Does Shorter Rehabilitation Limit Potential Recovery Poststroke?

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Objective. *To examine retrospectively the recovery of patients engaged in robotic research during a 6- to 7-week course of inpatient rehabilitation. Because timing of the interim evaluation at 3½ weeks was comparable to the present length of inpatient stroke rehabilitation, the authors assessed whether significant gains in motor abilities occurred after the time when most stroke patients today are discharged home.* Methods. *Fifty-six inpatients with a single, unilateral stroke were randomly assigned to a robot therapy or robot exposure group. Therapists blinded to group assignment administered the Fugl-Meyer, Motor Status Score, and MRC motor power test.* Results. *Significant improvements in upper-limb motor abilities occurred throughout a period approximately twice the present length of stay in inpatient rehabilitation. However, in the latter half of this period, patients who received conventional therapy showed little improvement, whereas patients who received robot training plus conventional therapy continued to improve.* Conclusion. *Further opportunities for recovery after stroke are possible by extending intensive therapy beyond present inpatient rehabilitation stays.*

Key Words: *Cerebrovascular accident—Upper extremity paresis—Robotic therapy.*

Stroke is the leading cause of disability in the United States. Each year, about 700,000 people experience a new or recurrent stroke, which can have devastating effects on cognitive, affective, sensory, and motor functions.[1] Research evidence indicates that the largest proportion of motor recovery after stroke occurs during the first weeks and months after onset.[2,3] However, cost containment measures and shorter rehabilitation hospitalizations have shifted therapy efforts away from attempts to restore lost motor abilities in the paretic limb toward the teaching of compensatory techniques (e.g., 1-handed techniques) to improve functional skills. This decline in rehabilitation services has, in many cases, occurred at the expense of impairment reduction.[4] Taub and others[5] have suggested that this focus on compensation early after stroke can lead to a pattern of learned nonuse and lower the potential for future gains in motor function of the paretic arm.

The length of rehabilitation hospitalization is mainly determined by a patient's functional status, as measured by the Functional Independence Measure (FIM).[6,7] A primary focus is the patient's ability to transfer and mobilize within familiar environments to allow safe return home. The FIM does not take into account the degree of motor function in the paretic arm after stroke during bilateral tasks or how much the patient is using compensatory techniques to accommodate for lost motor function. Thus, the use of FIM scores as the main criterion for discharge from rehabilitation services can limit a patient's opportunity to receive therapy directed toward improving motor function in a paretic limb after stroke, particularly if the period of motor recovery is likely to continue after hospital discharge. Although researchers have reported significant motor recovery in the paretic arm up to 16 weeks poststroke,[2,8,9] many patients with stroke-related motor impairments are being discharged home, often with limited home health or outpatient therapies, long before this time period has passed. Length of stay in inpatient rehabilitation hospitals after stroke currently averages from 20 to 23 days.[10]

Although functional independence is certainly an important goal for patients receiving stroke

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rehabilitation, outcome studies[8,11] have reported that loss of upper-limb motor function is one of the greatest long-term deterrents to self-care and involvement in social activities up to 4 years poststroke. This lack of congruence between the benefits of improving motor function in the paretic arm and the emphasis on functional performance ratings of the FIM during inpatient rehabilitation suggests that persons with stroke may not be receiving comprehensive, client-centered therapy services. Although many researchers are working to develop cost-effective therapies to improve motor outcomes after stroke, the ability to successfully implement novel rehabilitation methods will be limited if current reimbursement policies remain unchanged. Evidence is needed to support the use of rehabilitation resources to remediate motor impairments, in addition to addressing an individual's functional daily needs (i.e., self-care and mobility) after stroke.

Data from prior research at Burke Rehabilitation Hospital between 1996 and 1999[12,13] were retrospectively analyzed to examine gains in stroke motor recovery during the course of acute rehabilitation. Patients in this study received rehabilitation services prior to implementation of the prospective payment system for inpatient rehabilitation facilities,[10] and their length of hospitalization was approximately 2 times longer than that currently provided. Our main purpose was not to compare changes in motor abilities across treatment groups, as was previously reported,[12] but rather to examine whether each group improved between the admission and interim evaluations and from interim to discharge. Data from the interim and discharge evaluations allowed us to examine whether longer inpatient rehabilitation contributed to significant, continued gains in upper-limb motor abilities in these patients. Because timing of the interim evaluation was similar to the current length of stay for inpatient stroke rehabilitation,[10] this analysis provided a glimpse at the potential for improved upper-limb motor abilities after the time when most stroke patients today are discharged home with limited home health or outpatient therapies.

