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Neurorehabil Neural Repair. Author manuscript; available in PMC 2016 July 13.

Published in final edited form as:

Neurorehabil Neural Repair. 2008 ; 22(3): 305–310. doi:10.1177/1545968307311102.

Intensive Sensorimotor Arm Training Mediated by Therapist or Robot Improves Hemiparesis in Patients With Chronic Stroke

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Abstract

Investigators have demonstrated that a variety of intensive movement training protocols for persistent upper limb paralysis in patients with chronic stroke (6 months or more after stroke) improve motor outcome. This randomized controlled study determined in patients with upper limb motor impairment after chronic stroke whether movement therapy delivered by a robot or by a therapist using an intensive training protocol was superior. Robotic training (n = 11) and an intensive movement protocol (n = 10) improved the impairment measures of motor outcome significantly and comparably; there were no significant changes in disability measures. Motor gains were maintained at the 3-month evaluation after training. These data contribute to the growing awareness that persistent impairments in those with chronic stroke may not reflect exhausted capacity for improvement. These new protocols, rendered by either therapist or robot, can be standardized, tested, and replicated, and potentially will contribute to rational activity-based programs.

Keywords

Stroke; Recovery of function; Rehabilitation

Stroke causes permanent disability that is dependent in large part on motor impairment, and although most patients walk independently, often with a device or orthosis, recovery of arm and hand function occurs less often.[1–3] Despite the tendency to focus restorative treatments in the weeks soon after the stroke inasmuch as motor improvements, in general, plateau 3 to 6 months later,[4,5] a new convergence of animal and human studies has focused on the treatment efficacy of repetitive exercise of the paralyzed upper limb to alter motor performance in patients with chronic stroke.[5–13] These emerging data have stimulated the clinical development of activity-based techniques based on a combination of the control of guidance and speed of the movements and intensive practice.[14–19] In patients with chronic

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stroke referred to an outpatient clinic, we have attempted to establish a standard therapist-delivered intensive physical therapy program, and then to compare it to a treatment with a robotic-driven protocol that has been demonstrated to alter motor performance significantly in patients with chronic stroke.[15]

METHODS

Study Population and Design

We screened 55 patients with stroke referred to the outpatient clinic and who had impaired arm and hand mobility for at least 6 months. Twenty-one patients who met the inclusion criteria were randomized to robotic training that was identical to a past robotic trial[15] or to an intensive upper extremity movement-based treatment from a therapist. The therapist's protocol was designed by a group of senior therapists working in the stroke recovery program, and represented a combination of common practice treatments that, for the purpose of this experiment, matched the session duration, number, and timing of robot treatments. Patients were measured monthly for 3 months to test whether there was spontaneous improvement. Measurements of motor impairment were also obtained at the mid-point and the end of training and 3 months later. Two research therapists were trained to execute the specific treatment protocols. Therapists trained in the measurement techniques were masked to the group assignment and performed all clinical measurements.[20] All patients had an identical number of treatment sessions, and the sessions were of the same duration (1 hour per session, 3 times a week for 6 weeks).

The primary outcome measurement was the Fugl-Meyer Scale for Shoulder/Elbow (FM Sh/El; maximum = 42). The secondary impairment outcome measure was the Fugl-Meyer Scale for Wrist/Hand (FM W/H; maximum = 24)[21] and the Motor Power Scale for Shoulder/Elbow (MP; maximum = 70).[22] Other secondary outcomes included the Modified Ashworth Scale, passive movements graded 0 to 5, across 9 muscle groups.[23] Disability scales were measured by the Stroke Impact Scale (SIS; maximum = 80; version 2.0)[24] and the Action Research Arm Test (ARAT; maximum = 120).[25] We also measured shoulder dislocation (Joint Stability = Jt Stab; maximum cm of displacement = 9, 3 principal directions of dislocation),[26] pain scale from the Fugl-Meyer (maximum = 24), and the Beck Depression Scale (maximum = 63). The NIH Stroke Scale was derived from hospital records and scored by a certified examiner.

