Repeatability of Knee Arthroplasty Gait Outcomes Using an AI Video-based In-clinic Markerless Motion Capture System

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INTRODUCTION: Total knee arthroplasty (TKA) aims to provide patients with end-stage knee osteoarthritis pain relief, increased function, and a reduction of symptoms. Past work has highlighted persistent functional deficits in patients post-TKA,[1,2] and therefore understanding how to tailor surgical decisions more effectively to account for the pre-operative patient variability is important to reduce the post-operative burden of disability. Efforts to capture objective information on patient biomechanics have traditionally been isolated to laboratory-based marker-based optoelectronic motion capture systems, which have resulted in minimal clinical uptake due to lack of location flexibility, large collection time requirements, and therefore reduced patient throughput. The installation of motion capture systems within clinical environments is necessary to create patient-specific surgical plans and treatments that account for patient variability in objective measures of dynamic joint function. Video-based markerless motion capture systems driven by AI models are a new technology that mitigate some of the time and location constraints of traditional systems and therefore offer more promise for uptake in clinical environments[3]. Before adoption of the technology, it is important to ensure the validity of calculations of outcome measures that are relevant to arthroplasty surgery with this technology deployed in a clinic environment where ideal spatial layouts for capture volume are not possible. Therefore, the aim of this study was to analyze the day-to-day repeatability of knee kinematic gait outcomes relevant to knee arthroplasty surgery of a markerless motion capture system installed in a clinical hallway.

METHODS: Healthy adults with no lower limb gait pathologies participated in three gait analysis sessions at the Halifax Infirmary hospital. Participants gave written informed consent, and this study was approved through the hospitals' IRB. A data collection session was defined as a new camera setup with system calibration and could be a maximum of 45 days apart. Patients walked through an 8-foot-wide by 20-feet-long clinical hallway for a maximum of two minutes, where a 10-camera video-based motion capture system (Sony RX0ll cameras) was installed and integrated with markerless motion capture software for limb segment pose estimation at 60 Hz (Theia Markerless). The first twelve viable gait cycles for each patient for each session were processed to define stride characteristics and three-dimensional lower extremity joint angles during walking (Visual3D, C-Motion). Eight sagittal- and frontal-plane knee joint angle gait metrics that have been shown in past literature to be important knee arthroplasty outcomes (Table 1) were defined for further analysis. For each metric we calculated the session means and standard deviations (SD), intraclass correlation coefficients ($ICC_{2,k}$), and standard errors of measurement (SEM)[4].

RESULTS: Twenty subjects (13F/7M) were included with a mean session follow-up of 11 days with an average age and BMI of 37.2 years (± 10.5) and 26.2 kg/m^2 (± 3.4), respectively (n = 19 with demographic data). Session-average knee flexion and adduction angles normalized to 100% gait cycle are plotted for all subjects (Fig 1). Most $ICC_{2,k}$ values were excellent (0.88 or greater for 7 of the 8 reported kinematic metrics) (Table 1). The lowest $ICC_{2,k}$ value was found for the knee adduction range of motion in stance ($ICC_{2,k} = 0.72$), while the highest value was found for the maximum knee flexion in stance ($ICC_{2,k} = 0.94$). SEM values ranged from 1.28 degrees (mean adduction in stance) to 1.85 degrees (flexion ROM in stance).

DISCUSSION: We investigated the test-retest reliability of clinically relevant knee angles during gait using a markerless motion capture system using a novel installation in a confined clinical environment. The resulting 5 out of 8 $ICC_{2,k}$ values being over 0.90 indicated excellent reliability of most measurements. As compared to previous studies,[5-8] we report higher ICC and smaller SEM values, indicating that our in-clinic video-based system resulted in less variance within-subjects over time and a more precise measurement capacity.

