INTRODUCTION: In telemetry, force sensors are implanted inside the human body to measure the forces directly. However, due to high costs involved in developing the specialized implants, they are unsuitable for mass scale production and use. Therefore, computational modeling, an easy to reproduce theoretical approach based on the principles of mechanics, has been more popular. Due to the challenges with modeling the human body, mathematical models rely on some level of simplifying assumptions to generate a solution. Thus, a validation study comparing the results obtained from a mathematical model to those obtained using telemetry becomes important. A telemetric knee implant capable of measuring medial and lateral forces separately has been developed [1,2]. The telemetric implant incorporates four force sensors (2 each on medial and lateral side) in the tibial component and is been developed [1,2]. The telemetric implant incorporates four force sensors (2 each on medial and lateral side) in the tibial component and is a posterior cruciate retaining (PCR), fixed bearing type implant. We have also developed a mathematical model that is capable of predicting medial and lateral load distributions in the implanted knee. Therefore, the purpose of this study was to conduct a comparison of the results obtained from our model to those observed by telemetry.

MATERIAL AND METHODS: Telemetric data was collected while the patient performed gait and deep knee bend activities from full extension to 120º of weight bearing flexion under fluoroscopic surveillance in the sagittal plane. Ground reaction force data was also simultaneously recorded from a force plate. The fluoroscopic video was digitized, and images at 5º increments were analyzed using 3D to 2D registration process to obtain the in-vivo kinematics [3]. The kinematic data was made continuous using piecewise continuous shape preserving polynomials and was input in an inverse dynamic 3D mathematical model capable of calculating the femoro-polyethylene forces on the medial and lateral sides separately. The femur was modeled to roll with slip on the polyethylene as well as have an axial rotation. A constant frictional coefficient of 0.05 was used. The model treats the bones and the implant components as rigid bodies, musculotendinous units as linear elements and ligaments as non-linear elastic elements capable of carrying a tensile load only. Relevant dimensions, muscle and ligament attachment sites (approximated as points) were obtained from CT scans and previously published data and scaled with respect to the height of the patient. The model uses the reduction technique, where the system is always kept determinate by keeping the number of unknowns equal to the number of equations, for solution.

RESULTS: The subject exhibited consistent and similar movement of the lateral and medial femoral condyles on the tibia and experienced an anterior slide of the femur as has been reported in PCR implants previously [4]. During the deep knee bend, the femur moved posterior till about 40º of flexion after which it moved anterior and was close to its starting point at 120º flexion. The femur experienced a net -1.0º of axial rotation (internal femoral rotation relative to the tibia) and there was no incidence of "lift-off" in the patient. During gait, the kinematic patterns were similar to those previously published for PCR TKA.

DISCUSSION: Mathematical modeling provides an efficient and reproducible method of predicting in-vivo dynamics, but verification of the results generated by it is often challenging. In this regard comparison of forces with real-time telemetric data is probably the best alternative. Previously, Lu et. al. [5] compared a lower limb model prediction to loads measured by a distal telemetric femoral implant and obtained promising results. However, they used a 2D sagittal model and used a single femorotibial contact point. The model used in this study is 3D and is capable of estimating the medial and lateral femorotibial forces separately. The model predicts the maximum forces in the knee very accurately and also exhibits similar variation of forces with higher flexion angles. However, it under predicts the amount of force at full extension, which is assumed to occur because the model starts from a static position and does not take into account muscle activation dynamics. In our future analyses, we are incorporating muscle activation parameters into the model using EMG technology, in an attempt to make the model more accurate under static conditions, especially during early flexion.

References:

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