MEASURING SAGITTAL KNEE ANGLE AND MOMENT USING SENSORS EMBEDDED IN A PROSTHESIS

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Introduction

Optoelectronic motion capture systems and force plates are typically used to assess kinematics and kinetics in clinical gait analyses. However, these systems are bound to laboratory environments only [1]. For this reason, the performance of a patient in the laboratory often does not represent entirely real-life gait due to various limitations such as confined spaces and constrained but perfectly even pathways [1].

Inertial measurement units (IMUs) are wearable sensors that overcome some of the limitations of optoelectronic systems. These sensors can be used for the clinical gait analyses outside of a laboratory environment with good precision with respect to optoelectronic systems (e.g., less than 1° error in the knee angle [2]). However, IMUs are not without limitations, as for instance, the errors introduced when positioning the units to the limbs can translate into errors in the derived movements [3]. Importantly, some mechatronic lower limb prostheses are already equipped with embedded sensors (for control purposes), which are an attractive and easy solution for clinical gait analyses as they do not require external positioning. These sensors can measure orientation, acceleration, angular velocity, joint angles and loads when using a prosthetic device [4]. However, the validity and accuracy of these sensor data with respect to clinical gait analyses originating from laboratory measurements are still unknown. Therefore, there is a need to investigate how movement kinematics and kinetics obtained from the embedded sensors compares to that measured using laboratory-based clinical gait analyses.

Methods

Kinematic and kinetic data were collected from two patients with unilateral transfemoral amputation (mean ± standard deviation, age: 53.5 ± 3.5 years, height: 173.5 ± 6.4 cm, weight: 82.3 ± 3.9 kg, time since amputation: 42.5 ± 2.1 years, knee joint: GeniumX3) using an optical motion capture system and ground embedded force plates, as well as the sensors integrated in the microprocessor-controlled knee joint (GeniumX3, Ottobock, Germany). The embedded sensors provided hydraulic loading of the knee, knee joint angle, and orientation of the prosthesis in the sagittal plane (shank angle). The data were collected during level walking at three self-selected speeds (normal, slow, and fast), ramp ambulation (at 10° and 15° incline/decline), and stair ambulation. Five trials were collected for each task.

The variables of interest in this study were the sagittal knee angle (measured directly) and moment (estimated external moment). The outcome measures for the comparison between the optical motion capture system (gold standard, GS) and the device sensors (DS) were Pearson correlation coefficients, root mean square errors (RMSE), and maximum relative errors. The relative error was computed as the error over time divided by the range of GS values of the same trial.

Results and Discussion

The knee angle and moment measured in both subjects during level walking at normal speed is shown in Figure 1 (average, n=5 trials). In general, both were strongly correlated (ρ>0.9). Therefore, the overall trend and shape of the knee angle and moment obtained by GS is very well replicated by DS.

The knee angle RMSE and relative error were between 2.1-3.1° and 2.2-3.2%, respectively, and hence the deviations between DS and GS signals were rather small. Larger deviations were seen in the moments (6.4-7.0 Nm and 10.8-14.1%). Figure 1 further shows that both DS and GS could capture interindividual differences in the gait patterns.

Overall, these results demonstrate that the kinematics and kinetics measured using DS are close to that obtained using GS in shape as well as in amplitude. Further analysis including more participants, other tasks and measures are needed in order to generalize these results and establish that the embedded sensors are indeed a useful tool for clinical gait analyses.

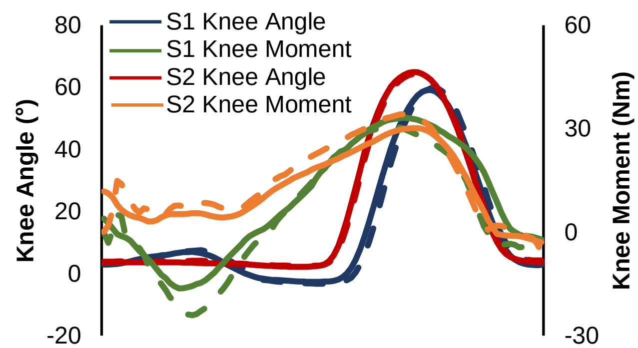

Figure 1: Knee angle and moment of subject one (S1) and two (S2), for gold standard (GS, dashed lines) and device sensor (DS, solid lines) data, respectively. The lines each represent the average of five trials. The data is normalized to one gait cycle (angle) and one stance phase (moment), respectively.

Significance

These results are relevant for the field of lower limb prosthetics in order to facilitate the development of more appropriate gait assessment tools which can be used for the assessment in real world and outside of a gait laboratory. The preliminary analysis indicated that the embedded sensors can be used to determine the knee angle and moment of the prosthetic leg during walking, while future work will evaluate if this also holds true for other measures and more participants.

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