

Robot-assisted motor rehabilitation after severe brain injury

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1. Introduction

Severe traumatic brain injury (TBI) affects 3-8 subjects per 100.000 inhabitants in the EU [1]. In developing countries, the annual incidence is expected to increase, as mass motorization is rapidly growing, see the recent presentation of the world's cheapest car by Tata company, India.

Common neurological motor sequelae after severe TBI are tetra- or hemiparesis in combination with a multitude of neuropsychological and behavioral deficits. The rehabilitation is multiprofessional, the restoration of upper and lower limb functions is an integral part, its outcome influences the aspired social and vocational reintegration.

Working with patients in neurorehabilitation, e.g. while practising gait, is labor intensive; budget constraints and the effort required from the therapists often limit the treatment intensity. Accordingly, robots may be a solution to intensify the therapy. Adaptations to the patients' individual ability level, documentation and functional assessment are additional advantages.

The last years have seen a rapid development of this new frontier, the robot-assisted motor rehabilitation, starting from the pioneering work of the MIT-Manus [2] for the upper extremity in the early nineties, and the Gait Trainer GT I [3] and the Lokomat [4] for the lower extremities in the late nineties. So far studies, at least to the authors' knowledge, have only been reported for stroke and spinal cord injury (SCI) subjects, TBI-studies are lacking so far. Accordingly, the authors will limit this article to the presentation of selected machines to highlight the principle and clinical examples.

2. Lower extremity rehabilitation

Two approaches can be distinguished: exoskeleton and end-effector based solutions.

The Lokomat [4] (and the AutoAmbulator, follow the exoskeleton principle. It consists of a treadmill with body weight support (BWS) and orthosis; the harness secured patients wear an orthosis with external drives to flex the hip and knee, the feet are moved passively on the treadmill. The Lokomat controls the movement of the centre of mass (CoM) in the vertical direction.

The Gait Trainer GT I [3] follows an end-effector principle (Figure 1). On the Gait Trainer GT I the harness-secured patient is positioned with BWS on two foot plates, whose movements simulate stance and swing [5]. The machine controls the CoM movement in both the vertical and horizontal direction. Fully programmable Functional Electrical Stimulation (FES) is optional.

In the mid-nineties, when theoretically discussing the different approaches, our group opted for the end-effector solution. Potential arguments in favor were less costs, easy donning and doffing, and the potential risk imminent to an exoskeleton of straining the joints in case of a malalignment between the internal and external joint axis. A restriction of the complex knee movement to only the sagittal plane also seemed unavoidable. Dynamic EMG-recordings in healthy subjects seem to confirm those former considerations. The EMG patterns of selected lower limb muscles on the Gait Trainer GT I correspond to the floor or treadmill walking condition, with the exception that the tibialis anterior activity is reduced on the GT I [6]. Subjects take advantage of the foot plate support

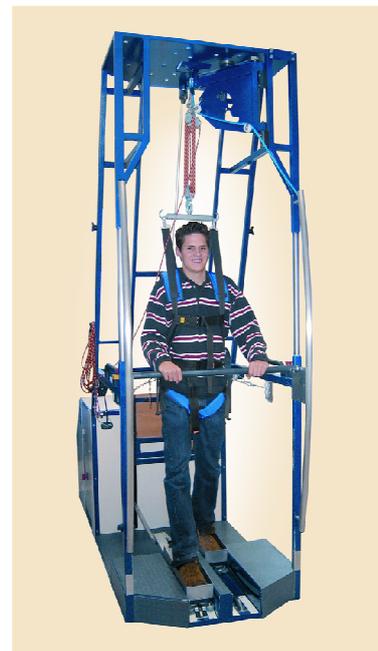


Figure 1: Gait Trainer GT I

during the swing phase putting approximately 15% of the body weight (BW) on the foot plate.

On the Lokomat, the shank activity was also reduced. At the same time the proximal weight bearing muscles showed an erroneous muscle activity during the swing phase and the patients seemed to resist being moved by the orthosis in the swing phase [7].

Unfortunately, no study so far has compared both principles with respect to clinical practicability, effectiveness and cost efficiency. In stroke subjects, the Gait Trainer GT I offers the strongest evidence at the moment [8-10].

