A Comparison of Sensor-based Free-Living Knee Kinematics and In-Clinic Video-Based Measurements in Patients Awaiting Knee Arthroplasty Surgery

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INTRODUCTION: Gait metrics including the knee flexion angle, knee adduction angle, and varus thrust have traditionally been measured in laboratory-based settings to predict knee OA progression and classify OA severity [1, 2, 3]. While these measures are considered useful in quantifying disease progression, their measurement requires sophisticated, high-cost equipment and expert analysis, thereby precluding most large-scale analyses. Wearable sensors offer a viable solution to monitor free-living gait over extended periods of time. However, it is unclear whether the kinematic measures captured by inertial sensors are representative of those captured in laboratory settings. Therefore, the objective of this study was to capture daily life metrics using a single tri-axial accelerometer and examine their association with knee kinematic gait outcomes using video-based motion capture measured in the clinic environment. It was hypothesized that frontal plane knee kinematic outcomes calculated from sensor data would be correlated with the knee flexion angle, knee adduction angle, and frontal plane knee angular velocity measured with the video-based system.

METHODS: A cohort of end-stage knee OA patients were recruited from participating surgeon's total knee arthroplasty waitlists and provided informed consent to participate in this study which was approved by the Nova Scotia Health Research Ethics Board. Traditional gait outcomes were measured using a video-based, ten camera markerless motion capture system (Sony, Theia Markerless). Participants walked along the clinic hallway for a maximum of one minute and ten gait cycles (heel strike to heel strike) were processed using an 8 Hz low pass filter prior to calculating knee flexion and adduction angles, as well as knee angular velocities (Visual3D, C-Motion). Free-living gait was measured using a single AX6 logging sensor, secured and anatomically oriented on the shank of the affected side of each participant (Axivity). The raw tri-axial acceleration data for each sensor were collected over a free-living period of seven days. Acceleration data reflecting a continuous one minute walking bout occurring on one of the central days were extracted for each participant for analysis. The raw acceleration peaks in the most vertical sensor axis were examined to identify heel strikes [4]. The data were then processed using a second order Butterworth 8Hz low pass filter and the axes of the sensor were aligned to the axes of the participant's body [5]. The medial-lateral sensor accelerations were integrated and processed to compute linear shank velocities in the frontal plane [6]. Steps were segmented using the heel strike locations, and the peak-to-peak thrust acceleration (associated with the prediction of knee adduction moments) during early stance was calculated for each step [7]. The mean video-based measurements during stance phase for all participants were compared to the mean sensor-obtained measurements of peak stance acceleration and velocity, range in acceleration and velocity from initial contact to the peak during stance, and thrust acceleration, during the first eight steps in all selected walking bouts. Pearson's correlation coefficients (r) were calculated for each comparison (very weak: 0-0.19, weak: 0.20-0.39, moderate: 0.40-0.59, strong: 0.60-0.79, very strong: 0.80-1).

RESULTS: The video-based and free-living sensor gait data from twelve participants with end stage knee OA (9M/3F) with an average age and BMI of 70 years (± 4) and 30 kg/m^2 (± 4), respectively, were collected and compared (r and p-values are displayed in Table 1). A higher peak knee flexion angle during stance phase (video) was found to be moderately correlated with a higher peak frontal plane velocity during stance (sensor), a higher frontal plane velocity range from initial contact to peak stance (sensor), and a higher thrust acceleration (sensor). A higher peak knee adduction angle in stance phase (video) was moderately correlated with a lower peak frontal plane velocity during stance (sensor). A higher peak angular knee adduction velocity during stance phase (video) was moderately correlated with a lower peak frontal plane velocity during stance (sensor).

DISCUSSION: The frontal plane dynamics obtained from single sensor data during free-living gait were moderately correlated with of the video-based clinical gait outcomes. While the strength of the relationships were not strong, the sensor data represent insight into gait mechanics that can be complementary to in clinic measures and may be more helpful in understanding patient functional variability. Stemming from a variety of factors that include differing environments and changes in participant attentiveness levels, gait varies between clinical and real-world settings. The development of new and clinically relevant metrics to quantify free-living gait mechanics using simple and affordable (ie single sensor) technologies may provide for better and more widespread translational uptake of gait considerations into clinical decision-making. Frontal plane metrics derived from free-living acceleration gait data could be of particular interest, as few studies have investigated sensor frontal plane dynamics [2,5,7].

SIGNIFICANCE/CLINICAL RELEVANCE: Video-based clinical gait measures used to predict knee OA outcomes may not be reflective of a patient's free-living gait characteristics. Wearable accelerometers could be utilized to remotely collect gait characteristics more reflective of a patient's everyday life.

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Table 1 - Correlation values from comparisons of gait metrics obtained through either a video-based motion capture system in a clinc setting or a single tri-axial accelerometer during everyday life.

Video-Based Gait Metrics	Sensor-Based Gait Metrics	r	p-value
Peak Knee Flexion Angle (Stance Phase)	Peak Frontal Plane Velocity (Stance Phase)	0.50	0.09
Peak Knee Flexion Angle (Stance Phase)	Frontal Plane Velocity Range (Initial Contact to Peak during Stance)	0.55	0.06
Peak Knee Flexion Angle (Stance Phase)	Thrust Acceleration	0.54	0.07
Peak Knee Adduction Angle (Stance Phase)	Peak Frontal Plane Velocity (Stance Phase)	-0.54	0.05
Peak Knee Adduction Velocity (Stance Phase)	Peak Frontal Plane Velocity (Stance Phase)	-0.59	0.04