In-vivo patient-specific joint contact forces on medial and lateral compartments in total knee arthroplasty patients during walking

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Introduction: Estimation of in-vivo joint contact forces and muscle forces during walking is of great importance in order to protect the knee joint from injury or provide adequate rehabilitation and exercise protocols [1]. Due to the difficulties of the non-invasive measurement of joint contact forces and muscle forces, conventional inverse dynamics analysis with optimization techniques have been used to predict the muscle forces and joint constrained forces [1]. Recently fluoroscopic images analysis techniques have been widely used to quantify the 3D in-vivo joint kinematics [2, 3]. However, one of the most important issues in these sequential processes is how to handle the location of the joint center during the motion. The objective of this study was to evaluate the joint contact forces and muscle forces at the knee joint during walking using measured data and geometric model information as well as various numerical analysis techniques.

Materials & Methods: Motion capture and ground reaction force data measured from a patient with instrumented total knee arthroplasty (TKA) implant during walking were provided for the grand challenge competition at the 2010 ASME Summer Bioengineering Conference [4]. Joint parameters (i.e., positions and orientations of lower extremity joints in the body segments) and inertial parameters (i.e., masses, mass centers, and moments of inertia of the body segments) were determined from the isolated joint motion and gait trial data using optimization techniques. Six quasi-static equilibrium equations at the knee with 20 muscles and three joint constrained forces were solved in the static optimization process.

Geometric data of the patient were used to develop the finite element (FE) model of the knee joint [4]. Rigid-to-elastic contact between the femoral component and the tibial insert and ligament was modeled as non-linear springs. Measured ground reaction forces and predicted muscle forces from the inverse dynamics analysis were applied to the model as external loads. The 3D in-vivo joint kinematics data using single-plane fluoroscopic images were used for the motion input of the FE analysis. Quasi-static FE analysis was then performed for entire gait cycle to calculate the medial and lateral contact forces. The joint contact forces on medial and lateral compartments of the knee of the TKA patient during walking were calculated and compared with measured data from the same patient.

Results: The total, medial and lateral contact forces predicted from finite element analysis combined with inverse dynamics analysis during walking have similar patterns compare with those in previous studies [3]. At about 10% of gait, the peak total contact force reduced from 1990 N to 1865 N when the joint center moved to 5 mm of posterior position. At about 40% of gait, the peak total contact force reduced from 2240 N to 2160 N when the joint center moved to 5 mm of anterior position. The total contact forces were reduced by alternating the joint center either anteriorly or posteriorly for different flexion angles. The joint contact forces on medial and lateral compartments were well matched with those in the measured data from the TKA patient [5].

Discussion: This study showed the integrated analysis techniques to estimate the patient-specific in-vivo joint contact forces on medial and lateral compartments of the knee during walking before and after TKA. The present results were well matched with those measured from the same TKA patient in the same walking motion. The validated present techniques would be able to utilize to understand the patient-specific contact force distributions of the TKA patients during daily activities to perform the optimal pre-operative planning and quantify the post-operative functional evaluation of the TKA surgery.

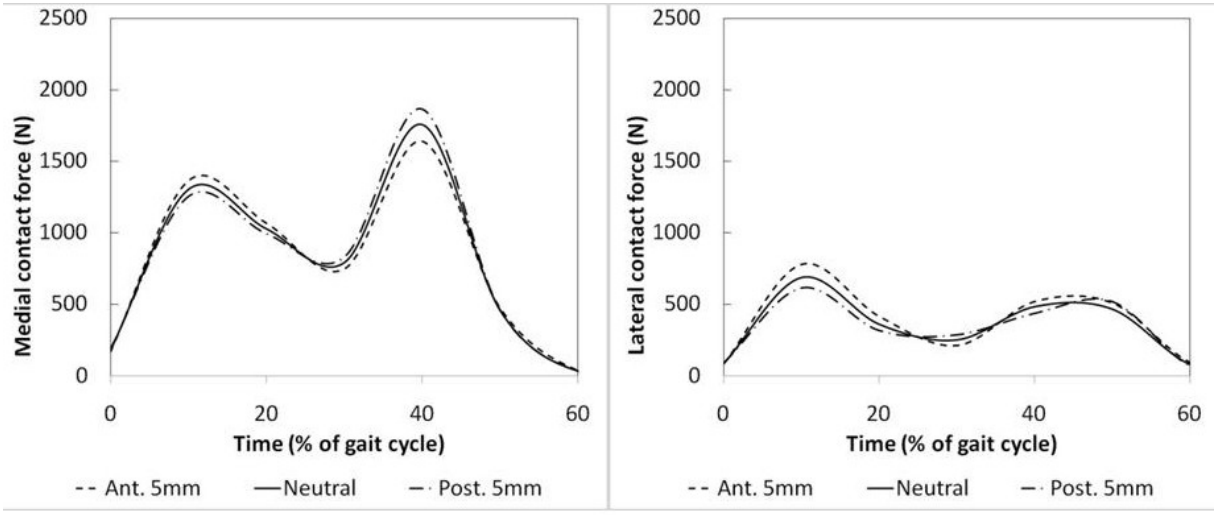

Figure: Medial and lateral contact forces of the knee joint in post-operative TKA patient during stance phase of walking

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