

BIO2006-158035

**THE RELATIONSHIP BETWEEN THE KNEE ADDUCTION TORQUE
AND MEDIAL CONTACT FORCE DURING GAIT**

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INTRODUCTION

The human knee joint is one of the most important joints in the human body and is frequently affected by osteoarthritis (OA). Adverse mechanical loading of the knee, and in particular high medial contact force, is believed to contribute to the development of knee OA. Unfortunately, noninvasive *in vivo* measurement of medial compartment contact force is not yet available. Consequently, researchers have investigated the use of external measures available from gait analysis to serve as surrogates for internal medial compartment contact force. To date, the peak external knee adduction torque has been identified as the best candidate [1-5]. However, the lack of accurate *in vivo* medial and lateral compartment force data is problematic for determining the relationship between the knee external torques and internal loads.

This paper investigates the relationship between the knee adduction torque and *in vivo* medial contact force and medial to total contact force ratio during gait. The adduction torque curve during overground gait was obtained with a motion capture system. The corresponding internal contact forces were calculated from data provided by an instrumented knee implant capable of measuring total axial force [6]. An equation for partitioning total force into medial and lateral contact forces was determined using fluoroscopic data collected from the same subject performing treadmill gait [7]. The correlation coefficients between the knee adduction torque and the internal forces were calculated.

METHODS

Data Collection

Data were collected from one patient with instrumented knee implant (male, right knee, age 80, mass 68 kg, height 1.705 m) eight months after surgery. Institutional review board approval and patient

informed consent were obtained. *In vivo* tibial force data were recorded simultaneously either with fluoroscopic motion analysis data during treadmill gait or with video motion capture during overground gait. The gait cycle was defined to begin at right heel strike, which was determined using synchronized tibial force and ground reaction force data collected during overground gait trials.

Treadmill Contact Forces

A dynamic contact model [8] of the patient's knee implant was constructed to predict *in vivo* contact forces on the medial and lateral contact surfaces of the tibial insert. The dynamic model was implemented within the Pro/MECHANICA MOTION simulation environment (PTC, Waltham,

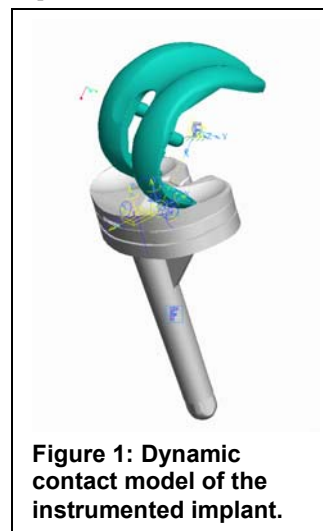


Figure 1: Dynamic contact model of the instrumented implant.

MA) (Figure 1) and incorporated a custom elastic foundation contact model. Linear elastic material properties (Young's modulus = 463 MPa and Poisson's ratio = 0.46) were used for the polyethylene tibial insert. 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 center of pressure measured experimentally. The medial and lateral contact forces acting on the tibial insert were calculated from the contact pressures acting across the surfaces.

Overground Contact Forces

The medial contact force during the overground gait was estimated using the load cells measurements and results of the treadmill gait simulation. The dynamic model could not be used to predict medial-lateral contact forces directly since accurate internal implant motion measurements were not available during overground gait. Medial contact force calculated with dynamic contact model during treadmill gait was fit as a linear function of the four load cell measurements provided by the instrumented knee implant (Eqn. 1, $R^2=0.99$, RMS error = 0.01 body weight).

$$F_M = C_1 F_{AM} + C_2 F_{PM} + C_3 F_{AL} + C_4 F_{PL} \quad (1)$$

Medial contact force during overground gait was then calculated estimated using this equation and the overground gait load cell measurements.

Statistics Analysis

Linear regression analysis with Pearson correlation coefficients was used to determine the individual significant correlations between the knee adduction torque and the medial contact force and the medial to total force percentage.

RESULTS

During overground gait, the peak measured total axial load was 2.45 BW with a corresponding peak predicted medial compartment load of 1.51 BW. The predicted medial load followed a similar trend to the total load (Figure 2a), as it did in the treadmill gait experiment. The peak right knee adduction torque during overground was 2.53 percent of body weight times height (%BW×H) (Figure 2b). The medial contact force and adduction torque curves exhibited similar trends, with the two peaks in the adduction torque curve during stand phase occurring slightly early in the cycle than did the corresponding peaks in the medial contact force curve.

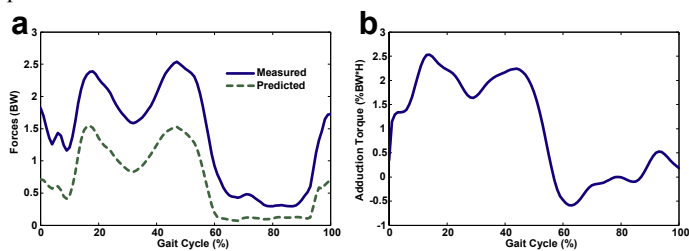


Figure 2: Measured total and predicted medial forces (a) and adduction torque (b) at knee joint during gait.

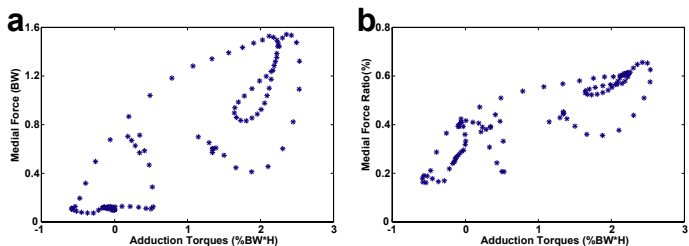


Figure 3: (a) Scatter plot of the adduction torque versus medial force. (b) Scatter plot of the adduction torque versus medial to total force percentage.

Statistically significant correlations were found between the adduction torque and both the medial contact force and the ratio of medial to total contact force ($P<0.01$). The Pearson correlation coefficient of adduction torque vs. medial force was 0.85 and for adduction torque vs. medial to total force ratio 0.87. These two r values were increased to 0.94 and 0.90 if the phase shift between the medial contact force and adduction torque curves was removed.

DISCUSSION

This study evaluated the assumption that the knee adduction torque measured externally using gait analysis is an accurate predictor for internal medial compartment contact force. The results showed that this assumption appears to be valid and that a strong correlation also exists between adduction torque and medial to total force ratio. These limited results for a single patient suggest that the peak external knee adduction torque can be used as a surrogate for internal medial compartment contact force.

One limitation of this study is that there was only one subject available. The medial compartment load during overground gait could not be measured directly due to the limitation that *in vivo* tibial axis force, fluoroscopic and motion capture measurements could not be performed simultaneously. The dynamics of the tibia might be helpful to explain the phase difference between the internal force and the external torque measurement.

Another method for obtaining medial compartment load was also investigated. The total load measured during overground gait was multiplied by the medial to total force percentage calculated by the contact model during treadmill gait. The results were similar to those presented above.

ACKNOWLEDGMENTS

This work was supported by an NSF CAREER award to B.J. Fregly and by the Biotion Foundation of Palm Beach, FL

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