Sensory or visual field impairment, aphasia, or cognitive impairment, including neglect or extinction to double simultaneous stimulation, were not exclusion criteria, but the patients needed to be able to follow simple instructions. Patients (n = 13) who were minimally impaired were excluded (FM Sh/El > 33, which means they could elevate and abduct the shoulder, and extend the elbow), but there was no exclusion of patients with severe impairment. Other exclusion criteria were neurosurgical procedure (n = 10), second stroke (n = 10), or fixed contracture (n = 1).

Intensive Treatment Protocols: Therapist

The intensive movement-based protocol was designed to reflect a combination of standard therapeutic activities in contemporary stroke rehabilitation for the upper extremity that were comparable to robotic training in intensity and duration. Treating therapists for the intensive program had a minimum of 1-year experience and held advanced training credentials. This protocol included static stretching, systematically varied levels of active-assisted arm exercise, and goal-directed planar reaching tasks based on Carr and Shepherd principles,[27] which were adapted by therapists using Bobath neurodevelopmental treatment techniques[28,29]; specifically, the therapists encouraged tone inhibition when appropriate and increased upright trunk positioning. The program started with active assisted arm exercise for 20 minutes total (6- to 7-minute episodes interspersed with other activities below) on the Monark Rehab Trainer™ (881E; Monark Bodyguard, Quebec, Canada) that was mounted on an adjustable table for bilateral arm training. For the duration of the movement, the glenohumeral joint never exceeded 90 degrees of flexion. A Hemi-Glide was utilized for humeral elevation exercises with grip fasteners. The patient's impairment level determined whether the position was short sitting (upright position, knees bent on the edge of the mat) or side lying. There were 3 trials of 15 repetitions with 30 seconds of rest between trials for the next 5 minutes. Concentric and isometric exercises for scapular elevation, depression, retraction, and protraction comprising the scapular stabilization drills occurred for the next 5 minutes. Static stretching focused on the adductor/internal rotator groups of the shoulder girdle and the elbow flexors. The patient was positioned supine on a treatment mat with the arm positioned in 90 degrees of glenohumeral abduction and full elbow extension in the first stretch for the next 5 minutes, maintained by a #4-wrist cuff sand-filled weight. In a supine position with the arm in 90 degrees of glenohumeral abduction, the humerus was rotated laterally 90 degrees for the second stretch, with care to avoid causing pain for the next 5 minutes.[28] The tabletop horizontal exercises consisted of goal-directed movements using a skate-board system. Patients were positioned (arm in 35 degrees of humeral elevation in the scapular plane) with their forearm resting on a hand skate atop a near frictionless tabletop surface. The exercises consisted of figure-eight movements for 5 minutes, and then reaching in a point-to-point fashion, side-to-side and forward for 5 minutes. Patients were assisted with each movement, and the therapist minimized compensatory trunk movements. Ten minutes of Bobath-based treatment activities were adapted to individual impairment level utilizing facilitatory and inhibitory techniques. These activities included closed-and open-chain tasks, and activities were advanced within and between treatment sessions. Closed-chain tasks included use of the affected limb for balance and support while reaching with the unaffected limb or to maintain postural control. Open-chain tasks refer to tasks that utilize the affected limb to perform activities in space, such as reaching for a cup.

Intensive Treatment Protocols: Robot

A patient's hand and fingers were attached by Velcro straps to a planar InMotion2 robot (the commercial version of MIT-MANUS produced by Interactive Motion Technologies, Cambridge, MA). Their forearm fit in a connecting trough, and they moved the robot arm. If a patient could not move the robot arm, the robot guided the trajectory and speed of the patient's arm to provide an adaptive sensorimotor experience.[30,31] The interactive robot features have been discussed at length elsewhere.[32]

The institutional review boards of the Burke Rehabilitation Hospital and the Massachusetts Institute of Technology approved the protocol. Written informed consent was obtained from all patients. For the primary outcome measure and the secondary impairment measures, we used repeated measure ANOVA with time of evaluation (3 pretreatment assessments, a midpoint, discharge, and follow-up assessment) and type of intensive therapy as between factors; age, months poststroke, and NIH stroke scale were covariates. We used *t* tests for clinical demographic and disability measures.

