INTRODUCTION

Knee contact force during activities after total knee arthroplasty (TKA) is very important since it directly affects component wear and implant loosening. While several computational models have predicted knee contact force, the reports vary widely based on the type of modeling approach and the assumptions made in the model. The knee is a complex joint, with three compartments whose stability is governed primarily by soft tissues. Multiple muscles control knee motion with antagonistic co-contraction and redundant actions which adds to the difficulty of accurate dynamic modeling. Knee contact forces can vary widely due to differences in subject anatomy, body weight, and kinematic patterns. For accurate clinically relevant predictions a subject-specific approach is necessary to account for inter-patient variability. The purpose of this study was to generate subject-specific computer models of a complex dynamic closed kinetic chain activity.

METHODS

Patients
Approval of an institutional review board and informed consent were obtained for this study. Data were collected from 3 patients who received a custom total knee arthroplasty tibial prostheses instrumented with force transducers and a telemetry system. The tibial bone cut was made at 90° to the long axis in the coronal plane and sagittal planes. The distal femoral cut was made at 5-7° valgus to the anatomic axis of the femur. Approval of an institutional review board and informed consent were obtained for this study. The posterior femoral cut was made at 3° external rotation with reference to the posterior condylar line. In vivo knee contact forces after TKA were measured during squatting in these 3 patients. Squatting was performed with both feet parallel to each other, up to knee flexion angles that were within subject tolerance (80 - 120°). Skin marker based video motion analysis was used to record knee kinematics.

Subject-Specific Computer Model

Patient anthropometric measurements were used to scale the body segments and 16 muscles were constructed for each lower limb. 3D surface models of the knee with implants was used to model the knee joint. Contact was modeled between tibiofemoral and patellofemoral articular surfaces. Knee ligaments (medial collateral ligament <MCL>, lateral collateral ligament <LCL>, and posterior cruciate ligament <PCL> were modeled with nonlinear springs. The attachments of these ligaments were adjusted to subject-specific anatomic landmarks and material properties were assigned from published reports. The quadriceps tendon and patellar ligament were modeled with contact-based elements to simulate contact and wrapping around the trochlear groove and tibial insert respectively.

RESULTS

Model predicted peak tibiofemoral contact forces were close to that measured in vivo for each of the subjects (Fig.4). Total ground reaction force was 0.9 - 1.1 xBW (times of body weight) during squatting. Force between implanted knee and non-operated knee were similar values. Model predicted peak patellofemoral contact forces were 0.9 - 1.1 xBW and peak quadriceps forces were 1.3 - 1.6 xBW. Mean peak ligament tensions were 122.9±13.6 N for MCL and 100.2±9.4 N for LCL.

DISCUSSION

The contact force between components is one of the major factors influencing polyethylene wear. While there are many reports of computer models predicting contact forces during various activities, few models have been validated with experimental data. We developed a validated subject-specific models that accurately predicted the femorotibial contact force based on in vivo measured tibial contact forces.

Some weaknesses of our model are that the soft tissue material properties were not subject-specific but were obtained from published data; muscle attachment locations were based on CT generated bony landmarks and not on actual muscle geometry. Despite these limitations, the model predicted tibiofemoral contact force accurately.

Difference of the femorotibial contact force between the computer model and in vivo data was within 0.1 xBW only. Peak knee contact forces were lower than expected in part due to the fact that not all subjects could squat beyond 80° of flexion. In addition, in this total knee arthroplasty group, the subjects flexed the trunk at higher knee flexion angles, presumably to reduce the flexion moment of knee. Peak patellofemoral contact forces and quadriceps muscle forces were also lower than previous reported. Although others have reported on hamstring muscle activity during the squat, hamstring forces were low in our models in qualitative agreement with the EMG data.

This musculoskeletal model validated with in vivo forces is valuable in analyzing knee forces during dynamic activities. This model would be a very useful tool to predict the effect of surgical techniques on contact forces. Such a model could be used for implant design development to enhance knee function and for predicting forces generated during other activities. Finally a subject-specific model could be useful for predicting clinical outcomes.

REFERENCES