In-vivo Kinematics during Gait in Asymmetrical Bearing Geometry Cruciate Retaining Total Knee Arthroplasty

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INTRODUCTION: Total knee arthroplasty (TKA) is a widely accepted surgical treatment for patients with moderate or severe joint degeneration. Recently, arthroplasty designs have incorporated various geometric features in order to replicate normal knee biomechanics. In fact, the recently-introduced Asymmetrical Bearing Geometry cruciate retaining (CR) TKA was designed to preserve proprioception and kinematics of the native knee by retaining the PCL. Additionally, the Asymmetrical Bearing Geometry CR TKA was designed to restore native knee kinematics, such as lateral condyle rollback and rotation during deep knee flexion, by introducing concave medial and convex lateral tibial components, with a posterior medial lip. However, there is a paucity of data available regarding its in-vivo kinematics during functional activities of daily living. As gait is considered to be the most commonly performed functional daily task, this study aimed to investigate in-vivo 3D kinematics of CR TKA during gait utilizing a validated dual fluoroscopic imaging system (DFIS).

METHODS: We evaluated fifteen well-functioning unilateral Asymmetrical Bearing Geometry CR TKA patients (6 males and 9 females), with no history of any surgical complication, for this institutional review board-approved study. All fifteen patients received computer tomography (CT) scan for the creation of 3D surface models of the knees and performed level walking on a treadmill at self-selected speed under dual fluoroscopic imaging system (DFIS) surveillance [2]. The average patient age was 68.4 years (± 5.8, range 61 to 81), while the average follow-up time was 14.5 months (± 12.6, range 1 to 42). For the contralateral non-operated knee, the femoral and tibial local coordinate systems were constructed using anatomical bony landmarks [1]. The anatomical coordinate systems of the operated knee were determined using a previously validated and published 3D mirroring technique. The 2D fluoroscopic images and the 3D subject-specific knee models were imported into the virtual DFIS environment for determination of knee six degree-of-freedom (6 DOF) kinematics. Wilcoxon signed-rank test was performed to determine if there is a significant difference in knee motion during gait by comparing 6 DOF kinematics between the non-operated and operated knees. Statistical significance was set at $p<0.05$.

RESULTS: Asymmetrical Bearing Geometry CR TKA knees demonstrated significantly larger knee flexion angles during stance phase at 48 to 50% of the gait cycle (9.2 ± 6.7° vs 7.3 ± 10.6°, Figure 1a) as well as during early swing phase (23.7 ± 12.6° vs 19.4 ± 18.6°, Figure 1a), when compared to the non-operated knee. CR TKA knees demonstrated significantly lower knee valgus angles during swing phase at 78 to 92% of the gait cycle, when compared to the native knee (-3.9 ± 2.7° vs -6.2 ± 4.8°, Figure 1b). CR TKA knees demonstrated significantly lower femoral internal rotation during swing phase at 79 to 100% of the gait cycle, when compared to the non-operated knee (0.6 ± 4.6° vs 6.3 ± 6.8°, Figure 1c). CR TKA knees demonstrated significantly less medial femoral translation during stance phase at 22 to 50% of the gait cycle (-0.6 ± 3.6 mm vs -3.2 ± 2.6 mm, Figure 1d) as well as swing phase at 50-58% of the gait cycle (-0.11 ± 3.9 mm vs -2.84 ± 3.0 mm, Figure 1d), when compared to the native knee. CR TKA knees demonstrated significantly larger proximal femoral translation during the entire gait cycle when compared to the native knee (34.7 ± 4.5 mm vs 31.0 ± 3.1 mm, Figure 1e). Similarly, CR TKA knees demonstrated significantly larger anterior femoral translation during the complete gait cycle when compared to the native knee (3.4 ± 3.8 mm vs -1.9 ± 4.7 mm, Figure 1f).

DISCUSSION: The contemporary Asymmetrical Bearing Geometry CR TKA was designed to restore native knee kinematics, such as lateral condyle rollback and rotation during deep knee flexion, by introducing concave medial and convex lateral tibial components, with a posterior medial lip. In comparison with the contralateral non-operated knee during gait, 6 DOF in-vivo kinematic analyses demonstrated that Asymmetrical Bearing Geometry CR TKA showed significantly larger proximal and anterior femoral translations during the entire gait cycle as well as significantly smaller medial femoral translations during large parts of the stance phase. Similarly, significant asymmetric external-internal and valgus/varus knee rotation angles were measured during treadmill gait in this cohort of patients, suggesting that the native knee kinematics during gait was not restored in patients with unilateral CR TKA. Further studies are required to investigate the potential effects of TKA design and component positioning on optimizing in-vivo TKA kinematics during functional daily activities.

SIGNIFICANCE/CLINICAL RELEVANCE: This study investigated in-vivo 3D kinematics in unilateral Asymmetrical Bearing Geometry CR TKA design with concave medial and convex lateral tibial components. Although CR TKA has the potential to restore knee kinematics, the results of the current study suggested that the native knee kinematics during gait was not restored in patients with unilateral CR TKA.

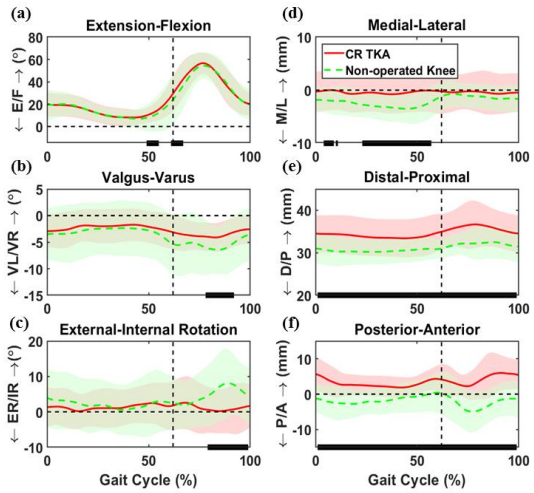

Figure 1: Average and standard deviation of knee extension/flexion (a), knee valgus/varus (b), knee external/internal rotation (c), tibial lateral/medial (d), posterior/anterior (e), and femoral inferior/superior (f) translations for the operated and non-operated knees in unilateral CR TKA patients during gait. Black bars on the horizontal axis (Gait Cycle %) indicate statistical significant difference between limbs. Black dashed vertical lines denote toe-off (end of stance phase).

REFERENCES:
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[2] Tsai, et al. "A novel dual fluoroscopic imaging method for determination of THA kinematics: in-vitro and in-vivo study." J Biomech (2013)