internally or externally rotate to maximize coverage independent of the location of the medial third of the tubercle. The largest sized base that fit the plateau with less than 2 mm of base overhang was identified for each of the five implant systems. The surface area of the tibial base was divided by the area of the resected plateau to determine the percentage of the tibial plateau covered by the base (Fig.3). In addition, the distance from the base border to the edge of the bone around the outer periphery of the base was measured. The percent bone coverage and base underhang was averaged across the patient population.

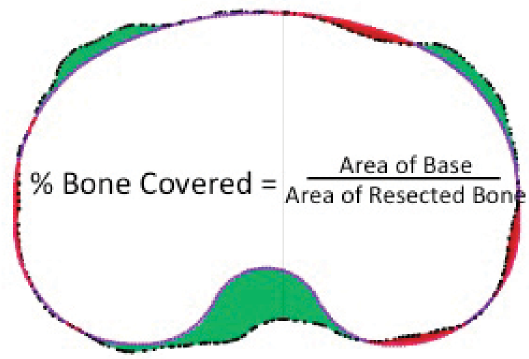


Figure 3: Calculation for tibial plateau coverage

Subsequently, a secondary analysis was conducted to understand the change in rotational base alignment if the surgeon was to rotate the base to maximize bony coverage. The automated algorithm used for the RP base in the first analysis was used to size and place the fixed bearing tibial bases, including (IE) rotation, to maximize tibial coverage independent of the bony landmarks. In this analysis, the coverage metrics were calculated in addition to the amount of base rotation from the medial third of the tubercle.

Results:

All bases in this study resulted in an average coverage of greater than 80% of the tibial plateau (Fig. 4). Among the fixed bearing bases, the ATTUNE System resulted in the greatest average coverage of the tibial plateau (83.8%±4.6%), followed by Genesis® II (82.6%±4.8%), Persona™ (81.1%±4.5%), and the SIGMA System (80.2%±4.7%). The ATTUNE RP Knee base had the best overall coverage among all the bases (85.6%±4.6%). Although the overall coverage was very similar between the different knee systems, the regions where resected bone was exposed differed based on the design features of the base.

As expected, both symmetric fixed bearing designs (SIGMA System and ATTUNE FB System) had increased levels of exposed bone along the posterior medial plateau. This was expected because the average native tibia is between

8% and 10% asymmetric.[8] The SIGMA System had ideal coverage along the posterior lateral plateau and moderate coverage along the medial and lateral borders of the base. The average M/L underhang of the SIGMA Fixed Bearing System base was 2.5 mm. Due to the increased number of sizes and the refined shape of the posterior aspect of the base, the ATTUNE FB System base had ideal coverage within 2 mm of the bone periphery along the bulk of the perimeter. This included the posterior lateral corner and around the anterior face to the medial border of the base, except a short region on the anterior lateral corner. The average M/L underhang of the ATTUNE FB System base was 1.4 mm.

As a result of the freedom to rotate to maximize coverage, the ATTUNE RP System base rotated internally an average of 3.55° ± 5.08°, enabling an increased base size in several knees. This resulted in improved coverage over the fixed bearing variant, specifically posterior medially.

The asymmetric features of the Genesis® II base enhanced its overall coverage. The base fit closely along the posterior lateral border of the tibial plateau and reduced the amount of exposed bone posterior medially as compared to the symmetric designs. This particular base design was less asymmetric than the average tibia, which explains why some bone was still exposed posterior medially. Having the second fewest number of sizes inhibited its ability to provide better coverage across the population. The average M/L underhang of the Genesis® II base was 2.0 mm.

In contrast to the Genesis® II base, the asymmetric elements in the Persona™ base did not result in improved coverage, despite the increased number of sizes. Because the asymmetry of the base was greater than the asymmetry of the native tibia, the best fit of the base was along the posterior medial corner of the knee coupled with an increase in the postero-lateral exposed bone. Furthermore, the anterior medial aspect of the base was reduced in size, which increased the level of exposed bone along the anterior aspect of the base, reducing the overall coverage.

When the fixed bearing bases were allowed to rotate to maximize coverage, the average coverage increased between 1.5% and 2.4% (Fig. 5). The SIGMA System, ATTUNE System, and Genesis® II bases all rotated internally by an average of 2.6°±4.4°, 3.6°±5.1°, and 3.7°±4.4°, respectively. In contrast, the Persona™ base rotated

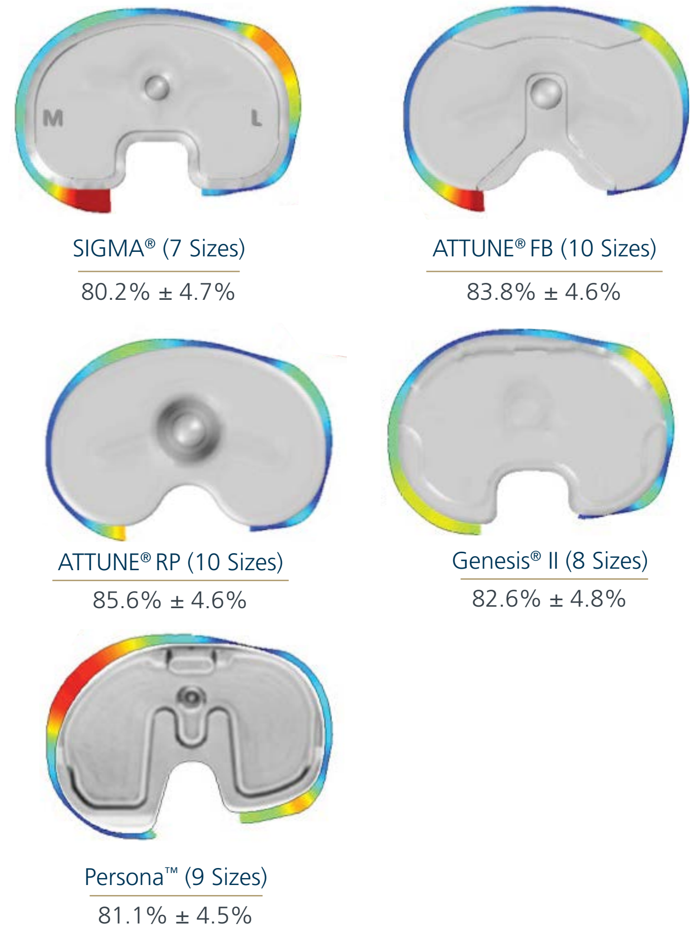
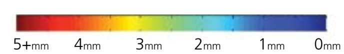


