A Supine Gait Training Device for Stroke Rehabilitation

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1 Introduction

Stroke is the leading cause of chronic physical disability in the developed world and can severely degrade walking function, leading to enormous negative ramifications on patients’ participation in social, occupational, and recreational activities.

During the acute and subacute stages of stroke, rehabilitation starts with manual manipulation of the limbs [1] as patients are still weak from the onset of stroke and are unable to utilize existing rehabilitation devices as they may not be able to endure certain constrained positions without vastly affecting their vitals [2]. Initial attempts at rehabilitation also require close supervision and heavy assistance from the physiotherapists. As a result, many acute stroke patients often lie in bed idly and do not receive the early rehabilitation they need, even though it has been proven through concepts of neuroplasticity that one should start rehabilitation as early as the acute phase [3] for optimal remodeling of the central nervous system (CNS) and hence, recovery.

Evidently, there is a need to address the lack of rehabilitation during the acute to subacute period. Thus, we have developed the Supine Gait Training Device to enable patients to perform early and task-oriented training right after onset of trauma. Specific aims of the device include: (1) to allow even acute stage patients to undergo rehabilitation at the bed, (2) to reduce effort required of physiotherapists while not compromising patient safety, and (3) to leverage on the brain’s adaptive plasticity to promote motor skills learning and neural function recovery in patients.

2 Method of Approach and Design

Instead of embarking on the specific design of the device immediately, a more broad-minded approach was adopted. There were two phases during brainstorming of the design—to observe and systematically examine all direct and indirect interactions of the stakeholders (patients, healthcare team, and engineers) involved, followed by the development of the device. Consultation with doctors and therapists together with hospital visits helped to highlight the various needs (both met and unmet) of the different stakeholders such that the device can be most suitably designed.

Clinical feedback was obtained throughout the design and testing phases.

2.1 Overall System. The Supine Gait Training Device (Fig. 1) consists of several components—the mechanical system which provides the underlying structure, actuators which move the structure, surface electromyography (EMG) sensors which provide biofeedback, and the real-time operating system (RTOS) controller which coordinates all the components.

2.2 Mechanical Design. The mechanical system (Fig. 2) consists of two parts: (1) metal linkages which form the thigh and calf linkages and (2) an ankle orthosis. It is designed to move the leg in the sagittal plane as walking is generally described as a sagittal plane movement. Thus, the thigh and the calf linkages run parallel to the patient’s thigh and calf to actuate hip and knee flexion and extension, while the ankle orthosis which encompasses both tibio-talar (TBT) and metatarsophalangeal (MTP) joints allow plantar flexion and dorsiflexion movements. This means that there is one degree of freedom each for the hip, knee, TBT and MTP joint, and each degree of freedom is actuated by a linear actuator.

2.3 Adjustability and Compliance. The main design features of the device are its adjustability and compliance. Adjustability is important not only for safety and comfort but also for effectiveness as the axes of rotation of the biological and mechanical joints should be aligned. Thus, the linkages and ankle orthosis are designed such that they can be adjusted to accommodate dimensional differences in patients. Compliance is introduced via the use of series elastic actuators (SEA) [4], to ensure that the device does not stiffly guide the movement of the foot and force the patient into a motion that the joints are unable to comply with.

2.4 Control. Control of the device was based and built largely on the fundamental scientific concept of stimulating neuroplasticity to enable faster and more effective recovery [5].

This was done on two fronts. First, the device was programmed to simulate a gaitlike pattern to direct and target the CNS reorganization for locomotion. Second, biofeedback was incorporated via a user interface (Fig. 3) where patients can see their EMG activity. Thus, with these in mind, as well as to provide more flexibility and cater to different strength conditions of patients, two control modes were then designed: the “Auto” and “EMG Trigger” modes. For weaker patients, the Auto mode guides them through the exercise without requiring physical input from them. Their minds, however, are still engaged by being able to see their EMG activity on the user interface. For stronger patients, the EMG Trigger mode only activates robotic movement when the device senses
that the patient is actively participating and putting in effort by exerting their muscle enough for their EMG activity to exceed a set threshold.

2.5 Load. A five kilogram load fashioned as a leg with joints was used to test the device. This custom load was made as it needed to have MTP joints to be actuated.

3 Testing

The device was tested, under the Auto and the EMG Trigger modes, with the leg-load and generated EMG signals of a healthy subject’s quadriceps.

We have successfully verified the ability of the prototype to support and move the load as well as the algorithms of both control modes. For both modes, the device is able to successfully guide the lower limb through a gaitlike pattern, from heel strike to midstance to toe off. The joints were actuated to the correct positions corresponding to the different phases of the gait cycle. At heel strike, the device assumed a configuration where the ankle is in a neutral position, the knee and hip in flexion. Progressing into midstance, the ankle dorsiflexes while the knee extends and the hip returns to neutral. Finally, the ankle plantar flexes, knee flexes and hip extends during toe off. For the EMG Trigger mode, the device is able to accurately respond to different set thresholds and actuated only when the EMG signal of the subject was above the set threshold value. In both modes, real-time biofeedback is displayed on the user interface (Fig. 3).

4 Discussion

Based on our preliminary tests of the prototype with a custom load, the Supine Gait Training Device is effective in safely guiding the lower limbs in a gaitlike fashion for both the Auto and EMG Trigger modes.

Future studies will look to incorporating other aspects of gait into the device. Other muscle groups of the lower extremity such as the hamstrings, tibialis anterior and gastrocnemius will be studied so that an accurate correspondence of EMG signals to the joint activations can be understood and incorporated into the EMG Trigger mode. More biomarkers of gait will also be developed for more comprehensive analysis during use of the device. The developed SEA can also be used for implementing force control of the device as well, providing an active compliance aspect into the device. Moving forward, clinical trials and market analysis will be conducted before commercialization.

Thus, the device has the potential to transcend the limitations of conventional rehabilitation by enabling patients to perform early and task-oriented gait training right from the onset of trauma, allowing them to leverage on the brain’s adaptive plasticity, promoting motor skills learning and neural function recovery. As it is based on neuroplasticity principles, it can be used in other neurorehabilitation settings as well.

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References