BIONIC MUSCLE-INSPIRED DESIGN OF CABLE-DRIVEN LOWER LIMB REHABILITATION EXOSKELETON (C-LREX)

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Introduction

Cable-driven are preferred over traditional link-driven exoskeletons due to lighter weight, remote actuator provisions, and negligible inertial vibration. Nevertheless, the cable can be routed in multiple ways to mimic lower limb trajectory and remains an open challenge. In this study, for the first time, we employ bionic muscle-inspired cable routing to design Cable-driven Lower limb Rehabilitation Exoskeleton (C-LREX). Two cases were explored with and without intermediate hinges between the origin and insertion hinges. The performance of the model in terms of gait trajectory tracking, cable tension requirements, and induced joint forces was studied and quantified.

Methodology

The bi-planer lower limb model has three degrees of freedom (DOF); two at the hip (adduction/abduction and flexion/extension), and one at the knee joint (flexion/extension) [1]. 3D bionic muscle-inspired cable routing configurations are shown in Fig. 1.

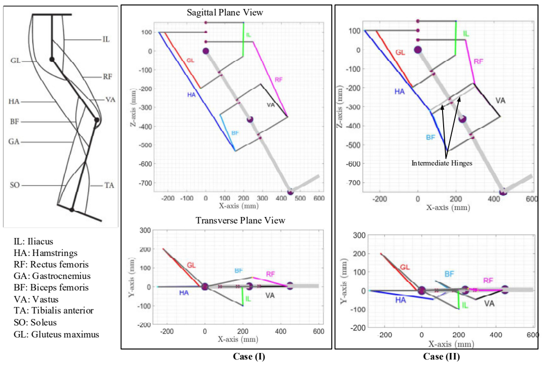

Figure 1. Bionic muscle-inspired design of C-LREX: Major muscle group contributing during gait [2] (left). Sagittal and transverse planes view of bio-inspired cable routing configurations using long cables (I) and with intermediate hinges (II).

Case I employed two long cables joining the hip and the shank to simulate the Hamstrings (HA) and Rectus Femoris (RF), while in Case II, two intermediate hinges were added between the origin and the insertion hinges of the long cables to guide them closer to the limb without constraining their free movement. Bi-planar routing was used for the GL cable to mimic the GL muscle group which is primarily responsible for adduction motion. Similar bi-planar routing was used for the IL cable to avoid interference with the RF cable. Furthermore, other cables are modified accordingly to avoid interferences in each case as shown in the transverse plane view in Fig. 1. The foot muscle group was ignored as the foot was kept fixed perpendicularly to the shank. The model, with both routing configurations, was simulated for one gait cycle and the predicted trajectory was compared to data from the literature [3]. The allowed cable tension ranged between 7 and 100 N to ensure that the cables were always taut, and the maximum tension remained within the specified range.

Result and Discussion

The bio-inspired cable routings (with and without intermediate hinges) successfully tracked the desired bi-planar reference trajectory. Case II required a smaller peak cable tension (Fig. 2) and induced smaller joint force components (Fig. 3). These are the additional forces produced by the C-LREX on the user's joints and should be minimized. The intermediate hinges provide restrictive support and guide the cable along a path that is closer to the lower limb, which makes the exoskeleton more compact and reduces the risk of cable instability and entanglement. Comparison with other configurations of cable routings in C-LREX will be done in a future study.

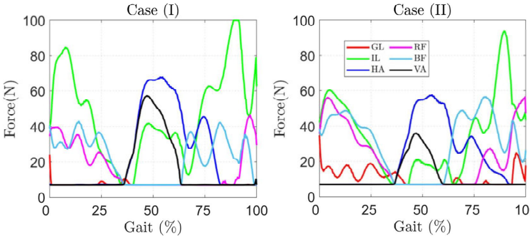

Figure 2. Cable tension requirements

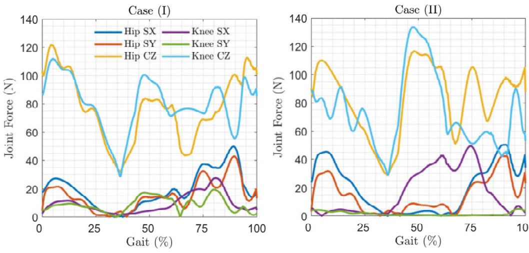

Figure 3. Cable - induced joint force components [CZ: compressive force. SX and SY: anterior-posterior and medio-lateral shear forces respectively].

References

1. Prasad et al., J. Sensors; [Accepted] (2023).
2. Kim et al., J. Sensors; 1–14;6747921(2017).
3. Fukuchi et al., *PeerJ*, 6: e4640 (2018).