INTRODUCTION
The adequacy of femoral implant fit in total knee arthroplasty (TKA), often characterized by the extent of overhang, is a matter of continuous debate. In this work we present a computational method for determining the probability of excess overhang or underhang (beyond an acceptable threshold value). Unlike most previous work which relied on simple landmark data or resection contours, we consider the entire distal femur, real implant models, and clinically accurate resection surfaces. The technique is demonstrated using a commercially available implant and a modified design intended to reduce overhang.

![Figure 1 Varying PDM control parameters PC₂ and PC₃, affecting anterior-posterior length and inter-condylar bone width.](image)

The methodology is based upon a model which describes variation in 3D femoral geometry constructed using sample bones segmented from computed tomography images. Using a principal component analysis (PCA) based surface registration technique optimized for shape model construction, the segmented data is consolidated into a point distribution model (PDM) with a size variable (PC₁) and several additional parameters (i.e. PC₂, PC₃, etc.) which represent the distal femur’s major modes of shape variation. (Fig. 1)

![Figure 2 Femoral components are automatically sized and aligned using landmarks anchored to the bone surface; conformity is estimated using the shortest distance from the implant edge to the resected bone and mapped. Under-hanging edges are colored red, over-hanging edges blue.](image)

The PDM is used as the basis for a Monte-Carlo style simulation where thousands of sample femurs are generated and virtually implanted to assess the overhang characteristics of implant designs. Surface landmarks, anchored to the PDM, are used to automatically fit and align each implant. Overhang and underhang characteristics are reported as scalar values along the implant edge adjacent to the resection surfaces of the bone, indicating the probability of excess overhang greater than a user specified tolerance value. The shape modeling and Monte-Carlo process were implemented with Arthron: a morphometric analysis interface based on the open-source Visualization Toolkit (VTK). (Fig. 2)

RESULTS & DISCUSSION
The commercial implant and modified design were evaluated using a femoral PDM constructed from the left knees of thirty-one Caucasian and forty-five Japanese subjects. The pre-existing commercial design (DePuy PFC Sigma®) features seven non-uniform size increments (1p5, 2, 2p5, 3, 4, 5, 6) and a fixed inter-condylar notch width. The 4N component was not included. A newly developed commercial design (DePuy Attune®) consisted of ten uniform size increments, an inter-condylar notch width proportional to size, and a narrower medial-anterior flange. To compare the two designs, one thousand femurs were automatically generated from Latin hypercube sampling of the PDMs control parameters. During the simulation, the probability of excess overhang was tabulated along the resection edge of each implant size. The overhang limit k was defined to be proportional to the medial-lateral bone width ML (the distance between the lateral and medial femoral epicondyles). We specified the limit to be \( k = \left( \frac{3}{70} \right) ML \) [mm], representing a 3mm overhang limit for a 70mm wide bone.

![Figure 3 Probability (p) excess implant overhang for Sigma component size increments 2-5. Yellow indicates p > 5%.](image)

![Figure 4 Probability excess implant overhang for modified component size increments 2-9. Yellow indicates p > 5%.](image)

CONCLUSIONS
Results indicate a significant reduction in the incidence of excess overhang on the medial-side of the anterior flange and around the intercondylar notch with the modified implant design (Fig. 3-4). Future work will include analysis of patient variation factors and surgical factors (i.e. implant alignment) and their effects on implant conformity.

SIGNIFICANCE
Recent evidence links excess overhang to poor patient prognoses including soft-tissue irritation and reduced joint mobility [1]; we present a computational method for predicting and comparing the excess overhang of femoral component designs beyond an acceptable threshold.

REFERENCES