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ON THE MODELING OF CRUTCH ASSISTED LOCOMOTION: EXAMINING THE INTERFACES WITH THE GROUND AND WITH THE HUMAN BODY

Maria Francisca Sousa[1,2], Mariana Rodrigues da Silva[1,2], Filipe Marques[1,2], Miguel Tavares da Silva[3], Paulo Flores[1,2]

[1] CMEMS-UMinho, Departamento de Engenharia Mecânica, Universidade do Minho, Campus de Azurém, Guimarães 4804-533, Portugal, {a92011@alunos.uminho.pt; m.silva@dem.uminho.pt; fmarques@dem.uminho.pt; pflores@dem.uminho.pt}

[2] LABBELS – Associate Laboratory, Braga/Guimarães, Portugal

[3] IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1, Lisboa 1049-001, Portugal, {miguelsilva@tecnico.ulisboa.pt}

1. INTRODUCTION

Over the years, assistive devices for locomotion, such as crutches, have been developed to provide support to patients suffering from mobility and/or independence impairments [1]. According to the World Health Organization, more than a billion people worldwide depend on one or more assistive devices, and this number is estimated to double by 2050 [2]. Patients suffering from disabilities, such as spinal cord injury, rely on crutches to preserve their base of support and balance, as well as to partially or fully unload the lower limbs by transferring their body weight to the upper limbs. Crutch use can either be temporary or permanent, and allow for a variety of gait patterns, namely swing-to, swing-through and reciprocal gait patterns.

The study of crutch-assisted locomotion using multibody techniques has been rising, and the resulting knowledge may help researchers explain biomechanical demands placed on the upper limbs and establish new design guidelines for crutch prototypes. One of the most critical aspects when studying crutch-assisted locomotion deals with the interfaces existing between the crutch and the surrounding environment. The modeling process of these interfaces is complex since it is strongly dependent on multiple factors, which significantly influence the behavior of the biomechanical model.

The present study extends the authors' previous work on biomechanical modeling of device-assisted locomotion [1] to focus on the modeling process of crutches. The aim is to understand how the interfaces between the crutch and the surrounding environment are approached, namely the interface between the crutch and the biomechanical model, and the interface between the crutch and the ground.

2. METHODS

An electronic database search was carried out on PubMed, Web of Science and Scopus in November 2023, with no restrictions on the year of publication. Studies using biomechanical multibody models to study crutch-assisted locomotion were identified. The search strategy was established with AND/OR Boolean operators and was introduced in the electronic databases as

Set 1: skeletal OR musculoskeletal OR musculo-skeletal OR neuromusculoskeletal OR biomechanic* OR multibody

Set 2: model* OR system

Set 3: crutch*

Search strategy: SET 1 AND SET 2 AND SET 3

After database search, all the articles extracted from the databases were exported to an Excel file (Microsoft® Office), and the duplicates were removed by software filter. All the titles, abstracts and keywords of the articles obtained from the initial database search were analyzed and subjected to a screening process. The studies found to be relevant to the present work were retrieved and their full-text was subjected to several eligibility criteria. The studies were excluded if: (i) did not use biomechanical, skeletal, musculoskeletal or neuromusculoskeletal models; (ii) did not consider crutches; (iii) were conference proceedings; (iv) were a reviews or meta-analyses; (v) were not written in the English language.

The primary database search provided 65, 315 and 85 results from the PubMed, Scopus, and Web of Science electronic databases, respectively, yielding a total of 465 studies. After the duplicate removal process, 335 articles were screened, and 124 full-texts were retrieved to be investigated. A total of 23 articles retrieved from database search, dated from 1985 to 2023, met the eligibility criteria and were included in the present work. After examination of the references lists of the 23 studies, an additional study was identified. The full-text of the 24 included articles was analyzed and information on crutch-assisted locomotion was extracted When the original paper provided partial information only, its references and the authors' previous publications were analyzed.

3. RESULTS AND CRITICAL ASSESSMENT

Figure 1 shows the time evolution of the 24 studies that analyze crutch-assisted locomotion. From the observation of Figure 1, it can be concluded that the interest in studying crutch-assisted locomotion with biomechanical multibody models has been rising, with the periods of [2010-2014] and [2020-2023] being the ones with the highest number of published articles. It is also important to note that this rising tendency is clearly evident from the fact that approximately 70% of the studies on crutch-assisted locomotion modeling were published after 2010.