For TBI patients, gait machines are an interesting option, particularly as treadmill training with BWS did not result in a superior gait ability when compared to conventional physiotherapy [11]. As discussed already, for stroke and SCI subjects the effort, e.g. to place the paretic limbs, probably prevents a sufficient intensity to achieve a superior gait ability during the manually assisted treadmill training.

For example, a 37-year old subject suffered a severe TBI resulting in left-dominated tetraparesis. Four months after lesion he was confined to a wheelchair including head support; he was apathetic, mutistic, and fully dependent in the activities of daily living. Physiotherapy put its emphasis on the verticalisation in the standing frame, transfer and wheelchair mobility. He was transferred into the GT 1 with the help of a crane. The subsequent locomotor therapy required the assistance of one person sitting in front of the patient to stabilize the paretic knees. The most striking improvement over time was better vigilance, communication and a vivid interest in his environment. This resulted in better competence in ADL-activities on the ward. Motor functions, such as transfer, standing and taking some steps with help, improved as well but he remained confined to an motorized wheelchair, unable to push himself. This example highlights the arousal character of enforced locomotor therapy of severe TBI patients (and patients enjoy it). Future studies should surely cover this aspect.

For less severely affected, young, ambulatory TBI patients, the treadmill offers a multitude of training possibilities, namely aerobic training, shaping (back- sideways walking, perturbations), and even running harness-secured. Going to a gym is trendy and appeals to young people. Our rehab programme should take this into consideration.

3. Upper extremity rehabilitation

Recent years have seen many machines and more will come. Controlled trials in stroke subjects either compared the robot vs. sham therapy [12, 13], vs. electrical stimulation [14] or vs. conventional therapy [15]. Similar to the situation in lower limb rehabilitation, no study so far has compared different devices.

The robots for upper limb once again can be distinguished in exoskeleton (e.g. Armeo, Armin, Armor) and end-effector machines (MIT-Manus, Bi-Manu-Track, NeReBot). The almost unlimited number of degrees of freedom of the human upper extremity (each finger alone has three joints) also makes a restriction of the movements to be trained unavoidable.

Accordingly, there are machines with a more proximal or a more distal approach. The larger cortical representation of the hand and fingers and the presumed competition of proximal and distal segments for plastic brain territory [16] suggest starting the rehabilitation of the severely affected upper extremity distally.

Another criterion of distinction is the bilateral vs. the unilateral approach. The bilateral practice intends to facilitate the paretic side via transcallosal fibres [17]. Opponents argue that the bilateral approach could further promote the already existing imbalance between the two cerebral hemispheres following an unilateral lesion [16]. Theory is theory, comparative studies are highly warranted.

Given the multitude of degrees of freedom of the upper extremity, our group opted for an arm studio consisting of various machines. Work stations are the Bi-Manu-Track [18] for plegic upper limb at all, the finger trainer Reha-Digit (Figure 2) for plegic upper limb at all, the mechanical arm trainer Reha-Slide [19] for upper limb paresis with beginning shoulder activity, the mechanical arm trainer Reha-Slide duo for upper limb paresis with possible active elbow flexion extension, and the EMG-triggered electrical stimulation for upper limb paresis with possible active wrist and finger extension. This list is a suggestion, but clinicians should be careful to clearly define the in- and exclusion criteria

and some sort of treatment algorithm for any kind of equipment. Examples of TBI patients will be presented.



Figure 2: Bi-Manu-Track



Figure 3: Reha Slide

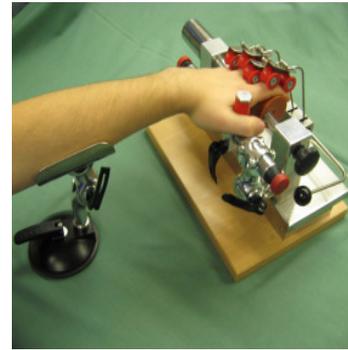


Figure 4: Reha-Digit

4. Summary

Robot-assisted treatment in neurorehabilitation is not meant to replace conventional physiotherapy, but to be complementary.

Currently, robot- and equipment assisted motor rehabilitation of CNS-lesioned patients is a hot issue. Almost every prestigious lab is developing its own device. There are more and more sophisticated machines and technical enthusiasm on the one side, and only few RCTs on the other side, namely in stroke and SCI subjects. TBI patients lag far behind. The future must see studies comparing the various approaches with respect to clinical practicability, effectiveness and cost efficiency. Only then will we be able to foresee a broad clinical basis for this fascinating new frontier.

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