INTRODUCTION

Patellar dislocation is the most common acute knee disorder in children and adolescents. Numerous surgical options are available for treatment of recurrent lateral patellar instability, with limited consensus on how to optimize treatment based on the pathology of an individual patient. In vitro and computational evaluations of surgical options have consistently been based on normal knees. The current study focuses on development of a technique for dynamic computational simulation of patellar tracking for knees with instability that can be used to evaluate surgical options.

METHODS

Computational models were developed to represent knees of four patients with recurrent patellar instability who participated in an IRB-approved study to quantify the influence of tibial tuberosity realignment on patellar tracking [1]. Both pre-operatively and post-operatively, each patient performed a 10 second knee extension exercise against gravity within the bore of a dynamic CT scanner (Aquilion ONE, Toshiba Medical Systems). Bone models were reconstructed from the CT images to represent the femur, patella and tibia at 5 or more time points. Shape matching techniques were used to represent each position of knee extension with a single model of each of the three bones. Patellofemoral and tibiofemoral kinematics were characterized based on anatomical coordinate axes using the floating axis convention. Cartilage surfaces and bone models were also reconstructed from MRI scans of the knees, and shape matching techniques were used to align the cartilage surfaces to the bone models developed from CT.

Each knee model was individually imported into a multibody dynamics simulation platform (RecurDyn, Function Bay Inc). The ACL, PCL, MCL, LCL, posterior capsule, patellar tendon, and lateral retinaculum were represented with multiple springs and dampers, with anatomical attachment points [2]. Medial retinacular structures were not modeled as they are damaged by recurrent dislocation. Nonlinear force-strain relationships were assigned to the ligaments [2]. Pre-operative and post-operative (following tibial tuberosity realignment) patellar tendon attachment positions on the tibia were established based on the respective CT scans. Quadriceps forces representing the vastus medialis obliquus, vastus lateralis, and the vastus intermedius were applied through springs representing the quadriceps tendon, with a total force of 600 N (Fig. 1). Hamstrings forces were applied with a total force of 100 N. The mass of the lower leg was represented with structures extended from the proximal tibia. With the femur fixed and no other degrees of freedom constrained, dynamic extension from flexion was induced with application of the muscle forces. Cartilage contact was governed by a compliant model based on simplified Hertzian

Figure 1: Dynamic knee motion for one knee: computational simulation (top) and in vivo motion (bottom). The computational model includes cartilage embedded within the bone surfaces.
contact [2], allowing for simulation of knee extension in less than 15 minutes. Knee kinematics were quantified using the same coordinate systems used for the computational reconstruction of in vivo motion. Linear regressions were performed to relate simulated patella tracking to the in vivo data at the knee flexion angles recorded for in vivo motion.

RESULTS AND DISCUSSION

Simulation produced kinematics trends similar to those measured in vivo (Fig. 1). For both the multibody dynamics models and the in vivo data, pre-operative patellar lateral shift and tilt tended to increase dramatically near full extension, and tibial tuberosity realignment tended to reduce both parameters near full extension (Figs. 2, 3). The in vivo data and the data from the simulations were significantly correlated (p < 0.001) with r^2 values of 0.71 and 0.61 for lateral tilt and shift, respectively. With the regression line passing through the origin, the slope of the regression was 0.98 for lateral tilt and 0.57 for lateral shift, indicating that lateral shift tended to be underpredicted, with more accurate predictions for patellar tilt.

The strengths of the modeling technique include an ability to represent unstable motion patterns, incorporate abnormal anatomy associated with instability, and rapidly characterize dynamic motion. Additional development is needed to improve the accuracy of representation of lateral shift and to represent functional activities more likely to induce patellar instability.

CONCLUSIONS

The multibody dynamics simulation models can be used to simulate in vivo patellar tracking patterns representative of knees with patellar instability. Tracking changes induced by surgical stabilization procedures can also be simulated. The modeling technique will be used to evaluate treatment options for patients with patellar instability while accounting for initial maltracking and abnormal anatomy.

REFERENCES

1. Elias et al., Knee Surg Sports Traumatol Arthrosc

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