INTRODUCTION: Patellofemoral (PF) complications remain one of the primary causes for revision surgery in current total knee arthroplasty, accounting for up to 50% of all secondary procedures [1]. Reported complications include anterior knee pain, patellar fracture, wear, instability, maltracking and loosening [1], all of which may be substantially influenced by the alignment of the patellar component. During surgery, however, patellar resection is frequently accomplished through basic freehand cutting or with aid of a patellar clamp in order to obtain a consistent thickness of remaining bone. The patellar component is subsequently aligned to optimize coverage or placed medially or superiorly depending on surgical philosophy. To improve the consistency of patellar alignment and soft-tissue balancing through advanced surgical instrumentation, the critical translational and rotational alignment parameters need to be identified, and these are likely design-specific. Hence, the objective of the present study was to determine the alignment variables that significantly influence patellofemoral kinematics and contact mechanics for anatomical and domed patellar components using a probabilistic finite element model of the PF joint.

METHODS: An explicit finite element (FE) model of an implanted knee joint was analyzed using Abaqus/Explicit (Simulia, Providence, RI). The model included three-dimensional bony surfaces reconstructed from medical images, size-matched total knee replacement (TKR) components of a cruciate retaining implant, and two-dimensional (2D) fully deformable soft tissue structures of the extensor mechanism (Figure 1a) [2]. Fluoroscopy-based six degree-of-freedom femoral kinematics were prescribed during dynamic flexion between 0° and 120°. A ramped quadriceps load (up to 4,000 N) was distributed [3] to the proximal ends of soft tissue structures representing the rectus femoris (RF) and five portions of the vastus tendon. Patellar components were treated as fully deformable while bones and femoral components were considered rigid. Contact was defined to allow soft tissue wrapping in deep flexion. Monte Carlo (MC) probabilistic analyses were performed using Nessus probabilistic modeling software (SwRI, San Antonio, TX) to investigate the effects of patellar and femoral component alignment and quadriceps load distribution on predicted PF kinematics and contact mechanics for anatomical and domed TKR designs (Figure 1b). Patellar component alignment was perturbed by translations along local medial-lateral (Pat M-L) and inferior-superior (Pat I-S) axes (1 standard deviation (SD) = 1 mm) and flexion about the M-L axis (Pat Flex), tilt about the I-S axis (Pat Tilt), and spin about the anterior-posterior axis (Pat Spin). Standard deviations of 3.3° were used for flexion and tilt and 5.0° for spin. Perturbations in femoral component internal-external (Fem I-E) alignment (1 SD = 1.6°) and contribution of the vastus medialis obliquus (VMO Cont) within the quadriceps load distribution (1 SD = 3.3% of total quadriceps load) were also investigated. MC analyses with 100 trials were conducted for each patellar design with all input variables normally distributed. Sensitivities were determined by averaging correlation coefficients between inputs and outputs over the entire flexion cycle for all MC trials at the 5 to 95% confidence level.

RESULTS: Results from the probabilistic analyses showed distinct differences in measured output sensitivities between the two patellar component designs. Model-predicted patellar flexion was more sensitive to perturbations in I-S position (Pat I-S) than flexion (Pat Flex) for the domed component compared to greater sensitivity to flexion with the anatomic design (Figure 2). Internal-external patellar tilt was most sensitive to tilt alignment in the anatomic and M-L position in the domed analyses. Maximum contact pressure and area were more influenced by patellar I-S, flexion, and spin alignment in the anatomic versus domed analyses (Figure 2). In both designs, femoral I-E alignment substantially influenced patellar tilt, M-L translation and M-L force (Figure 3). At the current input variability level, variability in VMO contribution was not as important to kinematics or contact mechanics as the alignment variability.

DISCUSSION: In this study, a probabilistic FE model of an implanted patellofemoral joint was used to identify the most important patellar and femoral alignment parameters affecting PF mechanics for domed and anatomic designs. Femoral internal-external rotational alignment was the most influential parameter for medial-lateral translations and contact force in both designs, while parameters affecting flexion and tilt kinematics and contact pressure were design-specific. Understanding the influence and relative significance of PF alignment parameters is the initial step in advancing instrumentation for optimal clinical outcomes.