Effects of Patellofemoral Loading on Gender Specific Femoral Knee Components

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Introduction: Orthopaedic surgeons have reported anatomical differences in women's and men's knees for years [1,2,3,4]. A female femur is narrower in the M/L dimension when compared to the male femur of the same A/P dimension [5]. Additionally, a female knee has less-pronounced anterior condyle [1] and larger trochlear groove angle [4]. To accommodate these anatomic differences, Gender Solutions™ female (GSF) femoral implant designs have been recently introduced, in which the component is narrowed mediolaterally, has increased trochlear groove angle, and reduced anterior flange thickness. The thinner anterior flange dimension for GSF femoral components may affect the strength of the implant when subjected to patellofemoral loading. This study uses Finite Element Analysis (FEA) to investigate the effects of patellofemoral loading on the anterior flange areas of GSF femoral components.

Materials and Methods: Gender Solutions Natural-Knee® Flex (N-K Flex GSF) femoral components (Zimmer Inc., Warsaw, IN) were used in this study. These components were designed based on the existing NexGen® Complete Knee Solutions GSF femoral components and Natural-Knee II (N-K II) femoral components (Zimmer Inc., Warsaw, IN), both previously marketed devices. The design of the N-K Flex GSF components incorporates the gender specific features mentioned earlier. Three FEA models were developed representing left N-K Flex GSF femoral components of sizes 2, 3 and 4 respectively. Peak stress values predicted by FEA were used to determine the worst-case size. The corresponding sized left N-K II femoral component was used to develop another FEA model which was analyzed under the same conditions. The location of the thinnest section was determined for each femoral component. (Figure 1a). The patella contacts the thinnest crosssection at approximately 20° of flexion for all the femoral components considered in this study. A conservative estimate of the patellofemoral force at approximately 20 degrees of flexion was calculated for each size of femoral components. Forces of 1223 N, 1309 N and 1413 N were applied for sizes 2, 3 and 4 respectively.

Each FEA model consists of an assembly of the femoral component with a patella component. The rim of the anterior flange was supported by a cortical bone, while the center portion of the flange was supported by a cancellous bone. Linear elastic material properties of cast Co-Cr-Mo (E=241 GPa), cortical bone (E=13.8 GPa) and cancellous bone (E=0.10 GPa) were used for femoral components, cortical bone blocks and cancellous bone blocks respectively. Elastic-plastic material properties of cast Co-Cr-Mo (E=241 GPa), cortical bone (E=13.8 GPa) and cancellous bone (E=0.10 GPa) were used for femoral components, cortical bone blocks and cancellous bone blocks respectively. Elastic-plastic material properties of UHMWPE (E=0.51 GPa) were used for the patellas. A sliding contact interface condition was defined between the femur and the patella with a 0.02 coefficient of friction. Fully bonded contact conditions were defined between the cortical bone-prosthesis, cancellous bone-prosthesis and cortical bone-cancellous bone interfaces. For each implant, the patellofemoral force was applied as a distributed load on the back (anterior) face of the patella (Figure 1b). The posterior face of the cortical bone was constrained against all motion (Figure 1c). All components were modeled using 10-node tetrahedron elements. Since the femoral component is the focus of this FEA study, stresses in the patella and bone layers were ignored. The peak maximum principal stresses predicted in the models were used to identify the worst case size of N-K Flex GSF femoral component. Peak maximum principal stress value predicted for the worst-case size of N-K Flex GSF component was compared with the value predicted in the corresponding size of existing N-K II femoral component. Nonlinear static analyses were performed for all the models using Ansys ver. 10 (Ansys, Inc., Canonsburg, PA) software.

Results: The purpose of this study is solely to compare stresses among models, therefore the discussion is not focused on the absolute stress values. For all the models considered in this study, peak maximum principal stresses were predicted in the lateral side of the pocket fillet on the superior/posterior side of the femoral anterior flange. Among N-K Flex GSF femurs, highest stresses were predicted for the size 3 component (Figure 2). Based on this prediction, FEA was performed on the existing size 3 N-K II femoral component for comparison. Table 1 lists the normalized peak maximum principal stress values (with respect to N-K Flex GSF size 3) predicted by FEA for all four models.

Discussion: Among all the sizes of N-K Flex GSF components, the highest maximum principal stress was predicted in size 3 component. Therefore, size 3 can be considered as the worst case size among all the N-K Flex femoral components. The peak maximum principal stress predicted by FEA in the worst case N-K Flex GSF femoral component (size 3) is about 8% lower than that predicted in the corresponding size of the existing N-K II femoral component, a previously marketed device. Therefore, it can be concluded that the design of N-K Flex GSF femoral components has sufficient strength to survive the worst case patellofemoral loading conditions. A thinner anterior flange in femoral knee designed for female anatomy does not automatically lead to increased stress. Other design features play a significant role in improving the strength of the implant to that of existing designs.

References: