

Abstract

Ankle-foot orthoses are designed to improve or restore movement and mobility in the ankle for people who have experienced neurological or physical loss of function. This review examines the key developments of ankle exoskeletons and the different ways it improved throughout recent years. It focuses on both active and passive exoskeletons and their mechanical advancements. Our review also examines how these devices can improve walking abilities and reduce the metabolic cost. In addition, there are still several challenges that remain in the construction and adaptation of ankle exoskeletons, including the weight of devices, their limited range of motion, comfort, alignment, and the need for designs to better adjust for individual users. Overall, the development of AFOs and ankle exoskeletons has increased their ability to support rehabilitation and mobility. However, continued research is still needed to address their current limitations.

Introduction

An ankle-foot exoskeleton is a wearable mechanical device designed to improve and assist with the user’s lower limb functions. Despite significant advancements, current limitations include the replication of natural ankle joint movement and a lack of reviews comparing active and passive designs of ankle exoskeletons. Therefore, this manuscript aims to depict the key developments in both active and passive ankle-foot orthoses (AFOs), construction and adaptation challenges, and discuss mobility benefits for patients. Through extensive research, this manuscript explores the benefits of passive exoskeletons, particularly their lightweight and energy-neutral nature and its ability to reduce the metabolic cost of human walking, and active (powered) ankle exoskeletons, which include mimicking limb functions and lowering muscle activity.

Methods

Our manuscript was written using Google Scholar, PubMed, Reaxys, ScienceDirect, and WEB of Knowledge. Because the studies included in this review were published between 2012 and 2024, we focused on referencing earlier publications that provided information related to ankle-exoskeleton design, control, biomechanics, or rehabilitation. We incorporated publications focused on lower-limb exoskeletons, ankle-foot orthoses, and prosthetic systems. Our most commonly used search terms include “ankle exoskeleton,” “ankle-foot exoskeleton,” “lower-limb exoskeleton,” “ankle rehabilitation,” “powered ankle exoskeleton,” “passive ankle exoskeleton,” and “exoskeleton gait assistance”.

Results

The reviewed studies have found that ankle exoskeletons can improve walking efficiency and reduce energy demands during gait. One study we found reported approximately a 7% reduction in metabolic cost with a passive exoskeleton at moderate walking speeds (40). Another ankle exoskeleton was designed to provide at least 30 Nm of assistive plantarflexion torque while minimizing added distal mass (17). Overall, the reviewed research showed improvements in gait assistance and energy efficiency, while weight, alignment, comfort, and customization remained common limitations.

Discussion

Our review supports that ankle-foot exoskeletons can improve gait efficiency, mobility, and rehabilitation results. The findings also indicate that personalized control, lightweight designs, and adaptive assistance are important for effective human-exoskeleton interactions. However, limitations such as device weight, alignment, battery life, and patient differences remain, currently leading to better adaptation for different users and real-world environments. Overall, the review supports the role of advancing technology in making ankle exoskeletons more effective and adaptable, while highlighting the need for better real-world and personalized research.

Conclusion

Ankle-foot exoskeletons have improved significantly in recent years by using advanced materials, robotics, and sensor systems. Ankle exoskeletons have evolved to not only act as support but also as a system that can aid human mobility. One of the main advantages of current ankle exoskeletons is gait phase assistance, energy efficiency, and enhanced balance. Recent advances in technologies allowed ankle exoskeletons to aid in more personalized and responsive support for a wide range of motion and circumstances. There are still key problems that remain in ankle exoskeletons, including excessive weight, limited joint freedoms, and the need for complex customization, which requires specific functions. In addition, an insufficient standardized protocol requires specific functions.

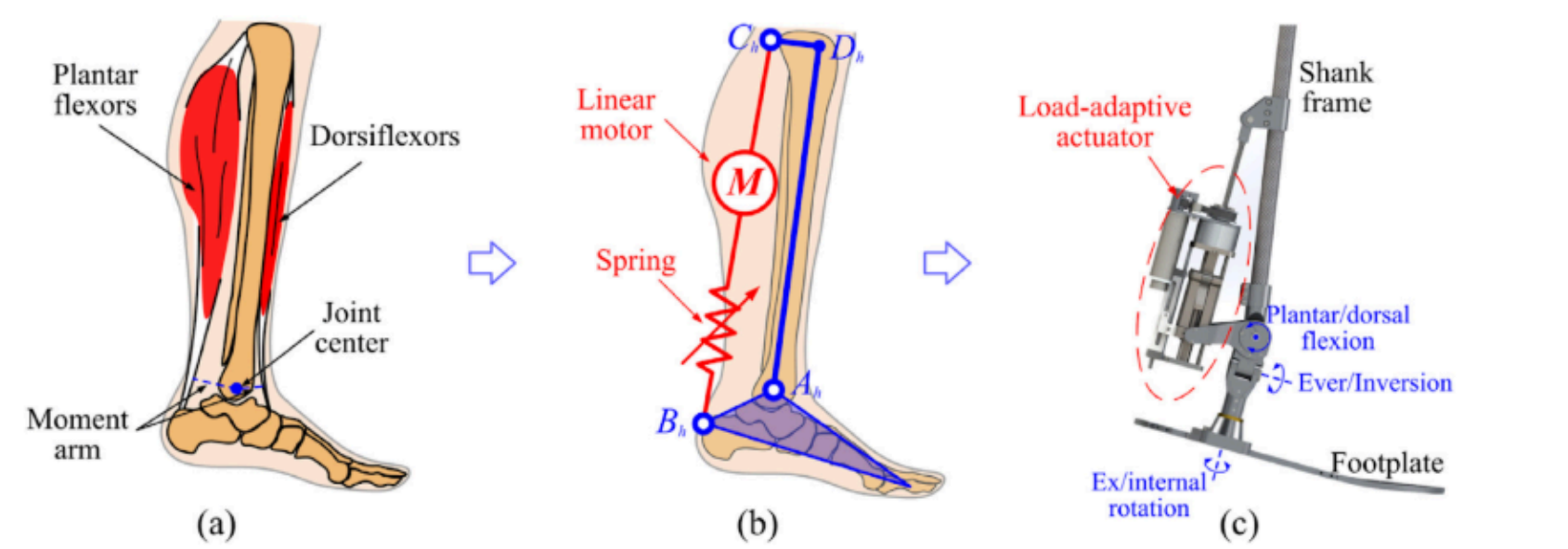


Figure 1. Experimental setup and design.