Table 1. Subject Characteristics

	Robot Therapy Group (n = 30)	Robot Exposure Group (n = 26)
Age (years)	62 ± 2.4	67 ± 2.3
Gender (female/male)	14/16	12/14
Paretic arm (left/right)	17/13	14/12
Type of stroke		
Hemorrhagic/nonhemorrhagic	4/26	3/23
Subcortex alone/cortex alone/subcortex and cortex	17/1/12	12/1/13
Lesion volume, cm^3	52.8 ± 11.4	76.6 ± 14.7
Stroke onset to rehab admission (days)	14 ± 0.9	16 ± 1.3
Rehab admission to clinical study admission (days)	9 ± 0.8	10 ± 0.9
Study admission to interim evaluation (days)	17 ± 0.6	18 ± 0.9
Interim evaluation to discharge (days)	17 ± 1.3	19 ± 1.6
Total days in inpatient rehabilitation (days)	43 ± 1.3	47 ± 2.8

Values are expressed as mean ± standard error. No significant between-group differences were found for any of these subject characteristics.[12] Although the robot exposure group showed a trend for sustaining larger volume strokes, a review of Table 3 indicates that this did not affect clinical score ranges.

METHODS

Subjects

Fifty-six stroke survivors admitted to an inpatient rehabilitation stroke unit between 1996 and 1999 after a single, unilateral stroke volunteered to participate in robotic therapy.[12] Subjects ranged in age from 27 to 83 years and presented with hemiparesis or hemiplegia of the upper and lower extremity. Sensory or visual field impairment, aphasia, and impaired cognition were not exclusion criteria, but all participants needed to be able to follow simple instructions during therapy. Patients participated in 1 of 2 treatment groups, as detailed below. Patient characteristics (including age, gender, stroke onset to rehabilitation admission, and type of lesion) were comparable across groups[12] (see Table 1). All subjects gave informed consent to take part in the study, which was approved by the institutional review board of Burke Rehabilitation Hospital and the Committee on the Use of Humans as Experimental Subjects at the Massachusetts Institute of Technology.

Intervention

Subjects were randomly assigned to either an experimental (robot therapy) or control (robot exposure) group.[12] Individuals in the robot therapy group were seen for five 1-h sessions each week and participated in at least 25 sessions of sensorimotor robotic training for the paretic arm.

Patients were asked to perform goal-directed, planar reaching tasks that emphasized shoulder and elbow movements. When the patient was unable to reach toward a designated target during therapy, the robot provided movement assistance.

Several factors differentiated the experimental and control groups. Individuals assigned to the robot exposure group were seen for only 1 h per week during their inpatient hospitalization. Patients were asked to perform the same planar reaching tasks as the robot therapy group. However, when the subject was unable to reach toward a target, he would assist with the unimpaired arm or the technician would help to complete the movement. In this group, the robot did not actively assist the patient's movement attempts. Further details of these interventions have been previously reported.[12-14]

Robot therapy was delivered with MIT-MANUS, a robot specifically designed and built for clinical, neurologic applications.[15,16] While participating in this clinical trial, all subjects also received conventional, interdisciplinary rehabilitation services.

Measures

To ensure the consistency of testing procedures, the same blinded therapist performed a patient's evaluations throughout the course of study involvement. Admission, discharge, and interim evaluations (completed approximately 3½ weeks after hospital admission) were administered. Measures included the Fugl-Meyer test of upper extremity function[17,18]; the Motor Status Score[14,19]; and the MRC test of motor power.[20,21] The Motor Status Score provided a more detailed measure of upper-limb isolated movement than the Fugl-Meyer allows and is composed of shoulder/elbow and wrist/hand subscales. The MRC test of motor power[20,21] was used to rate strength of the paretic arm during 4 actions: shoulder flexion and abduction and elbow flexion and extension. Reliability of these clinical evaluations has been reported.[18,19,21] In addition, the FIM[6] was completed at admission and discharge to measure changes in functional motor abilities.

