

## SENSITIVITY OF KNEE REPLACEMENT CONTACT CONDITIONS TO KINEMATIC MEASUREMENT ERRORS

B.J. Fregly<sup>1</sup>, S.A. Banks<sup>1</sup>, D.D. D'Lima<sup>2</sup>, and C.W. Colwell Jr.<sup>2</sup>

<sup>1</sup>Mechanical & Aerospace Engineering Department, University of Florida, Gainesville, FL; <sup>2</sup>Shiley Center for Orthopaedic Research & Education, Scripps Clinic, La Jolla, CA; email: [fregly@ufl.edu](mailto:fregly@ufl.edu), web: [www.mae.ufl.edu/~fregly](http://www.mae.ufl.edu/~fregly)

### INTRODUCTION

Dynamic measurement of artificial knee motion (e.g., via single- or bi-plane fluoroscopy, RSA, or point cluster techniques) is becoming increasingly common in orthopedic research. Such measurements allow researchers to animate the in vivo motion of the implant components during weight bearing activities such as gait. Realistic visualization of the moving geometry makes it tempting to use the animations to calculate contact conditions (i.e., medial and lateral contact forces, pressures, and areas) directly from the experimental motion measurements. However, the reasonableness of this approach has not been adequately investigated.

This study uses a dynamic contact simulation that reproduces in vivo contact force measurements made with an instrumented knee replacement to investigate the sensitivity of contact conditions to kinematics measurement errors.

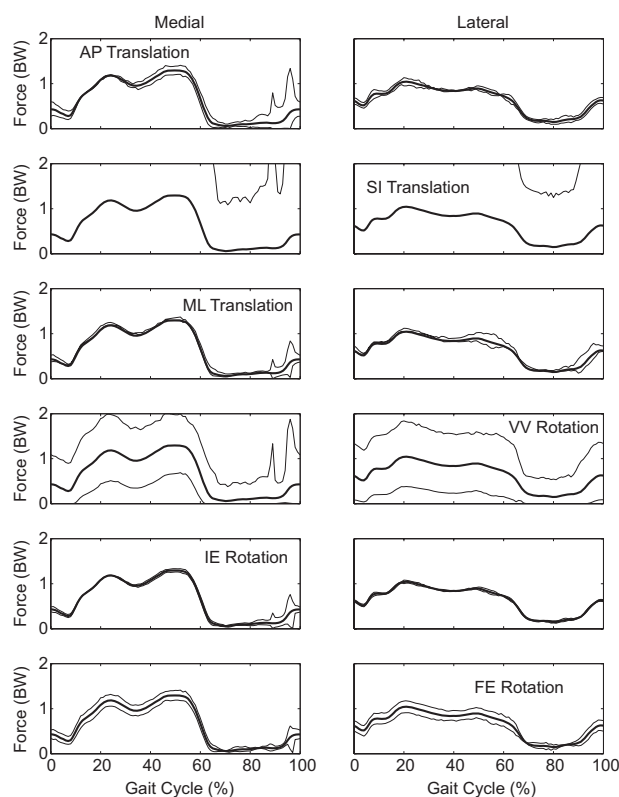
### METHODS

The starting point for the sensitivity study was a dynamic contact simulation of gait. The contact model was based on elastic foundation theory and used the same geometry as an instrumented knee replacement [1] from which in vivo contact force and single-plane fluoroscopic motion data were available during gait. The tibial insert was connected to the femoral component via a six degree-of-freedom (DOF) joint. Anterior-posterior (AP) translation, internal-external (IE) rotation, and flexion-extension (FE) were prescribed to match the fluoroscopically measured motion. Motion of the remaining DOFs was predicted via forward dynamic simulation. A time-varying axial load was applied to the inferior surface of the tibial insert based on the force magnitude and center of pressure measured in vivo by the instrumented implant. The axial load and center of pressure predicted by a one-cycle gait simulation were verified to match the experimental data [2].

Once a validated in vivo dynamic contact simulation of gait was available, the associated kinematics were treated as perfect experimental measurements. Each translation and rotation was then offset separately by  $\pm 0.1$  mm or deg to simulate the effects of small measurement errors. For each offset, an inverse dynamics analysis was performed to calculate the resulting changes in medial and lateral contact force, pressure, and area over the gait cycle. With six DOFs and two offsets (positive and negative) per DOF, this approach produced 12 sets of contact sensitivity results.

### RESULTS AND DISCUSSION

Contact conditions were highly sensitive to small errors in superior-inferior (SI) translation and varus-valgus (VV) rotation but insensitive to small errors in the remaining DOFs (Fig. 1, Table 1). An error of  $+ 0.1$  mm in SI translation caused liftoff on both sides while an error of  $\pm 0.1$  deg in VV rotation caused liftoff on one side or the other. When the sensitivity study was repeated using errors of  $\pm 0.5$  mm or deg, changes due to errors in SI translation or VV rotation



**Figure 1:** Sensitivity of medial and lateral contact force to dynamic x-ray measurement errors. Thick line is nominal, thin lines are  $\pm 0.1$  mm or deg of error in each DOF.

increased significantly, whereas changes due to errors in the other DOFs increased only moderately.

**Table 1:** Max percent change in max value.

Error	Force	Pressure	Area
AP Trans	8.60	2.54	6.85
SI Trans	204	100	117
ML Trans	7.15	3.66	6.56
VV Rot	76.7	24.7	49.5
IE Rot	3.62	0.937	3.27
FE Rot	13.3	3.69	10.9

These results have at least two important implications. First, extreme caution should be exercised when seeking to estimate contact conditions directly from dynamic x-ray or motion capture measurements. Second, assessment of the presence or absence of liftoff should be made with extreme caution. Leaving SI translation and VV rotation free to equilibrate under the influence of the applied axial load completely eliminates contact sensitivity issues but requires a good approximation of the axial load and its point of application.

### REFERENCES

1. D'Lima DD, et al. *J Biomech* **38**, 299-304, 2005.
2. Zhao D, et al., *J Orthop Res*, in press, 2007.