

Sensor-Based Free-Living Gait Cycle Variability in Patients with End-Stage Knee Osteoarthritis Awaiting Total Knee Arthroplasty and its Relationship with Clinic-Based Gait Outcomes

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INTRODUCTION: Pioneering developments in surgical robotic systems aim to provide tailored surgical approaches based on patient-specific biomechanical needs given the heterogeneity of individuals with knee osteoarthritis (OA) to address the pain-, function-, and satisfaction-based limitations experienced by many receiving total knee arthroplasty (TKA)^{1,2}. Key perioperative biomechanical measures during gait have been found to be useful predictors for post-surgical joint function, however the measurement of these metrics has historically required expensive, laboratory-based, and expert-operated motion capture systems which can only capture patient function at a single moment in time during which their movements may not be representative of free-living gait. Wearable accelerometers offer a low-cost and minimally intrusive alternative to the measurement of human movement in real-world settings over extended periods of time, thus increasing the possibility for widespread clinical uptake of gait-based metrics in patient-specific surgical planning. While recent work has sought to derive previously identified laboratory-based metrics using sensor data alone^{3,4}, it remains unclear how, if at all, the variability in free-living gait will affect the interpretation of these findings. Further, there is potential for sensor-based data to inform novel metrics reflecting variability in free-living gait. Variability in gait has been associated with increased frailty in healthy older adults, however laboratory-based evaluations in those with OA lack consensus on how joint function and clinical outcomes are affected by variability⁵⁻⁷. Therefore, the objective of this study was to examine the relationship between variability in accelerometer-derived metrics of end-stage knee OA free-living gait with laboratory-based clinically relevant metrics.

METHODS: Patients with end-stage knee OA approved for TKA were recruited for participation in this study according to the Nova Scotia Health Research Ethics Board. All participants provided informed consent and subsequently performed a 1-minute self-paced overground walking bout while their kinematics were measured using a 10-camera optical markerless motion capture system (Theia Markerless). A tri-axial accelerometer was then attached to the pre-surgical leg on the frontal aspect of the shank (Axivity, AX6) and used to monitor free-living accelerations over the subsequent 7-day period. The optical data were low pass filtered (8Hz) and processed to calculate sagittal and frontal plane joint angles, frontal plane angular velocity, and stride time across 10 stride cycles for each participant (between subsequent heel strikes (HSs)) (Visual3D, C-Motion). Based on the raw accelerometer data from the sensor, 10 strides from a steady-state walking bout were identified from the 3rd or 4th day of collection and segmented by HS⁸ to compute stride times prior to low pass filtering (8Hz) and functional alignment of the sensor coordinate system with the axes of the shank⁹ such that frontal plane accelerations and velocities could be computed. The variability of the stride parameters computed in free-living gait was characterized by a coefficient of variation (CV) for peak and maximum difference in acceleration and velocity in early stance (0-20% of the stride cycle), as well as for the computed stride times. These free-living metrics were compared with optical in-clinic gait outcomes (mean peak and range values across all strides for the flexion and adduction angles as well as frontal plane angular velocities) through Pearson correlation coefficients. (R; 0.00-0.19 (very-weak), 0.20-0.39 (weak), 0.40-0.59 (moderate), 0.60-0.79 (strong), and 0.8-1 (very-strong)) Stride time variability was compared between measurement systems through two-sample t-tests ($\alpha=0.05$).

RESULTS: Gait characteristics from 21 participants with end stage knee OA awaiting arthroplasty surgery (7F,14M; age: 69 ± 6 years, height: 169 ± 13 cm, weight: 96 ± 20 kg) were compared. Peak knee flexion angle in stance (optical) was found to be moderately correlated with the peak early stance velocity CV ($r = -0.57, p=0.02$) and the difference in early stance velocity CV ($r = -0.50, p=0.03$), and strongly correlated with the peak early stance acceleration CV ($r = -0.62, p = 0.01$). Flexion range of motion in stance (optical) was found to be moderately correlated with the difference in early stance velocity CV ($r = -0.56, p = 0.05$). Representative in clinic optical- and free-living sensor-based data from two participants can be seen in Figure 1. Free-living stride time CV was found to be moderately correlated with both the (optical) peak frontal plane angular velocity in stance ($r = 0.47, p = 0.03$) and the (optical) frontal plane angular velocity range in stance ($r = 0.46, p = 0.03$). The optical-based and free-living stride times and stride time CVs were significantly different ($p < 0.01$) with mean stride times of 1.14 ± 0.08 s observed in the in-clinic data and 1.26 ± 0.11 s observed in free-living.

DISCUSSION: These results suggest that a single shank-mounted accelerometer may provide valuable insight into stride-to-stride variability in free-living gait which is not currently captured by traditional laboratory-based measurements. Further investigation into stride-to-stride variability in free-living is therefore required to elucidate its causes and the implications of this variability on gait metrics and other clinical outcomes both pre- and post-TKA. Variability-based metrics may prove important in understanding mobility and frailty in arthroplasty patients and advance our understanding of the individual needs and expectations of patients with end stage OA. We must additionally be aware and understanding of the differences which may accompany the sensor-based capture of traditionally laboratory-based outcomes in free-living data due to this gait cycle variability prior to applying the same interpretations to these findings as we would in clinical-based settings. It is likely that the biomechanical measures currently proposed for patient-specific surgical tailoring do not represent free-living gait variability and as such, there is likely added clinical value in defining further biomechanical metrics which could be obtained from a simple, low-cost single sensor-based system.

SIGNIFICANCE/CLINICAL RELEVANCE: Stride-to-stride variability in free-living gait is not captured by traditional laboratory-based biomechanical metrics yet may prove clinically relevant in the understanding of mobility decline in patients awaiting arthroplasty. Novel metrics capturing this variability may therefore provide valuable insight to patient-specific surgical planning.

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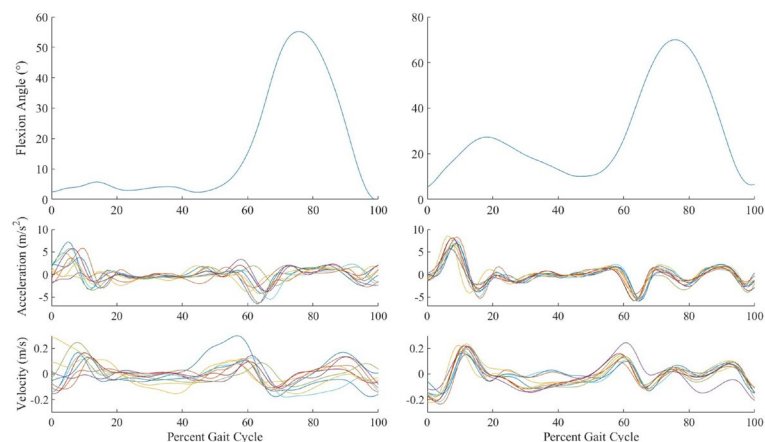


Figure 1. Representative mean knee flexion (+ve) angles (optical) from two participants demonstrating low and high peaks in stance, compared to the sensor-based frontal plane acceleration (lateral +ve) and velocity (lateral +ve) curves from each participant's 10-free-living strides.