Data Analyses

Both nonparametric and parametric analyses were performed and yielded similar results. To compare group changes over time, we completed 2 (group) × 3 (admission, interim, discharge evaluation) analyses of covariance (ANCOVAs) for each clinical outcome measure, using admission score as the covariate. Also reported are results of paired *t* tests that examined within-group changes in upper-limb motor abilities on each clinical impairment scale between admission and interim evaluations and from interim to discharge. To reduce the likelihood of type I errors during these within-group analyses, Bonferroni procedures were applied to the *t* test results.[22] Additional paired *t* tests were used to measure FIM score changes from admission to discharge. SPSS version 11.5 (SPSS, Inc., Chicago, IL) and Statview version 5.0.1 (SAS Institute, Inc., Cary, NC) were used for data analysis.

RESULTS

Days in Inpatient Rehabilitation

Descriptive data regarding time poststroke, time spent in the clinical trial, and length of inpatient rehabilitation are detailed in Table 1. The average time spent in rehabilitation between hospital admission and the interim evaluation was 26 days for the robot therapy group and 28 days for the robot exposure group. This period was approximately 5 days longer than that currently reported as the average length of rehabilitation hospitalization under Medicare guidelines.[10] The average length of rehabilitation from the interim evaluation to discharge was 17 and 19 days, respectively, for the robot therapy and robot exposure groups. There were no significant differences between groups on any of the clinical rehabilitation intervals ($P > 0.15$).

Clinical Evaluation Findings

Between-Group Differences

ANCOVAs revealed statistically significant group by time interactions for the Fugl-Meyer test, Motor Status Score for shoulder and elbow, and the MRC test of motor power. No significant group by time interactions were found on the Motor Status Score for wrist and hand (see Table 2). These results reinforced previous findings by Volpe and others.[12] When admission scores were held constant across groups, the ANCOVAs showed adjusted posttest scores to improve more in the robot therapy group across the 3 evaluation sessions (Table 2).

Table 2. Analyses of Covariance: Group by Time Comparisons

Evaluation (possible range) and Group	Admission Adjusted[a]		Interim Adjusted		Discharge Adjusted			
	M	*SE*	*M*	*SE*	*M*	*SE*	$F_{2,49}$	*P*
Fugl-Meyer test (0-66)								
Robot therapy group	9.6	0.0	14.1	0.6	16.8	1.2	5.21	0.009
Robot exposure group	9.6	0.0	11.9	0.6	15.2	1.3		
Motor Status Score, shoulder/elbow (0-40)								
Robot therapy group	7.3	0.0	12.2	0.6	14.4	0.7	3.16	0.05
Robot exposure group	7.3	0.0	10.6	0.6	11.6	0.8		
Motor Status Score, wrist/hand (0-42)								
Robot therapy group	3.0	0.0	4.7	0.7	5.7	1.0	0.33	0.72
Robot exposure group	3.0	0.0	3.8	0.8	4.8	1.1		
MRC motor power score (0-20)								
Robot therapy group	3.0	0.0	5.5	0.3	6.8	0.4	3.23	0.05
Robot exposure group	3.0	0.0	4.7	0.4	5.1	0.5		

a. Adjusted means and standard errors derived from analysis of covariance are presented.

Table 3. Clinical Evaluation Ranges and Mean Scores

	Robot Trained Group (n = 30)		Robot Exposure Group (n = 26)	
	Range	*M* ± *SE*	Range	*M* ± *SE*
Fugl-Meyer test (max = 66)				
Admission	0-40	8.6 ± 1.6	2-58	10.5 ± 2.6
Interim	4-49	13.2 ± 1.8	2-57	12.9 ± 2.8
Discharge	4-58	15.7 ± 2.0	4-64	16.3 ± 3.1
Motor Status Score, shoulder/elbow (max = 40)				
Admission	0-33	7.2 ± 1.5	0-36	7.2 ± 2.1
Interim	0-39	12.4 ± 1.5	0-37	10.4 ± 2.1
Discharge	1-38	14.4 ± 1.4	0-39	11.4 ± 2.1
Motor Status Score, wrist/hand (max = 42)				
Admission	0-24	1.9 ± 0.9	0-37	4.1 ± 1.9
Interim	0-31	3.6 ± 1.3	0-37	5.0 ± 2.3
Discharge	0-39	4.4 ± 1.6	0-39	6.1 ± 2.2
MRC motor power score (max = 20)				
Admission	0-13	3.0 ± 0.6	0-14	2.9 ± 0.9
Interim	0-15	5.6 ± 0.7	0-16	4.5 ± 1.0
Discharge	1-14	6.8 ± 0.6	0-15	4.9 ± 0.9

Within-Group Differences

Robot therapy group. Mean (unadjusted) clinical scores for both patient groups are reported in Table 3. Significant improvements were found between the admission and interim evaluations on 3 measures and also from interim to discharge on the Motor Status Score for shoulder and elbow and MRC test of motor power (Table 4). After Bonferroni procedures for multiple analyses were applied, gains in Fugl-Meyer scores from interim to discharge approached significance (P = 0.06). Changes in the Motor Status Score for wrist and hand were not significant for either period. These findings indicate that patients who received sensorimotor robot therapy to improve control of shoulder and elbow movements experienced significant reductions in motor impairment of the paretic arm up to 43 days after admission to rehabilitation (see Table 1).

