VALIDATION OF A THREE DIMENSIONAL MODEL TO QUANTIFY PATELLOFEMORAL JOINT FORCES

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INTRODUCTION

Although the patellofemoral joint is typically modeled as pulley system where the compressive force acting on the paella is created by the forces in the quadriceps tendon and patellar ligament, this assumption has not been validated. The purpose of this study was to validate a 3D model of the patellofemoral joint. To accomplish this goal, patellofemoral joint reaction forces (PFJRF's) that were directly measured from an in-vitro cadaveric set-up were compared to the PFJRF's, obtained from a computational model.

METHODS

In-vitro measurement of the PFJRF: Seven fresh-frozen cadaveric knees were used in this study. Each was dissected to separate the individual heads of the quadriceps, the central tendon and the patellar ligament. The knee was mounted on a custom jig that was fixed to an Instron machine frame. Quadriceps muscle loads were accomplished using a pulley system and weights, Muscle forces were based on previously reported muscle cross-sectional area data (vastus medialis: 67 N, vastus lateralis: 98 N, rectus femoris and vastus intermedius combined: 111 N). The line of pull of each muscle was based on its 3D muscle fiber orientation. To quantify the magnitude and direction of the PFJRF, a six axis load cell was incorporated into the femoral fixation system so that a rigid body assumption could be made. Care was taken to distract the tibia (5 mm) and cut all soft tissue connection between the tibia and femur so that the only force acting on the femur was from the patella. Using this set-up, PFJRF's (magnitude and direction) were obtained at 0, 20, 40, and 60 degrees of knee flexion. In addition to the PFJRF data, 3D coordinates of the line of pull of each muscle, the orientation of the patellar ligament relative to the tibia, and the patella flexion angle was quantified using a Microscribe digitizer. The force in the patellar ligament was obtained using a buckle transducer. The alignment of the femur relative to the tibia in the frontal plane was measured using a goniometer.

Computer-based estimation of the PFJRF: Following in-vitro testing, computational models based on the three-dimensional coordinates obtained from each of the cadaver knees were created. SIMM modeling software was used to model the four quadriceps muscle force vectors and the patellar ligament force vector. The 3D coordinates of the muscle force vectors relative to the patella and the orientation of the patella and patellar ligament relative to the tibia were identical to that of the in-vitro set-up. In addition, the exact muscle loads and the measured force in the patellar ligament were used. Lower limb alignment also was matched to in-vitro measurements. Based on the unit vectors of each of the quadriceps muscles forces noted above, a resultant quadriceps force vector (relative to the patella) was calculated. The magnitude and direction of the PFJRF was quantified as the resultant of the quadriceps force vector and the patellar ligament force vector. This calculation was repeated at 0, 20, 40 and 60 degrees of knee flexion.

RESULTS AND DISCUSSION

On average, the resultant PFJRF's estimated by the computer model was consistently higher, but similar in magnitude, to the measured in-vitro PFJRF's at all knee flexion angles (9.2% difference at 0°; 10.0% at 20°; 13.4% at 40°; and 15.6% at 60°, Fig. 1). The PFJRF distribution in all three planes was similar between modeling methods across all knee flexion angles. The Pearson's correlation coefficient revealed a significant association between the resultant PFJRF's estimated from the computer model and the measured PFJRF's from the cadaver specimens (r^2=0.89; $p < 0.001$)(Fig. 2)

SUMMARY

These results suggest that good estimates of the magnitude and direction of the PFJRF can be obtained using a computer-based model. Accurate modeling of PFJRF's is needed to define the biomechanical environment of the patellofemoral joint and to identify the factors contributing to abnormal patellofemoral joint loads during functional activities.

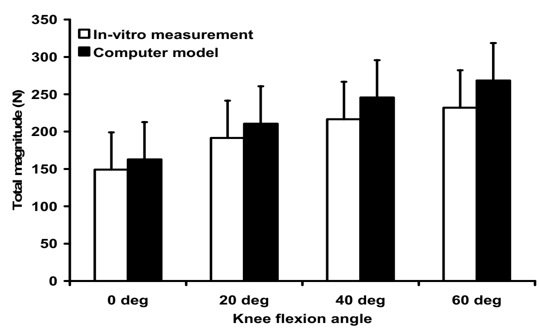

Figure 1. PFJRF output comparison between in-vitro measurements (white) and computer model (black).

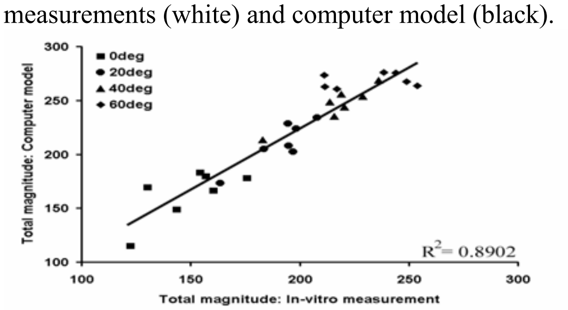

Figure 2. Association between in-vitro measurements and computer model output.

ACKNOWLEDGMENTS: This work was supported by a grant from the Whitaker Foundation