Development and Validation of a Musculoskeletal Human Model to Study Crutch-Assisted Gait

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Summary

The main purpose of this work is to present and discuss the development and validation of an advanced musculoskeletal human model to study crutch-assisted gait. For that, a 3D multibody approach is utilized, which incorporates the kinematic chain of the human body, the muscle structure, as well as the key features of crutches. The connection between the crutches and the human model is modeled by imposing kinematic constraints to the pair handle-hand. Moreover, the interaction between the crutches and ground is modeled using a penalty contact formulation. The skeletal muscle model for the lower limbs is based on the well-established Hill solution. In addition, an experimental analysis, performed at the Lisbon Laboratory of Biomechanics, is carried out with all the above-mentioned human model characteristics. From the key results obtained, it can be concluded that crutches' solutions are able to support different levels of load during assisted gaits.

Introduction

The computational modeling and experimental analysis of an advanced multibody musculoskeletal solution to investigate the human movement with device-assisted gait is presented and discussed in this work. This study focuses on four central aspects, namely the development of a 3D multibody model, the incorporation of musculoskeletal structure, the inclusion of crutches and the implementation of experimental approach. All these ingredients are included in a single solution that allows for the examination of device-assisted gaits.

It has been recognized that the device-assisted gait plays a crucial role in the wide scientific and technological domains of biomechanics with crutch-assisted motion [1]. In fact, the investigation of this special kind of gait requires new insights, which eventually lead to the formulation of novel design guidelines to achieve better locomotion patterns in terms of efficiency, reliability and end-user comfort. Bearing this set of aspects in mind, the present work deals with an integrated and global approach that includes several partners, namely scholars, a medical center for rehabilitation, and a company that designs, develops and commercializes medical devices.

Methods

Figure 1a displays an overview of the musculoskeletal human model considered in this study. By and large, this approach includes a total of 18 rigid bodies that represent the key human anatomic segments, which are linked by 17 kinematic joints [1]. The two crutches are added to the model via kinematic pairs, resulting in a system with 20 rigid bodies and 19 joints (Figure 1b). The crutch-ground interaction is formulated using contact penalty approach [2].

One adult female volunteer (29 years old, 162 cm, 53.34 kg) is considered. Unassisted and four-point crutch-assisted gaits are acquired experimentally. The marker set protocol applied to the volunteer follows the suggestions of the International Society of Biomechanics. Also, 12 passive reflective markers are placed in the crutches (Figure 1c). The acquired experimental data is introduced in the biomechanical models.

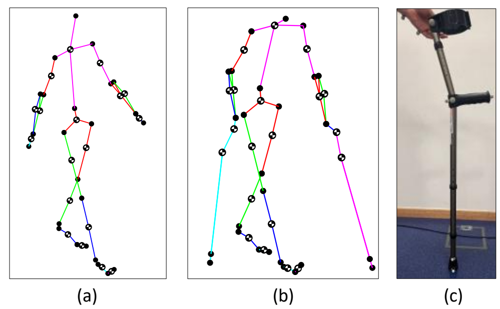

Figure 1: (a)-(b) Model without and with crutch; (c) Crutch.

Results and Discussion

From the main results obtained with the proposed approaches, it can be observed that, during crutch-assisted gait, the toe off occurs later in the gait cycle (78%) when compared to unassisted gait (61%). These differences are inherent to the particularities of the gait patterns. The ground reaction forces during crutch-assisted gait are half those observed during unassisted gait. For crutch-assisted gait, the glenohumeral joint is mainly in a flexed configuration, which magnitude is higher than that observed for the unassisted gait.

Conclusions

The development of an advanced multibody musculoskeletal model that includes crutches was successfully implemented to study device-assisted gait. The outcomes obtained in this investigation are quite promising in terms of practical application and development of new design guidelines of crutch-assisted clinicals and industrial solutions.

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