Optimization of prosthetic alignments with a mobile gait analysis system

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Introduction

The prosthesis alignment is of central importance for a harmonic gait of patients to avoid asymmetrical stress of the musculoskeletal system. Especially for transfemoral amputees the reduced sensorimotor functions on the affected side make high demands on the prosthetic alignment. Today alignment optimization is based on static measuring and the expertise of the prosthetic practitioners. To support the alignment process and to objectify its outcome, a wireless gait analysis system was developed at the TU Berlin. The analysis software adds dynamic gait parameters into the optimization process and gives a first recommendation for changes in the prosthesis alignment.

Methods

The mobile gait analysis system for amputees has been designed by combining inertial sensor based motion tracking with the Oktapod system for measuring forces and moments in a lower limb prosthesis. The eight wireless inertial sensors were placed at both feet, shanks, thighs as well as sacrum and sternum. For validation purposes all measurements were performed in a motion analysis lab with a 12m instrumented walkway. There the kinematic parameters were recorded using an optoelectronic camera system (Vicon® MX). The kinetic parameters were determined by means of two force plates (AMTI®) embedded in the floor. Level walking on even ground was performed to determine the biomechanical characteristics of common alignment changes. A comprehensive study with seven subjects was conducted, determining the actual alignment, the alignment recommended by the manufacturer and anterior and posterior displacement of the knee. With the stationary gait analysis system, one gait cycle (stride) per trial was recorded. By the mobile gait analysis system, the gait data were continuously recorded. The step recognition was fully automatic. To eliminate deceleration and acceleration processes from the measurements, a software-based step filter was used. The inertial sensors on both feet enabled automatic detection of the gait phases.

Results

Measured kinetic and kinematic data of the mobile system showed a high validity compared to the conventional gait analysis [1, 2]. The collected data with different prosthesis alignments had a high inter-subject variability. Also significant differences depending on the physical and mental state on the day of testing could be found. Measurements of the same alignment on different days often showed stronger distinctions than those of the alignment variations. Hence a first measurement is necessary, acting as a reference for alignment changes.
Nevertheless gait parameters that are consistent over all subjects could be identified for the anterior-posterior knee axis position. The knee axis position correlates with the maximum of the sagittal moment measured at swing phase initiation. Transfemoral amputees have to use the hip flexors in this phase to flex the residual limb and the artificial knee joint. The measured external hip moments can be used as an indicator for the activity of the residual limb musculature and high values are named as the likely cause of an increase in metabolic energy consumption. During mid-stance anterior knee axis shifting induces flexion moments at the knee joint. With further anterior shifting those effects were not measureable. Compensatory movements by the subjects that induce extension moments to attempt a highly individual level of security could be the reason. Those effects occur irrespective of an actual stance phase flexion. Once again an increase in metabolic energy consumption could be the consequence.

Conclusion

In addition to the high validity compared to the conventional gait laboratory, the mobile gait analysis system benefits from continuous data recording resulting in higher numbers of analysable steps, the absence of aiming effects occurring with visible force plates and the possibility of field measurements. Nevertheless the time for system setup and reference measurements avoids common use during daily patient-care. Further development of the system is needed to increase the usability. By means of the findings from the studies, a first alignment recommendation for the knee in the sagittal plane could be given by the software. Further Research is needed to cover a wide range of alignment variations.

[1] S. Oehler, M. Pusch, B. Westebbe, J. Thiele, A. Dobat, M. Kraft: Mobility Measurements of above Knee Amputees - Results of a 12 Months Field Study, ISPO Leipzig, 2010.
[2] T. Seel, T. Schauer, and J. Raisch, “Joint axis and position estimation from inertial measurement data by exploiting kinematic constraints,” in IEEE Conference on Systems and Control, pp. 45–49, 2012.