Post-stroke robotic training of the upper limb in the early rehabilitation phase

Stefano Masiero, MD a
Giulio Rosati, PhD a
Sara Valarini, MD a
Aldo Rossi a

a Department of Rehabilitation Medicine, University of Padua, Italy

Corresponding author: Stefano Masiero
UOC di Riabilitazione,
Università-Azienda Ospedaliera di Padova,
Via Giustiniani 2,
35128, Padua, Italy.
E-mail: stef.masiero@unipd.it

Summary

The successful motor rehabilitation of the upper limb of post-stroke patients requires early, intensive and task-specific therapy. The literature, albeit on the basis of a limited number of randomised controlled trials, shows that the use of robotics in upper limb neurorehabilitation has the potential to increase motor and functional recovery with respect to traditional therapy, especially if applied in the acute and sub-acute phases. This paper presents an overview of the literature on early robotic training of the upper limb after acute stroke.

KEY WORDS: cerebrovascular accident, recovery of function, rehabilitation, robotics.

Introduction

Stroke has a considerable social impact, leaving survivors with residual impaired arm function and disability in activities of daily living (ADLs): recovery is partial in 85% of stroke survivors (1), about 35% of whom are left with a major disability; traditional rehabilitation programmes leave about 30-60% still without functional use of the paretic/plegic arm (2,3). Moreover, the number of people requiring rehabilitation treatment after stroke is rapidly growing due to the aging of the population (4). The aim of rehabilitation in hemiplegic subjects is to promote their recovery of lost function, independence and early reintegration into social and domestic life. Traditional treatments rely on the use of physiotherapy and occupational therapy which are partially theory-based but also heavily reliant on the therapist's training and past experience. The available scientific literature suggests that the rehabilitation intervention is significantly more effective when it is delivered in the early phase of recovery (<6 months) – Paolucci et al. (5) provided evidence that prompt initiation of rehabilitation determines a better functional outcome –, and also when it is based on intensive, especially multisensory, stimulation (6,7). This kind of stimulation is associated with increased adaptive plasticity of the brain in the early post-stroke stages (8,9). Takahashi et al. (10) using magnetic resonance imaging, showed that task-specific training increases sensorimotor cortex activation during the therapeutic period, whereas a non-practised task does not. In the acute phase of stroke, rehabilitation includes interventions that, in terms of residual disability, can directly influence the clinical outcome. Thus, this aspect should be the focus of new therapeutic approaches. From this perspective, robot-assisted therapy looks very promising: the use of robotic devices in rehabilitation can provide high-intensity, repetitive, task-specific, interactive treatment (passive and/or active-assisted exercises) of the impaired limb and can serve as an objective and reliable means of monitoring a patient's motor progress (11). A recent Cochrane review by Mehrholz et al. (12) showed that the use of electromechanical devices in rehabilitation may not significantly improve the ADLs, although they did find evidence that upper arm motor function and strength may improve. Thus, the effective role of robot-assisted therapy in post-stroke rehabilitation remains to be clarified and there are currently no guidelines on how the design and use of such devices might increase their effectiveness (13). Nonetheless, the same review (12), which included four randomised controlled trials (RCTs) involving a total of 165 participants in the acute and sub-acute phases after stroke (within three months of stroke), showed that robotic training of the upper limb within this period of time can enhance motor learning and improve functional abilities more than chronic phase training does.

Rehabilitation robotics in the acute phase: clinical evidence

Optimal restoration of arm and hand motor function is crucial to the restoration of a stroke patient's ability to perform ADLs independently. After the acute phase, all patients require continuous medical care and rehabilitation treatment, often necessitating one-to-one manual interaction with therapists. The available scientific literature suggests that interventions in post-stroke rehabilitation are more effective if there is intensive and multisensory stimulation, and if they are started early (within six months) (7). Several studies have reported better motor outcome with various sensorimotor approaches, including repeti-
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The MIT-Manus is a two-degree-of-freedom (2-DoF) robotic device suitable for use at the bedside. However, gains in all treatment groups were equivalent at the six-month follow-up. The Bi-Manu-Track (27) is designed specifically to train distal arm movements in bilateral passive and active mode, by practising elbow pronation and supination as well as wrist flexion and extension in a mirror or parallel fashion. A multicentre study of this device included severely affected sub-acute stroke patients (32) with an initial Fugl-Meyer motor score <18 (0-66) and no voluntary activity of the wrist and finger extensors. For six weeks, the randomly assigned patients were trained either with the robot or with electrical stimulation of the paretic wrist extensors. Over time, both groups significantly improved their upper-limb motor control and power; the between-group comparison revealed superior results in the robot-trained group both at the end of the study and at the three-month follow up. It is interesting to note that both the proximal (0-42) and distal (0-24) Fugl-Meyer motor subscores improved evenly in the robot-trained group, showing that the treatment effect was generalised. The authors attribute the higher improvements in the robot-trained group to the greater number of repetitions and to the bilateral approach. The NeReBot (28) is a cable-suspended robot, in which three nylon wires are used to suspend the forearm of the affected limb and actively assist its motion over three-dimensional trajectories. Each exercise is set manually by moving the patient’s forearm along a set of points chosen by the therapist on the basis of the patient’s specific needs. The NeReBot can be programmed to perform repetitive assistive movements (flexion and extension, adduction and abduction, pronation and
supination, circular) of the upper limb (shoulder and elbow), integrated with basic visual and auditory feedback. Thanks to under-actuation, robot-patient interaction is highly compliant, giving the patient the very comfortable sensation of being guided through a “hand-over-hand” therapy. In one single-blind RCT (22), 17 patients received traditional rehabilitation with additional early NeReBoT training (4 hours a week for 5 weeks, starting within the first week post-stroke). Compared with the 18 patients in the control group (who received only standard rehabilitation), the patients who received robotic therapy in addition to conventional therapy showed significantly greater gains in motor impairment and functional recovery of the upper limb, and these gains were also sustained at the three- and eight-month follow-ups.

Discussion

A robotic system is a modern, effective and novel tool, capable of delivering intensive, reproducible, task-specific training of the paretic upper limb. The development of robotic treatments is driven by the need to improve clinical outcomes, by the increasing public health burden of stroke-related disability, and by the current emphasis on the need for cost reduction in healthcare (7). Most stroke survivors receive one-to-one physical and occupational therapy for the sensorimotor impairments caused by their stroke. Robotic devices can provide neurorehabilitation training without increasing the burden on clinicians and therapists or increasing healthcare costs. If commercially viable versions of these robotic devices were to be developed, the integration of robotic therapy into current practice could reduce the labour-intensive nature of neurorehabilitation and thereby increase the efficiency and effectiveness of physiotherapists’ interventions (26). Brain stimuli and motor gain seem to be greater in intensive, active-assisted repetitive movements than in non-assisted or passive movements (10). Robots might enrich the sensorimotor experience by providing novel patient-environment interactions during active repetitive training. This is important in view of the growing evidence that recovery from brain injury is heavily influenced by the sensorimotor experience following the injury (33). Robotic paradigms may enhance motor learning and rehabilitation beyond the levels possible with conventional training techniques (34). Despite the potential benefits of robot-mediated movement training after stroke, the clinical efficacy of this approach is still debated. Even though its motor benefits have been measured, there is still no evidence that robotic training can bring about greater improvements, at functional level, than traditional therapy, unless it is delivered in the early stage of recovery (12). Functional recovery is fundamental for the successful reintegration of stroke subjects into social and domestic life, which remains the main objective of rehabilitation programmes; hence, robot-assisted therapy must focus on the achievement of functional goals.

Ideally, a robot used in early functional post-stroke training should, in terms of arm motion, perform exercises that promote more natural movements (35). For example, a three-dimensional trajectory is a desirable feature in a robotic device for early post-stroke training because it can promote a large number of functional movements in different directions in space. Moreover, a robotic system for acute-phase rehabilitation, while assisting the patient’s movements, should guarantee a highly compliant interaction, in order to facilitate voluntary motion and to preserve the causal relationship between motor command and resulting arm motion, even when robotic assistance is provided. In addition, acoustic and visual feedback should be employed in order to ensure that the patient’s attention is sustained at a sufficient level throughout the therapy session. Finally, it is important to underline that in acute and subacute stroke patients, evaluation of the degree of motor impairment can determine their access to rehabilitation training. In the past (14,36), several studies have failed to prove the superiority of one type of conventional stroke regimen over another, but there is strong evidence that highly repetitive movement training can result in improved recovery. The application of robot-assisted therapy would enable patients to practise intensively with their upper paretic limb guaranteeing sensorimotor support and also resolving the issue of the staffing costs of rehabilitation. In multidisciplinary approaches to the post-stroke patient, the robotic assistive device has the advantage of implementing several modalities for facilitating voluntary movement in response to the motor command: passive, active-assisted, active, counter-resistance adjusted for each session, uni- or bimanual work. Also, sensory feedback reinforcement can be obtained by using an external means, from an approximate target on a screen to total immersion in an interactive virtual environment where subjects can visualise the path they describe. Nonetheless, more clinical testing is needed to corroborate the initial positive results, and more studies on motor learning during robot-patient interaction should be carried out in the near future, with the aim of optimising robotic system designs to maximise patient engagement during robotic training and functional recovery after robotic intervention.

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