RESULTS

There were no differences between the groups on all primary motor impairment measures (Table 1, $P > .5$). For the primary outcome measures of shoulder and elbow, namely, FM Sh/El and MP, there was a significant change over time (Table 2; FM Sh/El, $F = 5.2$, $P < .007$; MP, $F = 6.3$, $P < .003$) that was maintained in a 3-month follow-up (FU; $P > .5$, NS). There was no change in the FM W/H measure over time. Treatment with robotic training and an intensive movement-based protocol had comparable effects on improving motor outcome, as reflected in nonsignificant treatment interactions; also there were no interactions with age, months postinjury, or NIH stroke scale score. There were no differences in the pretraining motor outcome measures. Motor improvement in the intensive treatment groups was confined to the shoulder and elbow and did not generalize to the wrist.

There were no significant improvements in disability outcome measures or differences across treatments (Table 3). Ashworth Scale, the Joint Stability Scale, pain assessment, and Beck Depression Scale were comparable on admission and discharge (also Table 3).

DISCUSSION

These data demonstrate that intensive movement-based training, whether delivered by robotic device or by a therapist following a standardized dose-matched protocol, alters motor performance in patients with chronic stroke. Whether this magnitude of motor improvement occurs with the traditional outpatient therapy needs to be tested. Both activity-based therapies were matched for session duration, total number, and timing, and offer a guide to potential standard treatment protocols by exposing the patient to reproducible training session content. If a goal of therapy is to influence impairment of the proximal upper extremity, then the results support the efficacy of adding intensive movement training protocols, robotic driven or not, to the therapist’s tool-bag.

The results raise some important qualifications about the relationship of impairment reduction to disability burden in patients with chronic stroke. Disability from upper limb impairment depends primarily on the loss of hand function and finger dexterity, and only 1 patient in this study developed finger flexion and extension function. More reasonably, the patients aimed to improve dressing and grooming, and some few aimed to improve their ability to eat independently. In fact, anecdotal patient reporting suggested they experienced increased ease bathing and dressing. Other studies have demonstrated in patients with acute stroke that the changes in the Fugl Meyer (FM Sh/El) scale were comparable to the results in the patients reported here with chronic stroke; however, the degree of improved Fugl Meyer scale signaled greater change of the Stroke Impact Scale.[24,33] The current measures of disability may prove more resistant to change for those with chronic stroke, especially when compared to those with an evolving disability soon after acute stroke.

These results also demonstrate the intensity of therapist-delivered treatment required to match the outcome produced by robot training. Whether the intensive movement training protocols are consistent with current health care delivery models will require an economic analysis to overcome program inertia. These data along with work from other investigators[7–13] support an argument that intensive impairment reduction protocols are hard work, yet they can improve aspects of the impairment in patients with chronic stroke, a period more often characterized by diminished capacity for change.[16,32] These results also support the possibility, raised in the past,[16,34] that the so-called motor recovery plateau reflects a consolidation from practice experiences rather than some optimum biological recovery.

Finally, new data make clear that the expression of molecular and cellular restorative physiology after stroke describes time horizons that continue over weeks, perhaps months.[35] Future manipulation of these molecules and cells might encourage further stroke recovery, yet to capitalize fully on this novel biology, training protocols will require a new degree of rigor and reproducibility.

Acknowledgments

Supported by the Burke Medical Research Institute, the Skirball Foundation, NYS DOH Center for Research Excellence in Spinal Cord Injury, and the US Public Health Service (NIH R01-HD045343). Drs N. Hogan and H. I. Krebs are co-inventors in the MIT-held patent for the robotic device used to treat patients in this work. They hold equity positions in Interactive Motion Technologies, Inc, the company that manufactures this type of technology under license to MIT.

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Table 1

Clinical Characteristics

Group	Gender	Age	Disabled Limb	Months Post Stroke	NIH-SS	Stroke Type	Stroke Location	Stroke Severity
Intensive movement therapy: ROBOT (n = 11)	8 M/3 F	62 ± 3	5 L/6 R	35 ± 7	17 ± 1	1/10	1/0/10	2/9
Intensive movement therapy: THERAPIST (N = 10)	7 M/3 F	60 ± 3	5 L/5 R	40 ± 11	17 ± 1	0/10	0/0/10	2/8

Note: Baseline characteristics of the robot pilot and the randomized subjects. Categorical variables are expressed in frequency. Stroke type is divided between hemorrhagic and ischemic stroke, respectively, and stroke location is divided, respectively, among stroke restricted to the cortex/stroke restricted to the subcortex/stroke in both regions. Stroke severity is characterized by moderate/severe using the National Institutes of Health Stroke Scale (NIH-SS) of 12 as a cut. Age, time from stroke, and NIH stroke scale are mean ± SEM.

