Kinematics of Robotic-Assisted and Conventional Total Knee Replacements during Activities of Daily Living

Emma Donnelly[1], Megan Richards[2], Alex Galley[1], Brent Lanting[1,3], Ryan Willing[1,2,4]
[1]Western University, London, ON, [2]Northern Light Orthopedics, Bangor, ME, [3]Lawson Health Research Institute, London, ON, [4]Western Bone and Joint Institute, London, ON

edonne@uwo.ca

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INTRODUCTION: Robotic-assisted (RA) surgery has found its place in orthopedics, specifically with its continued growing popularity in use for total knee replacement (TKR).Despite the allure of RA surgery, and the suggested improved implant alignment [1]–[3], clinical assessment of their differences and measuring improved outcomes with return to activity remain largely reliant on patient reported metrics, making them very subjective. Therefore, this study investigates joint kinematics in TKR knees following conventional and RA joint replacement surgery under loads simulating activities of daily living (ADL).

METHODS: Institutional review board approval was received for this study. Eight (8) full-lower body specimens were used for the presented study. All knees underwent TKR surgery. For each pair of knees, one joint replacement was done using conventional manual methods, while the contralateral side employed a robotic assist (VELYS, DePuy Synthes). Regardless of method, all surgeries were performed by the same surgeon, applied neutral mechanical alignment strategies, and had a cruciate retaining, rotating platform (CR RP) implant system installed. Following each joint replacement surgery, specimens were truncated mid-femur and mid-tibia to isolate the knee joint. Both ends of the specimen were cemented into pots and mounted to a six degree of freedom joint motion simulator (VIVO, Advanced Mechanical Technologies Inc.) via custom fixtures, for biomechanical testing. The joint was pre-conditioned via a series of applied loads in all degrees of freedom to minimize the effects of tissue creep and confirm joint alignment with the simulator. Simulated loads representative of gait, stair ascent, and stair descent were applied to the joint. Applied loads were obtained from Orhtoload (https://orthoload.com/) [4] but reduced by 75% to prevent specimen damage. For each simulated ADL, 5 cycles were performed, 3 were recorded. The middle-recorded cycle was used for all subsequent analyses. Optical markers (Optotrak, Certus, NDI) were affixed to the femur and tibia. Tibiofemoral joint kinematics were computed using modified Grood & Suntay conventions [5], [6]. For each specimen, values at time points of interest were extracted and averaged based on TKR surgery approach (conventional vs. RA). Relevant time points for gait were selected based on those selected by Ahn & Hogan [7]. Observed time points during stair walking activities were deciding using similar rationale. Anterior/ posterior (AP) translation, internal/ external (IE), and varus/ valgus (VV) rotation values were extracted at time points of interest relevant to the observed ADL and compared via two-tailed paired samples *t*-tests. During gait, the time points of interest were (1a) at maximum knee flexion during the stance phase, (1b) at maximum knee extension during the terminal stance phase, and (1c) at maximum knee flexion during the swing phase. For stair ascent, (2a) maximum knee flexion during the swing phase (foot clearance), (2b) maximum knee flexion during the stance phase (weight acceptance), and (2c) maximum knee extension during the stance phase (forward continuance) were observed. For stair descent, the time points of interest were (3a) maximum knee extension during the swing phase (foot placement), (3b) at maximum knee flexion during the stance phase (weight acceptance), and (3c) at maximum knee flexion during the swing phase (pull through).

RESULTS SECTION: Statistically significant differences were identified in IE rotation at one point of each of the observed ADLs. At maximum knee extension in the terminal stance phase of the gait cycle, conventional TKR favored an externally rotated position knees (4.2° ±2.5), and RA TKR knees favored a slight internal rotation (-1.9° ±5.9) (p = .04). During the weight acceptance phase of stair ascent, conventional TKR (-5.8° ±3.2) knees again exhibited significantly less internal rotation than RA TKR knees (-8.8° ±5.5) (p = .04). Finally, during foot placement through stair descent, the two groups were significantly different (p=.04), again with conventional TKR knees favoring an externally rotated position (3.4° ±4.7) and RA TKR knees favoring a slightly internally rotated position (-0.5° ±3.9).

DISCUSSION: The presented results suggest RA and conventional TKR results in comparable AP and VV joint kinematics at the observed time points of interest through gait, stair ascent, and stair descent. This was also true for IE kinematics for 6 of the 9 evaluated moments. Where statistically significant differences were found in IE kinematics between the methods, they were at points of simulated single-leg weight bearing in gait and stair ascent. Overall, RA TKR kinematics favored internally rotated positions at the observed time points of the performed simulated ADLs. It can be observed that some positioning bias may exist as both cohorts have similar kinematic patterns across the cycle (Figure 1). However, it remains unclear whether any observed differences are due to implant positioning, soft tissues tensioning, or some other mechanism, and requires further investigation. Additionally, though no statistically significant differences were identified, it was observed that the standard deviations of VV kinematics of RA knees trended smaller than conventional TKR at the observed time points in gait and stair ascent. This was also true for AP kinematics through all ADLs, suggesting less variable kinematics of RA TKR knees in those degrees of freedom.

SIGNIFICANCE/CLINICAL RELEVANCE: These results could provide a greater understanding of patient outcomes and the implications on their return to activity following TKR, allowing for a more informed patient-physician decision when approaching a TKR.

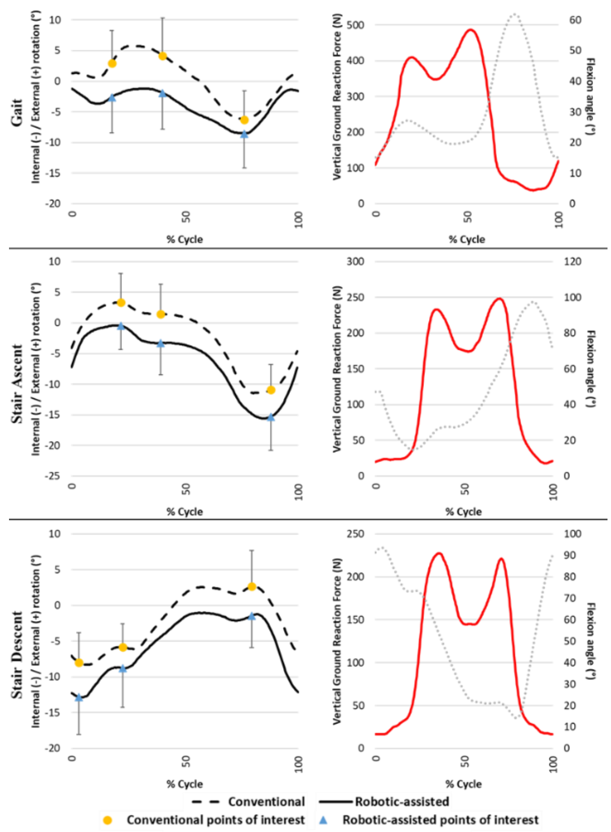

Figure 1: Internal / external rotation joint kinematics during simulated activities of daily living. Mean internal/external rotation of the conventional (dashed line) and robotic-assisted (solid line) TKR knees on the plots of the left column. The plots of the right column depict prescribed joint flexion (dotted line) and applied vertical ground reaction force (solid line) for each simulated activity.

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