Figure 4: Tibial plateau coverage when the tibial base is aligned to the medial third of the tibial tubercle.



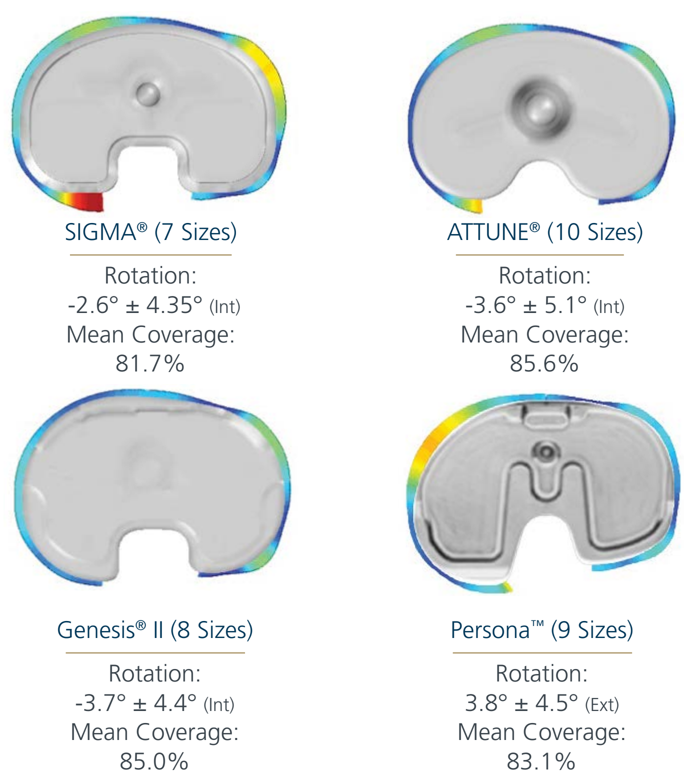


Figure 5: Tibial plateau coverage when the tibial base is positioned for maximum coverage.

externally an average of 3.8°±4.5° when maximizing coverage. Despite the difference in overall rotation, the standard deviation of the rotation remained consistent across the base designs, that is between 4.4° and 5.1°.

Discussion:

This analysis represents the most comprehensive assessment of base coverage to date across a large TKA patient population. Large variations existed in the size and shape of the proximal tibias among TKA patients[8] and yet modern base designs, whether symmetric or asymmetric, provided robust levels of coverage. No consensus exists on the minimum coverage required to prevent tibial subsidence, however, the robust coverage provided by the modern base systems studied here is likely the cause of the minimal tibial subsidence rates in the literature.

This analysis demonstrated that multiple different design factors contribute to the overall coverage of the base, including the number of tibial base sizes, the anterior and posterior contour of the base, and the amount of asymmetry incorporated into the design. The two knee systems with the highest level of coverage were both symmetric bases with 10 size options (ATTUNE FB System, ATTUNE RP System). The freedom to rotate the base to maximize coverage granted by the ATTUNE Rotating Platform System consistently yielded the best overall coverage. In contrast, incorporating tibial asymmetry has the potential to increase coverage with fewer tibial sizes, but only if incorporated using an appropriate approach. Incorporating excessive levels of tibial asymmetry can actually diminish the overall tibial plateau coverage.

Several authors have highlighted the difficulty and variability in using tibial bony landmarks to set the rotation of the tibial base[4,9] and others have documented the deleterious effects of mal-rotation.[1,2] Whether using a symmetric or asymmetric base, setting the rotation of the base by maximizing coverage induced a great deal of variation (standard deviations of rotations between 4.4° and 5.1°). To put the variability into context, when maximizing coverage using the Persona™ base, the base will be aligned more than 8.3° externally from the medial third of the tubercle for 1 in 6 patients. The only robust way to maximize coverage by rotating the tibial base is to use a rotating platform base, allowing the insert to rotate relative to the base, accommodating any mal-alignment with the femoral component.

In summary, maximizing tibial coverage while setting proper tibial rotation remains key to a successful knee replacement outcome. This can be accomplished using either symmetric or asymmetric tibial bases, but is aided with more base sizing options. Surgeons should avoid the practice of rotating the base to maximize tibial coverage and should instead focus on optimizing the rotational alignment to restore proper kinematics. Surgeons who are looking for a robust implant that decouples tibial rotation and maximizing coverage should consider the benefits of the ATTUNE Rotating Platform Knee design.

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0612-25-515 EO 1/14