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DEVELOPMENT OF A GRAVITATIONAL COMPENSATION EXOSKELETON FOR THE UPPER LIMB

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1 INTRODUCTION

One of the most essential skills in the activities of daily living (ADLs) is the manipulation of objects, a task that is primarily conducted by upper limbs [1]. This crucial function can be severely impacted when patients suffer from musculoskeletal or neuromuscular conditions, ultimately leading to reduced mobility and loss of quality of life. A potential solution to improve upper limb mobility is the use of exoskeletons with gravity-compensation mechanisms [2]. By neutralizing the effects of gravitational forces, such devices assist users in tasks involving gripping or carrying additional weights. Different types of gravitational compensation mechanisms are available, including passive and active solutions. While active systems offer a broader range of applications due to their adaptability to different conditions and loads, they tend to be bulky, heavy, and expensive. In contrast, passive or quasi-passive solutions provide a more compact, cost-effective alternative, which when correctly tunned can provide the required assistance to help users performing different ADLs, ultimately contributing to improve their quality of life [3].

Hence, this work aims to develop a passive gravity compensation exoskeleton for the upper limb that restores movement by balancing the limb's weight both dynamically and statically, while being practical and easy for patients to use in daily life.

2 METHODS

For the development of the exoskeleton, a structured design procedure specifically tailored for medical devices was applied [4]. The first phase of this process involved the clarification of the project, focusing on evaluating existing solutions and defining the initial exoskeleton concept. To achieve this, a comprehensive literature review was conducted to identify current compensation mechanisms, analysing the type of actuation (passive, quasi-passive, and active) and the systems to which they are applied (body-integrated devices or external systems). The major findings of this analysis were integrated into the concept design process allowing for the selection of the most suitable concepts for each of the upper limb joints.

The second phase centred on the computational design and analysis of the solution. This phase included 3D scanning to capture the user limb's geometry and CAD modelling to develop and computationally assess the solution. It should be noted that a modular approach was adopted, where each part is individually designed to facilitate the easy adaptation of the exoskeleton to different users and actuation needs. Finally, the third phase involved the production of the solution using additive manufacturing technology, followed by testing on a healthy volunteer to assess its functionality and usability. This step allowed for iterative improvements to the concept, enabling the evaluation of different actuation mechanisms' performance.

3 Results and discussion

From the literature review, the most compact solution identified was the WILMER Elbow Orthosis [5]. Despite its discrete design, this device is specific for the elbow and compensates for gravity only on two specific positions. In terms of range of motion, the best-performing solutions were typically larger devices connected to external supports (e.g., wheelchairs). Examples of these solutions include the LIGHTarm and WREX [3]. This analysis showed that while many existing solutions effectively compensate for gravity and arm weight, they either present limitations in the range-of-motion of the joint or are too bulky to be practical for daily use. Therefore, these devices fail to meet the goal of this project, which is to provide a compact and practical solution that can be comfortably integrated into everyday life.

Given these limitations, this project focuses firstly on developing an initial prototype centred around the elbow joint. To validate the concept, the prototype was tested on a subject without upper limb limitations for the gravity compensation of the forearm and exoskeleton combined weight. Additionally, and if present, the system should also be able to compensate for the weight of a handheld object used in ADLs. The proposed design consists of two structural components that attach to the upper arm and forearm, connected by two parallel rods, incorporating a linear spring. The global functioning system is a based on a compensation mechanism similar to the concept presented in [6] (see Fig. 1). It is important to note that the exoskeleton was designed to be produced using additive manufacturing technologies and commercially available elastic bands.

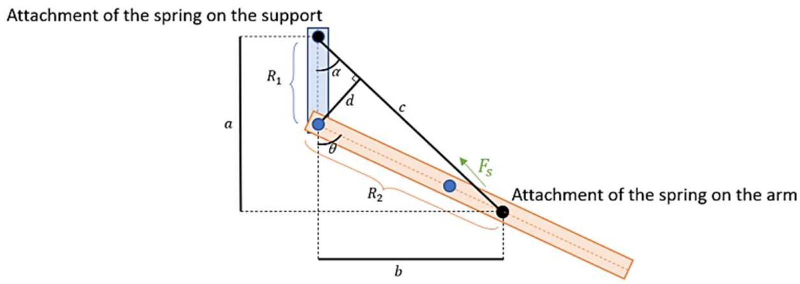

Figure 1 - 3D modelling of the prototype in *Solidworks*.

4 Conclusions

The purpose of this study was to design and develop an articulated orthosis with a passive gravity compensation mechanism, aimed at helping to restore the elbow function, thus enabling patients with muscle strength deficits to regain their natural movements. Future work will focus on validating the first prototype, refining it until reaching dynamic balancing, and incorporating additional joints to accomplish full gravitational compensation of the upper limb.

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