In-vivo Articular Contact Analysis during Step-Ups in Patients with Asymmetrical Bearing Geometry Cruciate Retaining Total Knee Arthroplasty

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INTRODUCTION: Advances in surgical technique and sophisticated implant design have resulted in successful pain relief and long-term-implant survival in patients who undergo total knee arthroplasty (TKA). However, about 20% of patients are still dissatisfied with their replaced knees. The exact reasons for patient dissatisfaction are not as yet understood. The new Asymmetrical Bearing Geometry cruciate retaining (CR) TKA design, featuring asymmetrical bearing geometry with concave medial and convex lateral tibial shapes, was introduced in 2013 with the aims to more closely replicate normal knee anatomy and kinematics. However, there is a paucity of information regarding in-vivo articular contact kinematics in the contemporary CR TKA design during functional tasks. As stepping up is a physically demanding task and a painful limitation for patients requiring TKA, the objective of this study was to investigate in-vivo articular contact kinematics of CR TKAs utilizing a validated dual fluoroscopic imaging system (DFIS) during step-up.

METHODS: In this Institutional Review Board approved study, 15 unilateral Asymmetrical Bearing Geometry CR TKA patients (6 male, 9 female; 68.4 ± 5.8 years; BMI 31.8 ± 9.9) with an average follow-up of 14.5 ± 12.6 months were enrolled for this study. All fifteen patients received computer tomography (CT) scan for the creation of 3D surface models of the knees. For the contralateral non-operated knee, the femoral and tibial local coordinate systems were constructed using anatomical bony landmarks [1], while the anatomical coordinate systems of the operated knee were determined using a previously validated and published 3D mirroring technique. All unilateral CR TKA patients performed the step-up test under dual fluoroscopic imaging system (DFIS) surveillance [2]. The 2D fluoroscopic images and the 3D subject-specific knee models were imported into the virtual DFIS environment for determination of knee 6 DOF kinematics. Medial and lateral condylar contact positions were quantified as the lowest point on the medial and lateral condyles with respect to the tibia and tibial tray. Average and standard deviation of the contact position along anterior/posterior and medial/lateral were calculated. A signed-rank Wilcoxson test was performed to determine if there is a significant difference in contact excursion between CR TKA and the native knee during step-ups ($\alpha = 0.05$).

RESULTS: Asymmetrical Bearing Geometry CR TKA demonstrated significantly larger anterior excursion of the lateral epicondyle contact point at 9 to 26° and 34 to 55° of knee flexion (-4.1 ± 4.8° vs -8.9 ± 5.7°, Figure 1b), when compared to the non-operated knee. Similarly, the contact point of the medial epicondyle of CR TKA shows significantly larger anterior excursion throughout the range of knee flexion angles (2.9 ± 2.3° vs -5.3 ± 5.1°, Figure 1e), when compared to the non-operated knee. CR TKA demonstrated significantly smaller lateral excursion of the lateral epicondyle contact point at 17 to 54° of knee flexion (24.3 ± 0.6° vs 27.3 ± 2.5°, Figure 1c), when compared to the non-operated knee. In contrast, CR TKA demonstrated significantly smaller lateral excursion of the medial epicondyle contact point only at the first two degree of knee flexion angles (25.1 ± 1.1° vs 27.1 ± 3.5°, Figure 1f). There is significantly larger external femoral rotation during knee flexion when compared to the non-operated knee, with the largest differences being observed for flexion angles from 5 to 34° (7.7 ± 6.4° vs 1.0 ± 5.6°, Figure 1d). Step-ups exhibited little pivoting variability with 73% (11/15) of patients displaying medial pivoting while the remaining patients showed lateral pivoting. In addition, medial condyle contact rollback was noticed in CR TKA when extending the knee during the first half of the step-up activity, with 86.6% (13/15) of patients experiencing a retrograde excursion (2.3 ± 1.2 mm) prior to forward motion.

DISCUSSION: Physically demanding activities such as step-up may be more sensitive tools for investigating kinematics abnormalities following TKA. This study demonstrated medial pivoting patterns during the step-up activity in the majority of patients, similar to those reported in the healthy knee [3]. However, this study has demonstrated significantly larger anterior contact excursions of the lateral and medial femoral condyles during step-up, when compared to the contralateral non-operated knee. Thus, the contemporary Asymmetrical Bearing Geometry CR TKA design did not fully replicate the non-operated knee articular contact kinematics during step-up. Future studies are required to investigate the effect of these discrepancies on joint performance and associated patient satisfaction.

SIGNIFICANCE/CLINICAL RELEVANCE: The majority of Asymmetrical Bearing Geometry CR TKA patients demonstrated and medial pivoting, similar to those presented in the healthy knee. However, there are significant differences in anterior excursions of both epicondyle throughout the range of knee flexion angles during step-ups.

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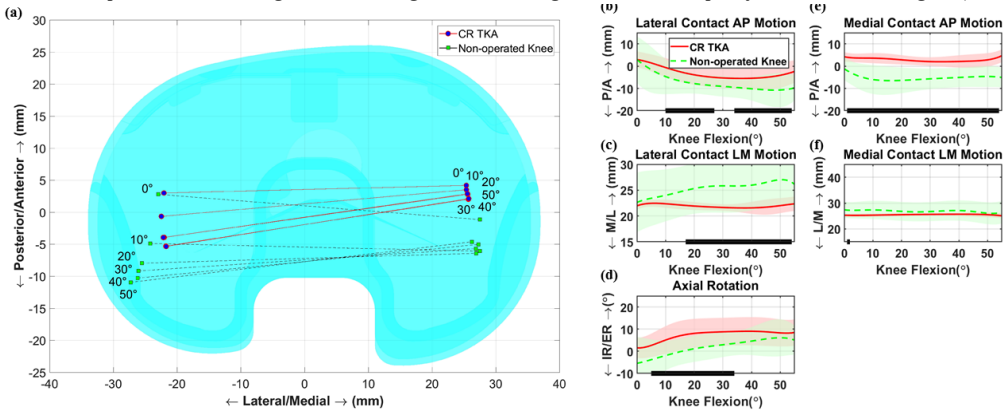

Figure 1: Average excursion of condylar contact points shown on the medial and lateral polyethylene inserts of CR TKA patients at selected knee flexion

angles during step-ups (a). Average and standard deviation of contact trajectory is shown along anterior/posterior and medial/lateral directions during step-ups (b-f).