Altered In-vivo 3-D Knee Kinematics and Kinetics in Posterior Cruciate Substituting Total Knee Replacements During Gait and Cutting Activities

Ruchika Chandran, M.A.[1], H. John Yack, PhD[1], John J. Callaghan, M.D.[2]

1. Orthopaedic Gait Analysis Laboratory, University of Iowa, Iowa City, IA
2. Department of Orthopaedics, University of Iowa, Iowa City, IA

Introduction: Total knee replacement has become the treatment of choice to restore function to the symptomatic arthritic knee. While overall clinical results using existing conventional fixed-bearing designs are good to excellent[1], altered kinematics, especially limited axial rotations, are considered primarily responsible for sub-optimal outcomes due to reduced conformity and unphysiological loading at the bearing surface[1]. Historically, error associated with tracking the thigh segment[2] precluded examining knee axial rotations and true three-dimensional (3-D) loading during functional activities using surface markers. However, using a new method to track the thigh, knee axial rotations can be reliably assessed using surface markers[3]. Therefore, the purpose of this study was to compare the axial rotation of the knee in subjects with fixed-bearing knee replacements with those seen in a control group and examine altered loading, if any, during gait and during cutting activities that present an increased knee axial rotation requirement.

Statement of Clinical Significance: Documenting the motion and loading in the prosthetic knee during functional activities is essential to determine the influence of physiological loads on performance and longevity of total knee replacements and to assess improvements, if any, in newer prosthetic designs.

Methodology: Eleven subjects (6 females and 5 males; age: 62.73$\pm$ 9.22 years) with unilateral posterior cruciate substituting total knee replacements (PCS-TKR) and ten healthy controls (5 females and 5 males; age: 60.60$\pm$ 10.23 years) with no previous history of lower limb pathology were recruited for the study. All subjects signed an informed consent form approved by the University of Iowa Human Subject Review Board. A five-segment model of the body with three non-collinear infrared diodes (IREDs) placed on each segment, the foot, leg, thigh, pelvis and trunk, was used to estimate joint kinematics using standard three dimensional motion analysis techniques. The method used to track the thigh segment provides the required accuracy (max. R.M.S. error = 1.5°) to record transverse plane kinematics with confidence[3]. Kinematic and synchronized force plate data was collected as subjects performed the three activities: 1) walking at self-selected velocity; 2) sidestep cutting and 3) crossover cutting at an angle of 45° at velocity selected for the walking trials. Kinematic data was sampled at 60Hz using an Optotrak® Motion Analysis System and filtered at 6Hz. Force plate data was collected at 300Hz and filtered at 8Hz. A minimum of three trials for each subject were ensemble averaged (2% intervals) over the stance phase and used to create representative patterns of each individual's knee joint kinematics and kinetics. These were then averaged to generate a representative pattern for the two groups.

Results: Both the groups performed the three activities at a similar speed and angle of cut ($p > 0.5$). The PCS-TKR group displayed decreased knee axial rotation compared to the control group during walking at self-selected velocity and during sidestep cutting (Fig.1). During the crossover cut an increase in rotation was seen compared to the other two activities (Fig.1).

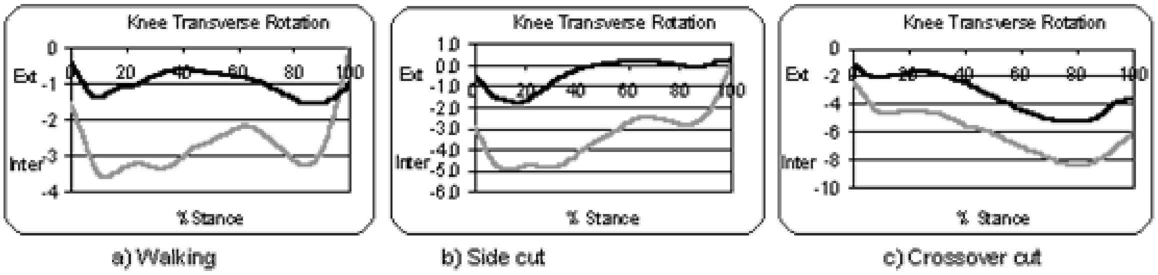

Fig.1 Knee transverse rotations in the control (▬) and PCS-TKR (▬) group

In the sagittal plane the PCS-TKR group also displayed decreased flexion and decreased extensor moments (Fig.2) compared to controls throughout stance across all three activities.

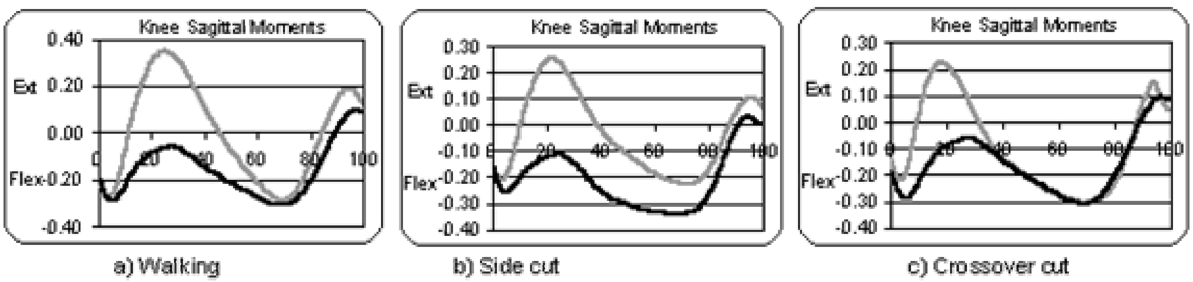

Fig.2 Knee sagittal moments in the control (▬) and PCS-TKR (▬) group

The PCS-TKR group did not demonstrate increased axial rotation at the ankle or hip compared to controls and demonstrated decreased or absent internal rotation moments across the ankle, knee and hip in early stance during all three activities.

Discussion: The PCS-TKR group demonstrates decreased internal knee rotation compared to controls during activities that do not challenge rotation requirements and only demonstrates comparable rotations in activities that demand increased rotation to meet performance criteria (fixed angle of cut). Whether the increased rotation during the crossover cut affords greater conformity or functionality, or comes at a price of increased wear and tear at limits of prosthetic function when the knee is close to extension, needs to be examined further. Studies indicate that increased motion may come at a price of increased wear and tear[4]. It appears that PCS-TKR subjects use a strategy to reduce or control axial rotation of the knee and ‘stiffen’ the lower limb during loading, supported by the decreased axial rotations and internal rotation moments seen across the lower limb joints in all activities and absent extensor moments. The decreased extensor moments are consistent with studies that report decreased loading at the knee in subjects with osteoarthritis. Whether the absent extensor moment in early stance in the PCS-TKR group is due to a gait pattern established due to the preexisting pathology or is an attempt to reduce loading of the prosthetic knee warrants further examination. The data indicate that subjects with fixed-bearing PCS-TKR demonstrate altered lower limb loading. Studies need to further establish if these altered loading conditions accommodate improved prosthetic function or are responsible for reduced function or increased risk of prosthetic failure.

References:

1. Callaghan, J.J. et al. The Journal of Bone and Joint Surgery 82A(7): 1020-1040, 2000.
2. Cappozzo, A. et al. Clinical Biomechanics 11: 90-100, 1995.
3. Yack, H.J. et al. Gait and Posture 11(2): 148, 2000.
4. Harmon, M.K. et al. Clinical Orthopaedics and Related Research 392: 383-393, 2001