Robot exposure group. Significant gains were evident between admission and interim evaluations and from interim to discharge on the Fugl-Meyer test. Statistically signifi- cant improvements were also found between admis- sion and interim evaluations on the Motor Status Score for shoulder and elbow and on the MRC test of motor power, but there was no significant improve- ment on these measures from interim to discharge (Table 4). In this group, gains in motor abilities (as measured by the Motor Status Score and motor power test) primarily occurred during the first 28 days of rehabilitation, prior to the interim evaluation.

Gains in FIM Scores

Patients in both experimental groups made significant improvements in FIM scores from admis-

Table 4. Clinical Evaluation Analyses

Evaluation	Robot Therapy Group (n = 30) $t(df = 28)$[a]	P	Adjusted P	Robot Exposure Group (n = 26) $t(df = 23)$	P	Adjusted P
Fugl-Meyer test						
Admission-interim	6.85	<0.0001	0.0008	5.22	<0.0001	0.0008
Interim-discharge	2.86	0.008	0.06	4.43	0.0002	0.002
Motor Status Score, shoulder/elbow						
Admission-interim	7.17	<0.0001	0.0008	6.17	<0.0001	0.0008
Interim-discharge	4.18	0.0003	0.002	1.71	0.10	NS
Motor Status Score, wrist/hand						
Admission-interim	2.33	0.03	NS	0.91	0.37	NS
Interim-discharge	1.64	0.11	NS	1.16	0.26	NS
MRC motor power score						
Admission-interim	7.02	<0.0001	0.0008	5.27	<0.0001	0.0008
Interim-discharge	3.15	0.004	0.03	1.21	0.24	NS

NS, nonsignificant.
a. Reported degrees of freedom for paired t tests reflect lack of interim data for 1 patient in the robot therapy group and 2 patients in the robot exposure group.

Table 5. Functional Independence Measure (FIM) Scores by Experimental Group

Group	FIM Upper Limb Self-Care (max = 42) Admission	Discharge	FIM Motor Upper and Lower Limbs (max = 77) Admission	Discharge	FIM Cognitive (max = 35) Admission	Discharge
Robot trained						
Mean ± standard error	19.6 ± 0.8	29.9 ± 1.2*	30.0 ± 1.3	53.5 ± 1.8*	24.9 ± 1.1	30.4 ± 0.8*
Mean per item score	3.3	5.0	2.7	4.9	4.9	6.1
Robot exposure						
Mean ± standard error	16.3 ± 1.1	25.0 ± 1.5*	25.1 ± 1.7	44.6 ± 2.6*	17.3 ± 1.5	23.2 ± 1.2*
Mean per item score	2.7	4.2	2.3	4.1	3.5	4.6

*Change from admission to discharge significant at $P < 0.0001$.

sion to discharge ($P < 0.0001$), as shown in Table 5. On average, patients in both groups attained a score of 4 to 5 (minimal assistance to supervision) on functional motor tasks (e.g., upper-body dressing, transfers) and a score of 4 to 6 (minimal assistance to modified independence) on cognitive subscale items at discharge.

DISCUSSION

This retrospective analysis of experimental data provided a unique opportunity to examine stroke motor recovery over a 6- to 7-week course of inpatient rehabilitation. The interim evaluations in this study were administered, on average, 3½ weeks after admission to rehabilitation; serendipitously, this time period is slightly longer than the total length of stay currently reported for Medicare patients.[10] As expected, we found significant gains in motor performance measures of the paretic arm at the time of our interim evaluation. More important, we found that statistically significant improvements continued beyond the first 3½ weeks of inpatient rehabilitation.

