INTRODUCTION
Achieving high flexion after total knee arthroplasty (TKA) is a major factor driving current implant design. Knee flexion angle is multifactorial in nature with preoperative flexion reported as the only consistent factor affecting postoperative flexion. Less is known about the effect of implant alignment and relative position on range of flexion. We used patient-specific computer models to evaluate the effect of implant position and alignment on flexion angle.

METHODS
Patients
Approval of an institutional review board and informed consent were obtained. CT scans were obtained from patients before TKA. Of these, 10 knees were selected to match the small, medium, and large sizes of a posterior cruciate-retaining design (Scorpio CR, Stryker Orthopaedics).

Component Alignment and Position
CT scans were reconstructed to extract 3-dimensional surface geometry using MIMICS (Materialise, Belgium). The center of the femoral head and the epicondyles were used to define the coordinate system of the femur. CAD models of the femoral and tibial components were implanted in the bony geometry.

In the reference position the femoral component was aligned perpendicular to the mechanical axis of the femur on the coronal plane and parallel to the epicondylar axis on the transverse plane. This implant position was then adjusted in the anteroposterior (AP) direction to avoid the notching of the anterior cortex as per standard surgical protocol (Fig. 1). In the reference position the tibial insert was centered in the mediolateral direction, perpendicular to the mechanical axis of the femur, and was aligned in the AP direction such that the lowest points of the insert contacted the lowest point of the femoral component (Fig. 2).

Peak flexion angle was recorded for 5 different femoral component positions (Reference, 2-mm anterior/ posterior, 2-mm proximal/ distal from the reference); 4 different tibial posterior slope angles; and 2-mm anterior/posterior translation of the tibial insert for a maximum of 10 mm. (Fig. 2: 10-mm anterior/ posterior). For each of these positions, we also measured the posterior condylar offset (Fig. 1: PCO).

RESULTS
The average maximum flexion angle in the reference position (posterior tibial slope = 0°) was 136.3° (130-143.7). Flexion angle increased 3° with a 2 mm more posterior femoral component position, and 9° with 10-mm anterior position of the tibial insert.

DISCUSSION
Implant position can significantly affect the range of flexion before impingement. Similar results have been previously reported in vitro using a plastic bone model. Our model with bony geometry from 10 different subjects supports the importance of implant placement in optimizing flexion angle.

The posterior condylar offset (PCO) correlated strongly with maximum flexion angle. The importance of PCO has also been demonstrated in postoperative fluoroscopic analysis in vivo. Although a direct correlation was not reported, the reduction in postoperative PCO is correlated with reduction in postoperative flexion. PCO can be affected by patient anatomy, implant position, implant size, and design of implant. Therefore all these parameters are important in improving flexion angle.

Flexion increased with a more posterior position of the femoral component and a more anterior position of the insert. A more anterior position of the insert is analogous to posterior rollback with flexion. Increased posterior tibial slope also increased flexion. This was likely due to the increased distance between the posterior lip of the insert and the posterior surface of femur in flexion.

Overall, anatomic variation accounted for a greater difference (13°) in flexion than each individual implant position parameter. An anterior insert position had the greatest net effect (9° over 10-mm translation). A mean flexion of 136° in reference position could be improved to a mean of 150° using a combination of posterior femoral component, anterior insert, and 7° tibial slope.

We used a computer model to calculate flexion based on implant-bone impingement. Our model did not account for soft-tissue tightness or impingement and analyzed only one single design. However, this model is very useful for evaluating design enhancements as well as for optimizing implant design and surgical placement with high flexion as the goal.

REFERENCES