Table 2

Change in Motor Performance After Intensive Training

Group	Pre 1 FM Sh/El (max = 42)	Pre 2 FM Sh/El	Pre 3 FM Sh/El	Avg FM Sh/El	Mid FM Sh/El	Dis FM Sh/El	FU FM Sh/El
Intensive movement therapy: ROBOT (n = 11)	12.55 ± 1.5	12.64 ± 1.7	13.18 ± 1.8	12.79 ± 1.6	14.82 ± 1.9	15.73 ± 2.0	15.82 ± 2.1
Intensive movement therapy: THERAPIST (n = 10)	11.60 ± 1.0	11.50 ± 1.0	11.20 ± 1.1	11.43 ± 1.0	13.40 ± 1.51	15.10 ± 1.7	14.80 ± 1.6
Group	Pre 1 MP (max = 70)	Pre 2 MP	Pre 3 MP	Avg MP	Mid MP	Dis MP	FU FM
Intensive movement therapy: ROBOT (n = 11)	29.91 ± 4.1	29.27 ± 4.2	29.18 ± 4.0	29.45 ± 4.1	34.27 ± 4.3	35.45 ± 4.1	36.91 ± 4.2
Intensive movement therapy: THERAPIST (n = 10)	27.70 ± 2.2	27.80 ± 2.1	27.10 ± 2.1	27.53 ± 2.1	30.90 ± 2.2	33.70 ± 2.7	33.40 ± 3.0
Group	FM W/H (max = 24)	FM W/H	FM W/H	FM W/H	FM W/H	DisFM W/H	FM W/H
Intensive movement therapy: ROBOT (n = 11)	2.36 ± 1.3	2.18 ± 1.3	2.82 ± 1.5	2.45 ± 1.3	3.64 ± 1.7	3.73 ± 2.0	3.00 ± 1.8
Intensive movement therapy: THERAPIST (n = 10)	1.60 ± 0.7	1.20 ± 0.7	2.00 ± 0.9	1.60 ± 0.8	2.00 ± 0.8	2.60 ± 0.9	2.30 ± 0.9

Note: Interval motor evaluation for 3 preliminary evaluations (Pre1, Pre2, Pre3), a calculated average admission (Avg), midpoint (Mid), discharge (Dis), and follow-up (FU) for the primary measures (mean ± SEM). FM Sh/El = Fugl Meyer for the shoulder and elbow; MP = motor power for shoulder and elbow; FM W/H = Fugl Meyer for the wrist and hand.

Table 3

Change in Disability, Tone, Joint Stability, Pain, and Depression After Intensive Training

Group	**Adm SIS**	**Dis SIS**	**Adm ARAT**	**Dis ARAT**
Intensive movement therapy: ROBOT (n = 11)	63.9 ± 3.1	67.1 ± 2.4	63.8 ± 1.6	65.0 ± 2.0
Intensive movement therapy: THERAPIST (n = 10)	64.7 ± 2.3	65.5 ± 2.4	62.6 ± 0.4	62.9 ± 1.6

Group	Adm Ashworth	Dis Ashworth	Adm Joint Stability	Dis Joint Stability	Adm Pain	Dis Pain	Adm Beck	Dis Beck
Intensive movement therapy: ROBOT (n = 11)	8.18 ± 1.4	6.27 ± 1.0	2.36 ± 0.3	2.18 ± 0.4	23.9 ± 0.1	23.1 ± 0.4	6.09 ± 1.7	4.90 ± 1.3
Intensive movement therapy: THERAPIST (n = 10)	7.40 ± 1.5	6.00 ± 1.3	1.90 ± 0.4	2.10 ± 0.2	23.3 ± 0.3	22.8 ± 0.5	6.90 ± 2.0	5.00 ± 1.6

Note: Secondary outcome measures include disability scores, Stroke Impact Scale (SIS), and Action Research Arm Test (ARAT). We also measured the Ashworth, joint stability (a lower score indicates decreased shoulder dislocation), pain, and Beck depression scores. Adm = admission; dis = discharge.