We realize that the generalization of these findings is limited to persons with similar stroke characteristics in the early stages of stroke recovery. However, our results indicate that current health care trends, which emphasize FIM-based criteria for hospital discharge and limit the duration and intensity of therapy services after the first 3 to 4 weeks of rehabilitation, do not adequately address a stroke survivor's potential for motor recovery. The potential for these individuals to maximize motor function of the paretic arm is at risk, particularly if remediative therapies directed toward motor retraining are discontinued too soon after stroke onset.

Longer-term gains in this study were more apparent for patients in the robot therapy group, who received intensive sensorimotor training for the paretic shoulder and elbow. Since both groups in this study were similar in terms of type of stroke (infarct vs. hemorrhage), location, and volume of the stroke lesion,[12] it is reasonable to assume that differences in motor recovery were related to the type of therapy provided over the course of rehabilitation. Notably, these robot-induced improvements were remarkably resistant to deterioration up to 3 years after discharge from therapy.[23]

Comparing the recovery of the 2 groups indicates that extra time in conventional therapy alone may do little to promote gains in motor abilities after the first few weeks of inpatient rehabilitation. Indeed, our findings lend support to the current practice limiting inpatient stays. Although it is possible that persons in the robot therapy group had better outcomes simply because they received more time in therapy, other researchers have found that the type of therapy provided (e.g., repetitive training of isolated movements, constraint-induced therapy, robot training) can have a greater effect on stroke-related motor impairments than increased therapy time alone.[24-27] Indeed, our results suggest that certain characteristics of robot training contribute to enhanced recovery of upper-limb motor function. These may include task-specific practice, intensity of repetition, robotic assistance, enhanced sensory feedback, continual motivation (because every trial yields a degree of success, even if robot assistance is required), and others. Although we do not yet know which of these factors is most critical, it is apparent that robotic therapy supports further recovery. Unlike patients in the robot exposure control group, those who received robot therapy did not show evidence of a plateau in clinical scores. It appears that the full potential for recovery was not reached even with the additional time spent in robotic therapy; further robotic therapy may afford additional benefits.

A comparison between discharge scores on the upper-limb subscale of the FIM and the relatively low Motor Status Scores for the wrist and hand implies that patients in both groups, on average, did not have sufficient distal control of the paretic arm to accomplish FIM self-care items without using compensatory, 1-handed techniques (see Tables 3 and 5). We did not control for the treatment interventions used during conventional therapy and understand that intensive training of distal motor function was not regularly provided. Although compensation for impaired motor function may have been necessary to complete basic activities of daily living, its early use can preclude a patient's attempts to involve the paretic limb during bilateral tasks. This behavior is believed to result in a phenomenon of learned nonuse,[5] which can contribute to increased pain, soft tissue shortening, and diminished motor function in the paretic arm.

A growing body of evidence has demonstrated immediate effects of intensive training on motor recovery and learned nonuse during both acute and chronic phases of stroke recovery.[24-26,28,29] In addition, separate follow-up analyses have shown that motor gains in the paretic arm are sustained in persons who receive intensive robot therapy and actually continue at a modest rate, up to 3 years after discharge from inpatient rehabilitation.[4,23] This research indicates that intensive movement therapies are capable of producing significant and sustained gains in motor function after stroke that do not end with discharge from inpatient rehabilitation. The fact that patients who received robotic therapy showed continued upward trends in motor scores from interim to discharge is consistent with improvements reported in persons more than 8 mo poststroke.[30-32] As a whole, this evidence suggests that the course of stroke recovery may be more related to the cessation of exercise and inadequate attempts to functionally use the paretic limb than to neural barriers that cannot be overcome.[33]

In conclusion, we understand that cost-containment measures will continue to influence the delivery of rehabilitation services. Our "take home" message is that effective and intensive therapy should not be confined to inpatient rehabilitation immediately following stroke onset. Novel technologies and treatment methods, such as robotics or telerehabilitation, promise to deliver repetitive movement therapy across the continuum of care, from inpatient rehabilitation to home and outpatient settings. More effective interventions will arise from scientific knowledge concerning an individual's recovery potential after stroke and the therapeutic mechanisms likely to produce the greatest benefit. This retrospective study reinforced the hypothesis that significant reductions in stroke-related motor impairments continue after the first few weeks of inpatient rehabilitation when patients are given intensive robot training. Research evidence must be used to advocate for the reimbursement of rehabilitation to optimize motor function of the paretic limb, in addition to improving functional status on the FIM. Only through the implementation of comprehensive, client-centered rehabilitation programs will we be able to help persons with stroke attain their long-term goals.

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