Robot assisted therapy in neurorehabilitation

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Introduction

Robotics allow patients to intensify repetitive task specific training programme in neurorehabilitation.

Task specific locomotor training means repetitive practice of gait with the help of gait-machines in in-patients and of treadmill training with body weight support in out-patients.

For gait-machines two approaches can be distinguished: end-effector[1] (like GaitTrainer GT1 and LokoHelp) and exoskeleton based solutions[2] (like Lokomat and Auto-Ambulator). A recent Cochrane Report states, that robotic assisted gait training in combination with physiotherapy improves chances to regain independent walking capacity. Herein the strongest evidence is given by the Gait Trainer GT 1.

For out-patients speed training on treadmill (TT) with body weight support (BWS) improves walking velocity and endurance, although the personnel requirements, necessary to provide TT, may limit its application.

For the upper extremity there are also exoskeleton (e.g. Armor, WREX) and end-effector systems[3] (e.g. MIT-Manus, Bi-Manu-Track, Reha-Slide, Amadeo). A systematic comparison of the devices is difficult because of the variability of the robotics and movement's complexity of the upper limb. Nevertheless several reviews show an improvement of the upper limb motor function when robotics were used in combination with physiotherapy. The most effective systems are the Bi-Manu-Track with a bilateral distal approach and the MIT-Manus InMotion2 with a proximal approach. The MIT-Manus InMotion 2 can be coupled to the InMotion3 wrist module or to a grasp-sensor, providing a distal approach too. New promising strategies in the distal approach embrace the rehabilitation of the hand. The most promising devices for this rehabilitation strategy are the Reha-Digit and the Amadeo.

Lower extremity rehabilitation

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

The Lokomat[2] and the AutoAmbulator, follow the exoskeleton principle. They consist 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 1[4] follows an end-effector principle. On the Gait Trainer GT I the harness-secured patient is positioned with BWS on two foot plates, whose movements simulate stance and swing. The machine controls the CoM movement in both the vertical and horizontal direction. Fully programmable Functional Electrical Stimulation (FES) is optional.

A third device for lower extremity rehabilitation is represented by the LokoHelp[5] and lies in between these approaches. It consists of a treadmill with BWS, like the Lokomat, and the LokoHelp device itself, which is positioned on the treadmill and is coupled to a boot, guiding the feet along a fixed trajectory. Although taking the treadmill from the Lokomat philosophy, this device has to be considered end-effector based too. In fact, by moving the feet, it moves the end effector and does not show any robotic driven exoskeleton components at all.

In the mid-nineties, when theoretically discussing the different approaches, our group opted for the end-effector solution. Potential arguments in favour were less costs, easy donning and doffing, and the potential risk imminent to an exsokeleton of straining the joints in case of a misalignment 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 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.

The first study on the LokoHelp[5], was a feasibility study The study recruited six patients with impaired walking function: two after stroke, two after spinal cord injury and, as said, two after brain injury. The intervention consisted in twenty additional training sessions on the LokoHelp, performed over a study-period of 6 weeks. Patients improved with regard to Functional Ambulation Category

(FAC) from mean 0.7, SD = 1.6, to mean 2.5, SD = 2.1 (p = 0.048), Motricity Index from mean 94 points, SD = 50, to mean 111, SD = 52, (p = 0.086), Berg Balance Scale (BBS) from mean 20 points, SD = 23 to mean 25, SD = 23, (p = 0.168) and Rivermead Mobility Index (RMI) from mean 5 points, SD = 4, to mean 7, SD = 5, (p = 0.033).

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 stroke subjects, the most relevant study in the last years is given by the Deutsche gangTrainer Studie DEGAS[9]. The purpose of this study was to evaluate the effect of repetitive locomotor training on the GangTrainer in addition to conventional physiotherapy in subacute stroke patients. A patient pool of one hundred and fifty-five non-ambulatory patients with first-time stroke less than 60 days was divided in two groups. Group A received 20 min locomotor training and 25 minuntes of physiotherapy; group B had 45 minutes of physiotherapy every week day for four weeks. The outcome showed that at treatment end a significantly greater number of patients in group A could walk independently: 41 of 77 versus 17 of 78 in group B. Also, significantly more group A patients had reached a Barthel Index higher or equal to 75: 44 of 77 versus 21 of 78 (P B < 0.0001). At six-month follow-up, the superior gait ability in group A persisted (54 of 77 versus 28 of 78,), while the Barthel Index responder rate did not differ.

Further evidence is provided by the Cochrane Report[10]: it investigated the effect of automated electromechanical and robotic-assisted gait training devices for improving walking after stroke. Independently selected trials were reviewed, the trial quality was assessed and the data were extracted. The primary outcome was the proportion of patients walking without assistance or help of a person at follow up. Eight trials with a total of 414 participants were included. Electromechanical-assisted gait training in combination with physiotherapy increased the odds of becoming independent in walking: odds ratio (OR) 3.06, 95% (confidence interval (CI) 1.85 to 5.06; P < 0.001), and increased walking capacity (mean difference (MD) = 34 metres walked in six minutes, 95% CI 8 to 60; P = 0.010).

The next step for the end-effector based strategy will be gait machines with fully programmable foot plates. Patients will be able to practice not only walking in plan, but also climbing up and downstairs, or, with support of virtual reality, even more complicated gait patterns like walking through every day situations. A first prototype of such a machine is given by the Haptic Walker[11].

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, NeReBot, Bi-Manu-Track, Amadeo). 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 MIT-Manus InMotion2 is considered an end-effector machine with proximal approach, nevertheless it is also called Shoulder-Elbow Robot. A study[16] aimed at characterizing training-related changes in synergies apparent from movement kinematics. The extent to which they characterize recovery and whether they follow a pattern of augmentation of existing abnormal synergies, or if they are characterized by a process of extinction of the abnormal synergies was discussed. The paretic arm movements of 117 subjects with chronic stroke were trained and analysed with the InMotion2. Comparison with performance at admission on kinematic robot-derived metrics showed that subjects were able to execute shoulder and elbow joint movements with significantly greater independence. At discharge subjects were better able to draw circles, a task for which they received no training at all.

The larger cortical representation of the hand and fingers and the presumed competition of proximal and distal segments for plastic brain territory[17] suggest starting the rehabilitation of the severely affected upper extremity distally. The MIT-Manus InMotion3 follows the distal approach. It consists of a robotic handle for training flexion and extension, as well as pronation and supination of the affected wrist. This Wrist Robot dynamically adapts to the patient's skills in order to offer continually an appropriate challenge. The InMotion3 may operate both as a standalone device or as an InMotion2 module.

Another criterion of distinction is the bilateral vs. the unilateral approach. The bilateral practice intends to facilitate the paretic side via transcallosal fibres[18]. This Principle is embraced by the BiManu-Track[19]. A study[20] compared the BiManuTrack with electromyographic-initiated electrical stimulation (ES) of the paretic wrist extensor in severely affected subacute stroke patients. A total of 44 patients, 4 to 8 weeks after a stroke with severe arm paresis corresponding to a Fugl–Meyer Motor Score (FM) lower than 18, were randomly assigned to either the BiManuTrack or ES. All patients had 20 minutes of therapy every workday for 6 weeks. BiManuTrack patients performed 800 repetitions per session with the robot and ES patients performed 60 to 80 wrist extensions per session. The primary outcome measure was the blindly assessed FM (0 to 66), and the secondary measures were the upper limb muscle power (Medical Research Council [MRC] sum, 0 to 45) and muscle tone (Ashworth score sum, 0 to 25), assessed at the beginning and end of treatment and at 3-month follow-up. FM and MRC sum scores improved overtime in both groups but significantly more in the BiManuTrack group, FM score was 15 points higher at study end and 13 points higher at 3-month follow-up than the control ES group. MRC sum score was 15 points higher at study end and at 3-month follow-up compared with the control ES group. Muscle tone remained unchanged, and no side effects occurred.

Opponents of the bilateral training 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 have still to come.

The devices working most distal are the Reha-Digit and the Amadeo Hand Therapy System. Both are end-effector based finger trainers. The therapy with the Reha-Digit consists of the stimulus of the proprioception by camshaft, a tactile stimulus given by the camshaft's texture and a vibration. The Amadeo consists of six linear sledges – it has a sledge for the left as well as for the right thumb - on which the finger tips get positioned. There are many therapy options, ranging form controlled passive movement CPM, assisted therapy and active therapy. Actually there are no studies on these hand therapy robots available so far. But work is in progress and the first test results will be available soon.

Given the multitude of degrees of freedom of the upper extremity, our group opted for an arm studio consisting of various machines. The strategy suggested herein is going from distal to proximal, starting first with devices like the Amadeo or the Reha-Digit. The next step should be therapy on work stations like the Bi-Manu-Track or the MIT-Manus InMotion3. In case of upper limb paresis with beginning shoulder activity, the shoulder elbow devices MIT Manus

InMotion2 or the mechanical arm trainer Reha-Slide[21] as well as the mechanical arm trainer Reha-Slide Duo should be considered. 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.

Conclusion

Robotics improve motor function in neurorehabilitation. Gait machines improve significantly the chance of regaining an independent walk in in-patients. The exoskeleton and the end-effector solution work both, but the latter has more scientific evidence. Speed training on TT with BWS improves walking velocity and endurance in out-patients. The robotic devices for the upper extremity, for what concerns the shoulder, the elbow and the wrist, have shown improvements in motor function too. The scientific outcomes for the various hand therapy systems have still to come; the preliminary test results are promising.

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