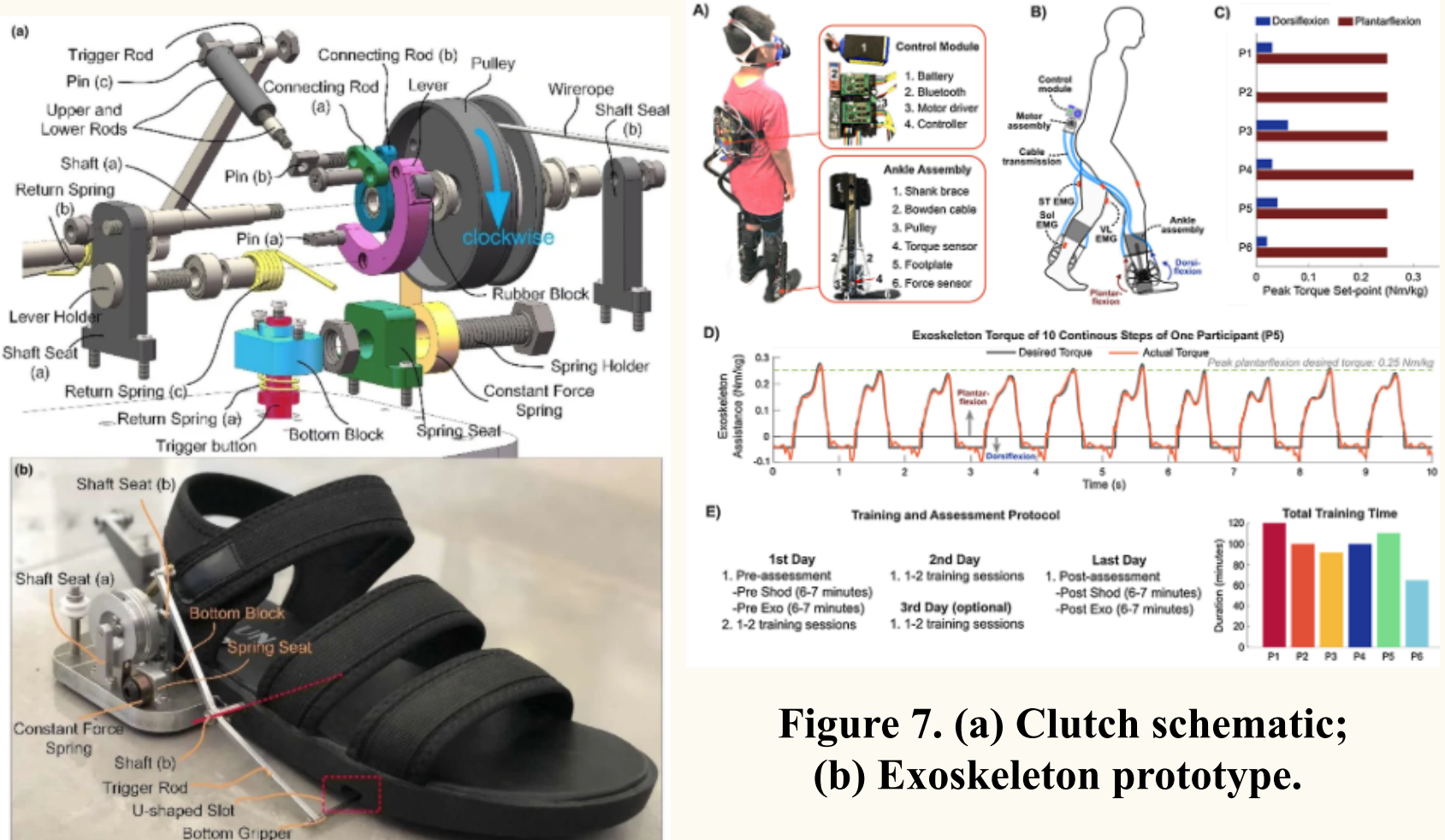


Figure 2. Conceptual design of the ankle exoskeleton.

Figure 6. Proportional myoelectric propulsion (PMP) control diagram for plantarflexion assistance.

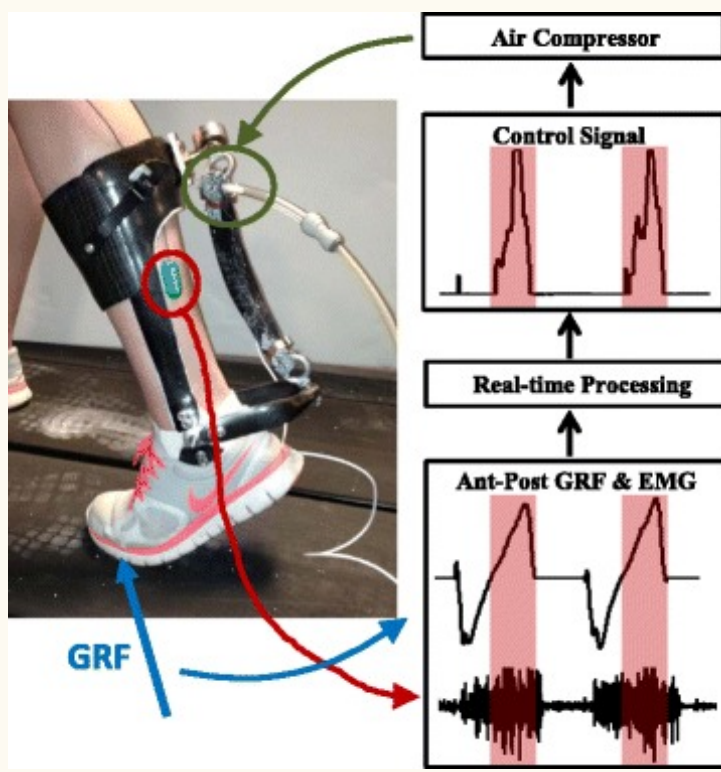


Figure 7. (a) Clutch schematic; (b) Exoskeleton prototype.

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