INTRODUCTION:

The constraint and flexion characteristics of a total knee replacement (TKR) 'in-vivo' are critical factors in the success or failure of the replacement. While many studies have tried to predict the resulting constraint or flexion characteristics of a knee after implantation, there is also an interest in determining these characteristics independent of any patient specific and surgical variables. Inherent differences exist in the performance of a TKR versus a natural knee. This is due to the necessary removal of soft tissues and higher conforming surfaces to lower contact stresses for UHMWPE wear consideration. Constraint in a TKR, in the absence of ligaments and other soft tissue, is dependent on the flexion angle, contact surface geometry, conformity, axial load and friction. The flexion-extension characteristics of a TKR, such as femoral rollback and screw-home, are a function of the contact surface geometry. It is believed that an implant design which naturally exhibits similar constraint and flexion kinematics as the intact knee will perform better 'in vivo'. Computational simulation can be performed to assess the performance of candidate TKR designs less expensively, in terms of time and cost, compared to traditional experimental approaches, provided the simulation accuracy has been confirmed experimentally. This study compares the results of a computational approach to simulating TKR constraint and kinematics to those obtained through experiment.

METHODS:

Experiment A size 3 DePuy Sigma CR knee system was assessed in terms of constraint and flexion kinematics. The cobalt chrome (CoCr) femoral component and UHMWPE insert were installed onto an AMTI Force 5 high-knee simulator. Custom made components were designed to allow better control in terms of which degrees of freedom were free or fixed. Tables 1 and 2 below outline which degrees of freedom were prescribed (P), fixed (X), or free (O) for the femoral (Fem) and tibial (Tib) components, during the constraint and unconstrained flexion experiments. These degrees of freedom are depicted in figure 1 below.

RESULTS:

Optimization of the simulation parameters was performed in order to minimize the simulation versus experiment error. The AP and IE laxities for the CoCr-UHMWPE implant and ABS-ABS implant were all considered. The average error in predicting the force (or torque) at a given displacement (or rotation) was minimized to a value of 4.73%. As a result of tuning for laxity, the average error in predicting the AP displacement of the tibial component during unconstrained flexion was 5.63%. The tuned laxity results for the CoCr-UHMWPE implant design are compared to the experimental results in figure 2. Figure 3 compares the AP displacements of the tibial component during unconstrained flexion simulation and experiment.

DISCUSSION:

Once the program was tuned to predict the laxity results from experiments, it was able to reasonably predict the unconstrained flexion kinematics which were also determined through experiment. Optimization provided an excellent approach to automatically tune the simulation rather than adopting a time consuming manual method. After further validation using different implant geometries, this code will be implemented into a larger computational framework for implant multi-objective shape optimization considering wear and kinematics.