

# SENSITIVITY OF JOINT CONTACT MODEL PREDICTIONS TO IMPERFECTLY SYNCHRONIZED MOTION DATA INPUTS

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## INTRODUCTION

Fluoroscopic measurement of knee kinematics is a useful tool for comparing implant designs and surgical techniques [1]. A wide variety of activities have been studied in this manner, including gait. Unfortunately, fluoroscopy by itself cannot provide an unambiguous determination of gait events like heel-strike and toe-off. This presents little problem if kinematics are the sole use for the data, but becomes a critical issue when studying kinetics. For this purpose, the kinematics and force recordings must be time synchronized for correct interpretation.

Recently, the first instrumented knee implant capable of measuring the *in vivo* axial loads applied to the tibia has been reported [2]. This device allows the total axial load and center of pressure (CoP) to be calculated under dynamic conditions from force measurements made by four uniaxial load cells located at the corners of the tibial tray. By augmenting these *in vivo* load measurements with *in vivo* motion measurements performed simultaneously using video fluoroscopy, one can use a multibody dynamic contact model to calculate the time history of medial and lateral contact forces during gait.

The purpose of this study was to determine the sensitivity of computed joint center of pressure to synchronization errors in the input data. Experimentally measured ground reaction forces, whole body kinematics and internal knee kinematics were used as inputs to a joint contact model and time shifted to determine the effect on predicted joint loads. Tibial loads measured directly by the instrumented implant were used as the reference.

## METHODS

Data were collected from one patient with instrumented knee implant (male, right knee, age 80, mass 68 kg) eight months after surgery. Institutional review board approval and patient informed consent were obtained. *In vivo* tibial forces were recorded simultaneously with either fluoroscopic motion analysis data (treadmill gait) or video-based motion analysis and ground reaction force data (overground gait). The heel strike event on the treadmill was identified by determining the location in the instrumented knee load data where the vertical ground reaction force measured during overground gait become nonzero (Fig. 1).

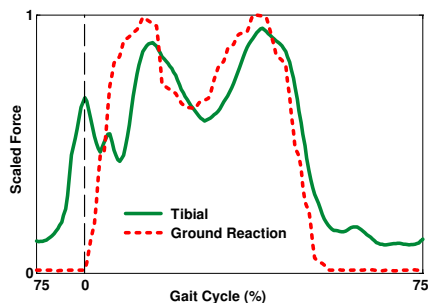


Fig. 1. Scaled simultaneously measured *in vivo* tibial force and ground reaction force.

A dynamic contact model of the patient's knee implant was constructed to predict *in vivo* contact forces, pressures, and areas on medial and lateral contact surfaces of the tibial insert. The model was implemented within the Pro/MECHANICA MOTION simulation environment (PTC, Waltham, MA) and used a previously reported elastic foundation contact model with linear material properties [3]. 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 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.

By shifting the phase of fluoroscopically measured gait within  $\pm 5\%$  (0.06 second) (Fig. 2), the CoP locations in the ML and AP directions were calculated for comparison with the experimentally measured CoP locations.

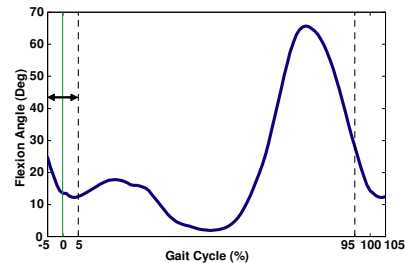


Fig 2. Fluoroscopically measure flexion angle during gait (2 miles/hour).

Another approach to examine the sensitivity of the AP CoP error to the heel strike event is to shift the AP CoP results obtained with the original data within  $\pm 5\%$  to calculate linear correlation coefficients between model prediction and experimental measurement.

## RESULTS

The model prediction of AP CoP location was sensitive to time shift of heel strike. Dynamic contact simulation results showed the minimum CoP root-mean-square (RMS) error during stance phase in AP COP occurred with a -2% phase shift (Table 1).

Table 1. CoP RMS errors during stance phase in AP and ML directions.

Phase shift	+5%	0%	-2%	-3%	-5%
Flexion angle (Deg)	24.6	13.5	12.3	12.2	12.4
AP CoP error (mm)	3.4	2.1	1.9	1.9	2.4
ML CoP error (mm)	0.2	0.1	0.2	0.3	0.2

The model predicted AP CoP locations matched the experimental measurement best at the -2% shift of AP CoP locations. The linear correlated coefficients results were consistent with these experimental results (Fig. 3).

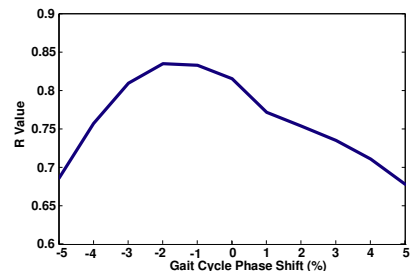


Fig. 3. Correlated coefficient (R) between shifted model prediction and experimentally measured CoP load in AP direction.

## DISCUSSION

Minimization of the CoP error of the dynamic simulation provides a method to accurately determine the instant of heel strike from fluoroscopically measured gait kinematics. The local minimum of the flexion angles appears to correspond to the instant of heel strike.

## REFERENCES

- [1] Banks et al. *IEEE T-BME*, **43**:638-649, 1996 [2] D'Lima et al. *J Biomech*, **38**:299-304, 2005 [3] Fregly et al. *J Biomech*, **38**:305-314, 2005

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