SIGNIFICANCE/CLINICAL RELEVANCE: This study is the first to capture the test-retest reliability of arthroplasty-relevant knee kinematic gait outcomes captured using an in-clinic markerless motion capture system and showed excellent reliability for the majority of the reported clinically relevant measures in healthy patients. We therefore have confidence in the adoption of markerless motion capture technology for in-clinic gait analysis for relevant outcomes for arthroplasty patients. The adoption of this time and space-efficient technology will allow for the uptake of objective gait outcomes into high volume clinical trials and translational opportunities for clinically targeting functional outcomes for patients.

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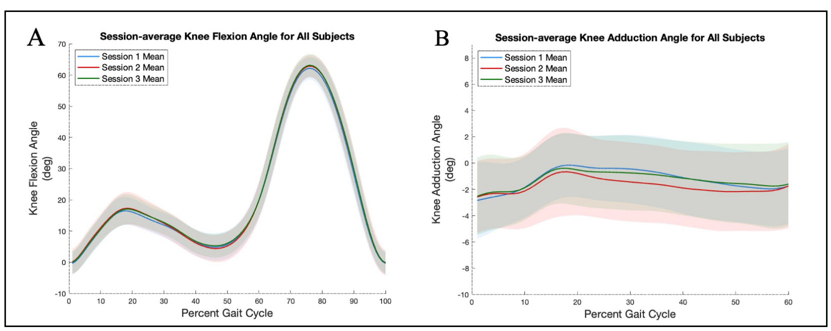

Figure 1: Ensemble average waveforms for knee flexion (+ve) and adduction (+ve) angles for n=20 healthy adults. The shaded bands represent one standard deviation of each session group from their respective mean.

Table 1: Reported kinematic (angle) knee metrics relevant to patient total knee arthroplasty kinematic outcomes. Metrics defined during following ranges: 1. Between heel strike (0%) to 45% gait, 2. Maximum-minimum (between 0% to 45% gait), 3. Between 0 to 100% gait, 4. Between 0 to 100% gait, 5. Between 0% to toe-off, 6. Between 0% to toe-off, 7. Mean from 0% to toe-off, 8. Maximum-minimum (between 0 to 20% stance for minimum). SD = standard deviation, $ICC_{2,k}$ = intraclass correlation coefficient type 2, k, SEM = standard error of measurement.

Knee Metric	Session	Mean (SD)	ICC 2,k (95% CI)	SEM (95% CI)	Knee Metric	Session	Mean (SD)	ICC 2,k (95% CI)	SEM (95% CI)
1. Maximum Flexion in Stance	1	17.3 (3.8)	0.94 (0.87, 0.97)	1.75 (1.48, 2.16)	**5. Maximum Extension in Late Stance**	1	4.2 (3.7)	0.90 (0.79, 0.96)	1.79 (1.51, 2.21)
	2	18.0 (4.8)				2	3.8 (3.8)		
	3	17.6 (4.4)				3	4.6 (3.1)		
2. Flexion ROM in Stance	1	18.1 (3.2)	0.91 (0.82, 0.96)	1.85 (1.56, 2.29)	**6. Maximum Adduction in Stance**	1	1.0 (2.3)	0.88 (0.74, 0.95)	1.46 (1.23, 1.81)
	2	18.5 (4.8)				2	0.6 (2.9)		
	3	17.9 (3.6)				3	0.9 (2.7)		
3. Maximum Flexion in Gait Cycle	1	62.6 (2.9)	0.88 (0.76, 0.95)	1.55 (1.31, 1.91)	**7. Mean Adduction in Stance**	1	-1.3 (2.2)	0.90 (0.79, 0.96)	1.28 (1.08, 1.59)
	2	63.4 (2.9)				2	-1.7 (2.8)		
	3	63.6 (3.0)				3	-1.3 (2.6)		
4. Flexion ROM in Gait Cycle	1	63.4 (3.8)	0.93 (0.86, 0.97)	1.71 (1.44, 2.12)	**8. Adduction ROM in Stance**	1	4.5 (2.0)	0.72 (0.41, 0.88)	1.30 (1.09, 1.60)
	2	63.8 (4.4)				2	4.0 (1.5)		
	3	63.8 (3.9)				3	4.1 (1.7)		