CAN FLUOROSCOPY DERIVED KINEMATICS BE USED TO INFER CORONAL KNEE LOADS?

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INTRODUCTION Single-plane fluoroscopic imaging has been used for the past 15 years to record and quantify the motions of knee replacements during a wide variety of activities. This information has been useful to compare various implant designs and surgical techniques, and more recently has been used to drive computational models of contact stress and wear in knee replacements. Kinematics determined from shape-matching in fluoroscopic images have uncertainties of approximately 0.5°-1° for rotations and 0.5mm for in-plane translations of each implant component. These uncertainties are acceptable for many purposes, but may not be adequate for use as inputs to dynamic knee models. Of specific concern is how uncertainties in relative varus/valgus rotations might affect the computation of medial/lateral loading and contact or loss-of-contact in either the medial or lateral compartments.

The goal of this in vivo analysis was to compare varus-valgus rotations measured fluoroscopically with those computed from internal tibial load measurements and an elastic contact model for both gait and stair-climbing activities. The working hypothesis was that fluoroscopy-derived kinematics would predict greater mediolateral excursion of loads than actually were measured.

METHODS Data were collected from one patient with an instrumented knee implant (male, right knee, age 80, mass 68 kg) eight months after surgery. IRB approval and patient informed consent were obtained. *In vivo* tibial force data were recorded simultaneously with fluoroscopic motion analysis data during treadmill gait, and step-up/down activities. Knee kinematics were determined from the fluoroscopic images by registering the CAD models to the image using modified Levenberg-Marquardt non-linear least squares optimization. For the gait activity, the data were formed from multiple trials normalized to a gait cycle beginning at right heel-strike. Gaps in the fluoroscopic data, which occur when the knee is out of view or occluded by the opposite limb, were filled by spline interpolation. The data for step motions were un-averaged time series.

Dynamic contact models of the patient's knee implant were constructed to predict *in vivo* contact forces, pressures, and areas on medial and lateral contact surfaces of the tibial insert. The models were implemented within the Pro/MECHANICA MOTION simulation environment (PTC, Waltham, MA) (Fig. 1) and used a deformable contact model utilizing elastic foundation theory. A 6 degree-of-freedom (DOF) joint between the fixed femoral component and moving tibial insert was used to measure relative (i.e., joint) kinematics for contact calculations. Femoral AP translation, internal-external rotation, and flexion-extension were prescribed to match the fluoroscopically measured kinematics while the other three DOFs, **including varus/valgus rotation**, were predicted via forward dynamic simulation. The location at which the axial force was applied to the tibial tray was prescribed to match the CoP measured experimentally. The medial and lateral contact forces acting on the tibial insert were calculated from the contact pressures acting across the surfaces. The CoP location in the ML and AP directions was also calculated from the model for comparison with the experimentally measured CoP locations.

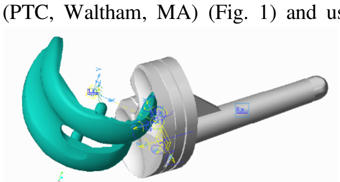

Figure 1. Dynamic contact model of the instrumented knee implant.

RESULTS The dynamic contact model was able to match the measured mediolateral center of pressure with RMS errors of 0.6 mm for the averaged gait data and 0.0 mm for the step data. Comparison of measured and modeled varus/valgus angles showed RMS errors of 0.67° (0.47°) for gait data with interpolation (and without), and 0.49° during step activities (Fig 2).

DISCUSSION It is conceptually attractive to use in vivo measurements of knee kinematics to drive computer models that further enhance the understanding of knee mechanics and implant damage. Unfortunately, single-plane image-based measurements have uncertainties on the order of millimeters/degrees, while articular surface interactions usually occur on scales of microns. Thus, extreme care may be warranted using these in vivo measures directly as inputs to computer models.

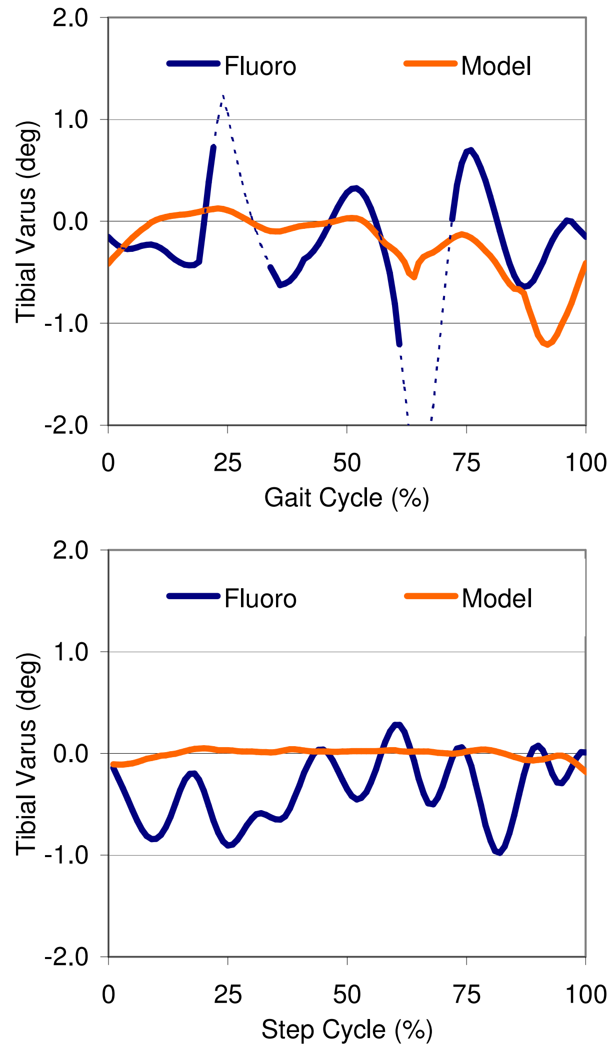

Figure 2. Tibial varus determined from single-plane fluoroscopy and shape matching techniques ("Fluoro") and from a dynamic computational model matching measured mediolateral center of pressure locations ("Model"). The top graph shows gait data, the dashed line indicates where gaps in the Fluoro record are filled by spline interpolation. The lower graph shows step-data.

The instrumented knee implant coupled with the contact model provides a unique opportunity to evaluate the accuracy of fluoroscopic measurements. The telemetry/contact model provides direct measures of the coronal center of pressure and the compatible articular surface interactions. Comparison with fluoroscopic data showed RMS errors of approximately one-half degree. This finding confirms that image-based measurements provide reasonably accurate measures of coronal rotation, but further suggests that these measures should not be used directly as inputs to computer models of the knee. Even with carefully measured kinematics, it is certain that the image-derived motions will predict greater coronal load excursions than actually occur in the knee under load.

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