A framework for representing knee flexion and adduction angles during walking using inertial sensors in patients awaiting knee arthroplasty surgery

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Summary

This study evaluated the feasibility of using advanced processing of wearable inertial measurement unit (IMU) data to obtain knee joint sagittal and frontal plane angles during walking in patients with end-stage knee osteoarthritis (OA). Overground gait data was collected simultaneously with IMUs and an optoelectronic motion capture system from six patients. Results showed angular ranges of motion in both sagittal and frontal planes were comparable between the systems, supporting the potential for patient gait monitoring with IMUs to aid clinical decision-making.

Introduction

Knee flexion and adduction angles during walking have been shown to be relevant to understanding knee OA progression and response to knee arthroplasty surgery [1],[2]. These outcomes have been traditionally measured in laboratory-based settings, which may not fully reflect gait mechanics during everyday life. IMUs offer an opportunity to remotely monitor knee angles over extended periods in a variety of environments, providing valuable insight to clinicians for conditions such as knee OA. While both sagittal and frontal plane mechanics are relevant for OA patient decision making, there has been much more advancement in IMU processing for the sagittal plane [3],[4]. Therefore, the purpose of this study was to build an advanced IMU processing framework for representing relevant sagittal and frontal plane knee joint angle gait metrics in a clinical end-stage knee OA population, and to demonstrate the feasibility of the IMU system by comparing outcomes to those captured through an optoelectronic motion capture system.

Methods

Patients with end-stage knee OA were recruited from participating orthopaedic surgeons' knee arthroplasty waitlists and their gait was measured in Dalhousie University's Dynamics of Human Motion laboratory using two systems: a wearable sensor system that included IMUs secured to the shank and thigh of each patient's surgical side (Opal, APDM), and an optoelectronic motion capture system (Motion Analysis Inc.). Three-dimensional acceleration and angular velocity data from the sensors were aligned to the knee joint's coordinate system using a functional calibration movement, and strides were segmented from five walking bouts [4],[5]. Knee joint angles in the sagittal and frontal planes were computed following the application of a quaternion-based orientation estimation algorithm [6]. Ranges of motion (ROM) were obtained in the sagittal plane during stance phase and from late stance to swing phase, as well as in the frontal plane during stance phase and early stance (first 20 percent of the gait cycle). Optoelectronic system data from the same walking bouts were processed to calculate the same knee joint angle metrics (Visual3D, HAS-Motion). Bland-Altman analysis was conducted on corresponding metrics obtained by the sensor and optoelectronic systems to examine agreement between outputs from the two systems.

Results and Discussion

Gait data were measured from six patients (2M;4F; age = 64 years ±11; BMI = 33 kg/m^2 ±6) using the two systems (shown in Figure 1). The Bland-Altman analysis determined average differences between the two systems of 1.4° for knee flexion ROM during stance, 3.1° for knee flexion ROM from late stance to peak swing phase, 2.6° for knee adduction ROM during stance, and 1.5° for knee adduction ROM during early stance. Differences fell within the joint angle error range suggested to be reasonable for clinical interpretation [7].

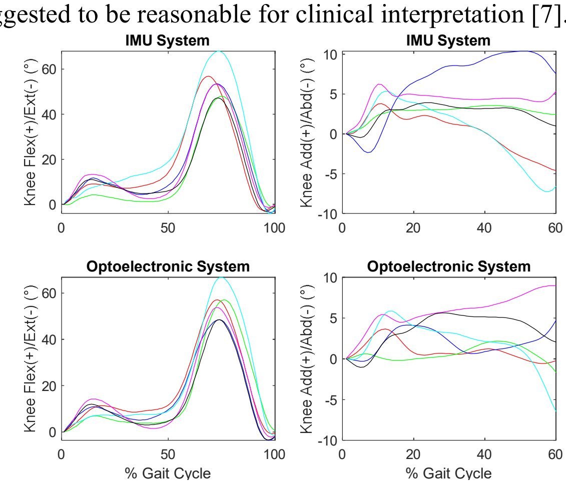

Figure 1: Mean knee flexion and adduction angle waveforms obtained by both systems for each patient.

Conclusions

This study demonstrated the feasibility for IMUs to obtain clinically relevant sagittal *and* frontal plane knee joint angles for a clinical cohort of patients with knee OA through advanced processing techniques, building on previous successful attempts at defining knee joint angles in the sagittal plane [3],[4]. These results provide support for further development of remote monitoring of clinically relevant gait outcomes for those with knee OA.

References

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