FEMORAL COMPONENT DESIGN AFFECTS ACL TENSION IN BICRUCIATE RETAINING TOTAL KNEE REPLACEMENT
++Siggelkow, E; *Labhart, M; *Muenchinger, M; ++Zimmer GmbH, Winterthur, Switzerland
eik.siggelkow@zimmer.com

INTRODUCTION:
Total knee replacement (TKR) has a long clinical tradition in orthopedic arthroplasty and is a procedure to reduce pain and increase function in patients with arthritis. Different types of prostheses are available according to the patient’s anatomical and biomechanical requirements. Most differences in prosthesis design refer to the issues of integrity and balance of the cruciate ligaments. Bicruciate retaining TKRs provide the potential benefit of a more natural feel of joint [1] and more physiologic kinematics [2]. For prosthesis design and surgical technique the interaction between the prosthesis and the ligaments plays an important role. One potential risk is an increased tension in the anterior cruciate ligament (ACL) due to impingement of the ligament against the femoral component. This risk is pronounced in extension of the knee joint.

In this study it was analyzed, how the design of the femoral intercondylar notch affects the tension of the ACL in extension.

METHODS:
A subject specific finite element analysis (FEA) was performed. The geometry of the FE-model is based on a subject’s magnet resonance imaging (MRI) data from which the femoral condyles, tibial plateau and the anterior and posterior cruciate ligaments (PCL) were created using Mimics (Rev. 9.01), Raindrop Geomagic (rev. 8) and Unigaphics NX2. The physiological knee FE-model including the cruciate ligaments was validated via the ACL and PCL reaction force in dependency to the flexion angle against literature [3].

Three different designs of femoral components were implanted (Zimmer Inc.): A) NexGen CR Flex femoral component (PCL retaining), B) NexGen CR Flex with an intercondylar notch of the Natural Knee II (NKII) femoral component, which has a longer AP length and an increased anterior width (PCL retaining), C) a bicruciate retaining component with an increased anterior medial notch width.

The final CAD models were imported into Patran 2005r2 for meshing and definition of boundary conditions and material properties (Figure 1).

The femoral and tibial bones, as well as the implant components, were meshed using 4-node linear surface elements and defined as rigid bodies. The cruciate ligaments were meshed mimicking two different structures: the matrix and the fibers. The matrix was meshed using 8-node hexahedral elements and the fibers were created by a system of nonlinear spring elements. The matrix was defined to be incompressible hyperelastic [4-8] and the material property of the fibers was defined using non linear force-displacement data from literature [9]. Frictional contact (µ=0.1) was modeled between the femur and the ligaments for the intact model and between the femur/implant and the ligaments for the implanted model as well as between both ligaments to simulate wrapping.

The tibia was fixed in all 6 degrees of freedom while the femur (for the intact model) or the femur and femoral component were transformed by performing a translation and a rotation from 20° flexion to full extension. The motion is based on in vivo MRI measurements on the intact knee performed at 20° flexion and full extension.

The Abaqus/Standard solver (rev. 6.5) was used for the nonlinear static FEA.

The tension (reaction force) of the ACL in extension was analyzed for the intact knee joint as well as for three implanted femoral components.

RESULTS:
The implanted NexGen CR Flex with the standard intercondylar notch (A) resulted in the highest tension (reaction force) in the ACL followed by the implanted NexGen CR Flex with the intercondylar notch of the NKII femoral component (B). The bicruciate retaining femoral component (C) resulted in the lowest ACL reaction force, which was comparable to the reaction force in the intact knee FE-model. The results are summarized in Figure 2.

DISCUSSION:
The results of the ACL reaction forces of the four different models showed that the design of the femoral component’s intercondylar notch affects the tension of the ACL in extension. However, the differences of the reaction forces between the implanted models B and C were small. A greater difference in ACL reaction forces was anticipated due to the differences in the geometry between the models B and C. The material model used to simulate the ligament behavior may not have been sensitive enough to detect the differences in component design in the ligament reaction force. A refined number of parallel modeled spring elements mimicking the fibers of the ligament in further analyses may help to achieve more differentiated results.

CONCLUSION:
The design of the femoral component’s intercondylar notch affects the tension of the ACL in extension.

The reaction force of the ACL found for the implanted bicruciate retaining design of the intercondylar notch was similar to the one at the intact knee model.
The effect of the geometry of the intercondylar notch should be taken into account, when designing a femoral component for bicruciate retaining TKR.

REFERENCES: