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Original Article

Exercising daily living activities in robot-mediated therapy

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Abstract. [Purpose] Investigation of the efficacy of robot-mediated therapy of the upper limb in patients with chronic stroke, in task-oriented training activities of daily living in real environment. [Subjects and Methods] 20 patients, each more than one year post-stroke (13–71 months) received 20 sessions of upper limb robot-mediated therapy. No other treatment was given. Each therapy session consisted of a passive motion and an active task therapy. During the active therapy, subjects exercised 5 activities of daily living. Assessments of the subjects were blind, and conducted one month prior to, at the start, at the end, and three months after the therapy course. The following outcome measures were recorded: Fugl-Meyer Scale—upper extremity subsection, Modified Ashworth Scale, Action Research Arm Test, Functional Independence Measure, Barthel Index. [Results] Significant improvements were observed between the start and the end of the therapy, except for Modified Ashworth Scale and Barthel Index. Results still held up at the follow-up visit three months later. [Conclusion] Practicing activities of daily living in real environment with robot-mediated physical therapy can improve the motor and functional ability of patients, even with relatively good initial functions, and even years post-stroke.

Key words: Robot-mediated therapy, Stroke, Upper limb

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INTRODUCTION

Supplementation of traditional manual physiotherapy with robot assistance has been increasing in importance in the rehabilitation of post-stroke, traumatic brain injury[1], spinal cord injury[2], cerebral palsy patients[3] and patients with other neuromotor deficits[4]. This kind of therapy is considered to be useful first of all in case of goal-oriented, repetitive exercises. Subjects typically have to do exercises with point-to-point motions presented in video games. Task difficulty level, the joints involved and the number of repetitions are adjustable. This kind of robot-assisted therapy proved to be effective in acute[5], subacute[6], and chronic[7] state post-stroke according to several clinical trials[8].

There are several publications of attempts for increasing the efficacy of robot-mediated therapy (RMT). Although the existing robotic systems implement different technical solutions[9], the ultimate aim beyond improving motor scores is carrying these skills over to real functions. Several robotic devices provide feedback to the patient only through some kind of virtual reality with limited modalities. It seems, therefore, to be reasonable to practice tasks in real environments, resembling real life situations as close as possible.

The first prototype of the Reharob Robotic Therapeutic System had been developed in the framework of a European Research and Development (RTD) project. The first version of Reharob assisted passive shoulder-elbow therapy. The recently completed second version can extend robot-mediated motion therapy to the wrist and hand too. It also does active

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Table 1. Patient characteristics

Age (mean ± SD; years)		60.4 ± 11. 3
Gender	Female	8
	Male	12
Time elapsed since stroke (mean ± SD; months)		32.0 ± 17.3
Type of stroke (number of subjects)	Ischemic	16
	Haemorrhagic	4
Hemiparetic side (number of subjects)	Right	13
	Left	7

assisted therapy in addition to passive exercises. Moreover, active assisted therapy goes beyond mere point-to-point motions, supporting functional tasks, namely five activities of daily living (ADL): 1. picking up a cup by its handle and moving it to the mouth; 2. picking up and putting down a phone; 3. zipping and unzipping a vest; 4. opening and closing the door of an enclosure; 5. moving a towel to the mouth and drying it. These exercises require concerted motions of the patient both in proximal and distal anatomic joints. ADL No. 1 and No. 2 are classified as mechanically free motions; ADL No. 3 and No. 4 are classified as kinematic, whereas ADL No. 5 as force constrained motions.

During the lifetime of Reharob, three clinical trials have been conducted. In 2003 the first clinical test of Reharob was done with 8 subjects in order to gain experience with the system. It proved to be safe, nevertheless some subsystems of the device (instrumented orthosis, safety release device, patient's enabling button) were selected for major redesign[10]. The second test was a controlled trial in 2005–2006, involving 30 post-stroke subjects with hemiparesis[11]. Half of the subjects formed the experimental group receiving traditional therapy plus RMT. The other half formed the control group receiving only traditional therapy. The clinical trial concluded that spasticity decreased statistically significantly only in the robotic group.

The third clinical trial—reported in this paper—was carried out in 2014–2015 to test the efficacy of the system improved with ADL-based active therapy modality.

SUBJECTS AND METHODS

This study was approved by the National Scientific and Research Ethics Committee and the Office of Health Authorisation and Administrative Procedures of Hungary (number of permission: 10128/2012/OTIG).

Twenty patients (12 male, 8 female) participated in the clinical trial; all of them were over one year post-stroke. The average age of the subjects was 60.35 years. The main characteristics of the patients are shown in Table 1. The inclusion criteria were the following: hemiparesis caused by ischemic or haemorrhagic stroke; brain lesion confirmed by CT or MRI; time elapsed since stroke: minimum one year and maximum 6 years (Since all subjects were in chronic state post-stroke, their status was supposed to be stable with no spontaneous improvement during the trial.); age: 18–80 years; height: 160–190 cm; medically stable status; cooperative subject; signed consent form. The exclusion criteria for all patients were: incapacitated or partially incapacitated person; pregnant or breastfeeding women; imprisonment or subject to criminal proceedings; epilepsy; cutaneous diseases precluding the use of braces; musculoskeletal or other diseases that prevent patients from sitting quietly during treatment.

The clinical trial was executed with the Reharob v2 Robotic Therapeutic System. Both versions of the system are a dual robot arm upper-limb-motion rehabilitation system. It includes two retrofitted industrial robot arms: type IRB140 and type IRB1600 of Asea Brown Boveri (ABB). The system is manipulandum type, where only the end-effector of the robot is connected to the body part. In case of Reharob v2 the IRB140 robot arm is connected to the elbow, whereas the IRB1600 robot is connected to the hand of the upper limb. The system update became possible mainly due to the evolution of industrial robots beginning in the mid-2000s, when market demand pressured manufacturers to deliver enhanced interaction capabilities such as force control. With ABB's Force Control option, control cycle times can be reduced as short as 4 ms. A master-slave control system has been developed for Reharob v2. The robot holding the hand is the master- and the other holding the elbow is the slave robot. An admittance control strategy has been adopted for active ADL therapy, in which a viscoelastic actuator generates correction force and torque as soon as the subject deviates from the reference ADL trajectory. Benefitting from the hardware updates, Reharob v2 covers full range shoulder-elbow-wrist motions of the affected upper limb and delivers ADL based therapy in 5 selected tasks under admittance control based correction strategy. Each patient received a total of 20 sessions of RMT, in the course of 6 weeks. Patients got 15 minutes passive and 35 minutes active assisted therapy in every session. The passive phase consisted of a series of exercises programmed by the physiotherapist on-line through demonstration to the robots. In the active phase the robot executed all five pre-defined ADLs: each ADL task took 7 minutes, with 1 passive and 5 active assisted repetitions.

To verify that there were no spontaneous improvements in patient condition, the clinical status of subjects was measured

Table 2. Results in motor and functional assessment scores

	Normal score	T1 mean ± SD	T20 mean ± SD	U1 mean ± SD
FM -UE	66	48.3 ± 15.0	52.5 ± 13.9*	55.3 ± 13.2*
MAS	0	2.6 ± 2.9	2.6 ± 2.9	2.8 ± 3.1
ARAT	57	24.9 ± 13.8	28.9 ± 13.8*	32.9 ± 12.5*
FIM	126	117.6 ± 8.2	118.4 ± 8.4*	120.9 ± 4.9*
Barthel	100	92.3 ± 10.6	93.0 ± 11.0	95.7 ± 6.1

*$p<0.05$ when comparing assessment result between T1–T20 (p_1) and T1–U1 (p_2) visits using repeated measures ANOVA with Bonferroni post hoc test, FM-UE: Fugl-Meyer Upper Limb subsection; MAS: Modified Ashworth Scale (Shoulder adductors + Elbow flexors +Wrist volarflexors); ARAT: Action Research Arm Test; FIM: Functional Independence Measure; T1: assessment before the first session; T20: assessment at the end; U1: follow-up visit (three months after the end of the therapy course)

one month before (E1) and just prior to the start of the trial (T1). If there was no change in the clinical status during this one month, the patient was allowed to commence the therapy course. The subjects were assessed again after the 10th session, at the end of the therapy (T20), and three months after the end of therapy (U1). The examiner was an independent physiotherapist taking no part in the trial at any other point (blind assessment). The following assessment scales were used: Fugl-Meyer Scale—upper extremity subsection (FM-UE)[12, 13], Modified Ashworth Scale (MAS)[14], Functional Independence Measure (FIM)[15], Barthel Index (BI)[16], and Action Research Arm Test (ARAT)[17].

Statistical calculations were performed by the software Statistica v13. from StatSoft Inc.

Though all subjects were in chronic stage post-stroke, in order to prove that there was no spontaneous recovery, the results of E1 and T1 were compared with t-test for dependent samples. To be included in the RMT phase, a patient's assessments had to be without significant difference.

For the assessment of therapy efficacy the outcome measures recorded at T1, T20 and U1 were compared with repeated measures ANOVA with Bonferroni post hoc test.

RESULTS

Results were evaluated for four aspects. From the aspect of safety, it is remarkable that patients received a total of 20 000 minutes (20 × 20 × 50) = 333.33 hours of RMT. There haven't been any adverse events during this time. Nevertheless, some technical inadequacies have been observed: in addition to the physiotherapist, an engineer was also required to be present in therapy sessions. In case of certain technical errors (overspeed, overforce, singular configuration, etc.) the standard controls of the industrial robots had to be used for system reset. The physiotherapists were not trained for operating these controls. Commercialization would require the elimination of this shortcoming, which can be achieved by additional high-level software development. Sometimes singularities occurred during the passive free exercising. In case of arm-type robots singularity means loss of control due to axis collinearity. Application engineers in industrial scenarios can effectively overcome singularities by careful path and trajectory planning. In case of rehabilitative robot application physiotherapists need more training in programming to prevent singularities. During active ADL assistance subjects may deviate from normal path/trajectory with abnormal magnitude, which may also lead to the robot singularity. This shortcoming can only be eliminated by improving the system layout design, although there are unsurmountable structural limits. Another solution would be the use of robots with kinematic redundancy, which in our opinion will be a key characteristic of future robot arms. However, this irregularity is not a safety issue: it always automatically triggers the system to go into emergency stop state.

An ergonomic inadequacy: to fit every patient comfortably, orthoses are needed in more than three different sizes.

Motor scales represent the second aspect of the results (Table 2). The values measured at the start and at the end of the therapeutic course were compared and evaluated. The FM-UE improved statistically significantly. The MAS of shoulder adductors, elbow flexors and wrist flexors did not change.

The third aspect is functional assessment. ARAT was significantly better after therapy than before. Examining the FIM, significant improvement was observed at the end of the treatment. The BI improved, but not significantly.

Fourteen out of 20 participants appeared for the follow-up visit three months after the end of the therapy course. The significant improvements of FM-UE, ARAT and FIM values endured.

The fourth aspect was user experience. The answers given to the questionnaire pointed out that all the patients participated in the robotic therapy with pleasure. Most of them found the duration of sessions ideal and the level of resulting weariness and fatigue within their tolerance. Only one patient complained about discomfort when getting off the system in an emergency stop situation.

DISCUSSION

Lately a number of researches and investigations dealt with the symptoms[18] and problems of post-stroke patients. Ways of improving the condition of these patients are also in the focus of attention. In a systematic review, Prange et al. concluded, that RMT may improve the paretic upper extremity's short and long-term motor control more effectively than conventional therapy[19]. According to the review of Kwakkel et al., significant improvement was found in upper arm motor function, but ADL functions did not improve significantly[20]. Mehrholz et al. in their Cochrane review found an increase in motor scores and slight improvement in the functional scales, but no significant change in muscle strength[21]. In their updated review the same group of authors concluded that electromechanical and RMT improved ADL, arm and hand function, and arm and hand muscle strength, but the quality of the evidence was low to very low[22]. Due to the application of diverse methodologies and outcome scores of the referred studies, the evaluation of the efficacy of RMT is often difficult[23].

The aim of this clinical trial was to investigate the efficacy of RMT with active ADL exercises. The study targeted chronic post-stroke patients. Each subject received 15-min of passive and 35-min of active assisted training. The latter part consisted of exercising 5 ADLs. Technical results, motor scores and functional scales were evaluated.

Robot-mediated exercises are most often executed in a virtual reality environment. In this study patients manipulated real objects in a real environment. Similar setups are rare in the literature. Johnson's et al. physiotherapy robot ADLER was developed for post-stroke patients to practice functional ADL-like tasks with and without physical objects. According to his results, function improved on tasks involving primarily the proximal part of the upper limb, but not grasping[24] although the tests stalled at initial prototype tests with one healthy and one stroke subject.

Timmermans et al. executed a trial with 22 chronic stroke patients using real objects (cup, knife, fork and purse): the ARAT score showed significant improvement only in the experimental group[25]. This trial involved a sub-study: Lemmens et al. evaluated 16 chronic stroke patients measuring the activities with an accelerometer. They found no significant changes either in the robot-supported or in the control group[26]. Park described a two-week-long task-oriented training with two chronic post-stroke patients (not applying robots) and found this kind of therapy effective[27]. Grasping various real objects requires more sophisticated motor control function from the patient than grasping the handgrip of a robot.

The application of real objects makes the task more difficult both for the patient and the robot. Nevertheless, exercising ADLs are closer to real life than training in virtual reality. It would be useful to compare these two types of therapy.

From a technical aspect, 333 hours of RMT without any adverse events can be considered a very good result. This is in concordance with the literature: RMT-studies proved to be safe.

Regarding the changes in motor scores, in 6 of 20 patients high improvement was observed. Considering the subjects' relatively high motor scores at the inclusion, these changes are remarkable. All subjects participated in the study were chronic stage patients whose MAS scores were stabilized on a low level years post-stroke. An improvement in this scale, therefore, was not expected.

There was only slight improvement in functional scores. It is probably due to the patient's good functional status at the inclusion. Grasping objects and executing ADLs requires even selective finger movements. The loss in hand function of participating patients had to be no worse than moderate.

A limitation of this study is the subjects' relatively good functional status at the inclusion. To execute the ADLs, patients had to be capable of some finger movements. Nevertheless, testing the system with subjects of weaker hand function would stand to reason. Another limitation is that the number of patients dropping out before the three-month follow-up visit was relatively high. Lost subjects were severe- to moderately severe stroke patients.

In conclusion, this study suggests that practicing ADL tasks in a real environment with the assistance of a robot can improve the motor and functional functions of patients, even with relatively good initial status, as well as years post-stroke. Nevertheless, further research is necessary to compare the efficacy of exercising in real-life to exercising in a virtual environment.

Conflicts of interest

The authors declare no conflicts of interest.

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