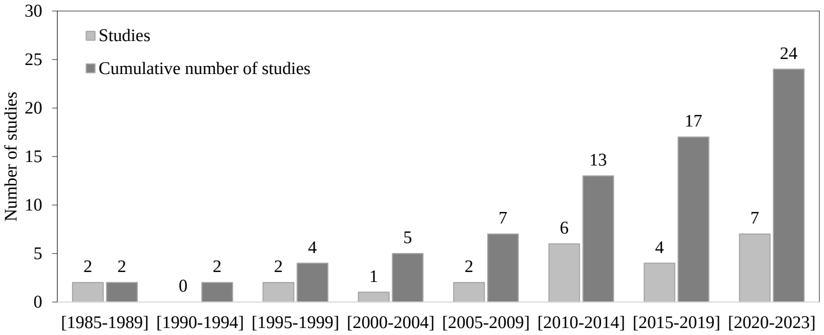

Figure 1. Evolution of the number of studies on crutch-assisted locomotion modeling over the years.

A variety of strategies for modeling the crutch-model interface was found, as observed in Figure 2a. Some studies quantified the forces and moments at the cuff and/or handle with the use of crutches instrumented with sensors, while others considered the crutch rigidly connected to forearms or hands. Other strategies utilized virtual muscles or considered the application of forces and/or moments to the utilized biomechanical model. Somes studies determined the crutch-model interface by means of the biomechanical model. In some cases, multiple strategies were applied by the same study.

Five different strategies for modeling the crutch-ground interface were found, as seen in Figure 2b. The majority of the studies utilized crutches instrumented with force sensors to measure the forces and moments on the crutch tip or below the crutch handle, while others recorded the reaction forces of the crutch with the ground with force plates or considered a revolute joint between the crutch tip and the ground. One study applied a constraint force holding the tip of the crutch and the shoulder joint at a constant distance, and, thus the crutch-ground reaction force had equal magnitude and opposite direction as the constraint force. More recently, other studies considered contact models to model the crutch-ground interface. It is important to note that, in some cases, the same study applied more than one strategy to determine the interface between the crutch and the ground.

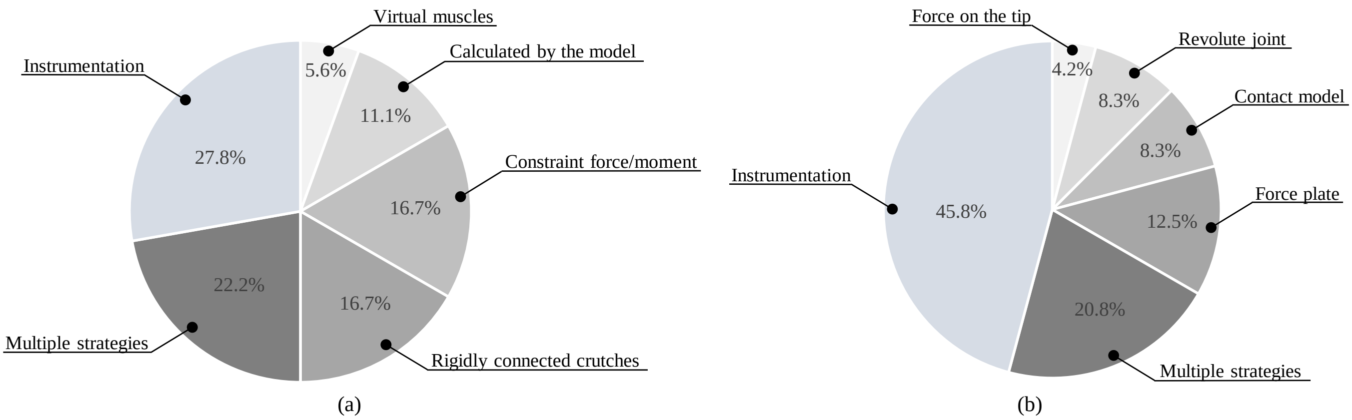

Figure 2. Distribution of the approaches for (a) crutch-model and (b) crutch-ground interfaces considered in the studies included in this work.

4. CONCLUSIONS

A diversity of strategies for modeling the interface between the crutch and the ground, and the interface between the crutch and the model were found. Despite significant advances, there are still difficulties in ensuring an accurate representation of these interfaces. Thus, further efforts are needed to solve persistent problems and improve the quality of life of crutch users.

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