
Objective: Assessment of the effectiveness of constraint-induced (CI) movement therapy and quantitative evaluation of the effects of CI therapy.

Design: Intervention study; case series; pretreatment to posttreatment measures and follow-up 3 months after intervention.

Setting: An outpatient department.

Patients: Five chronic stroke patients with moderate motor deficit; convenience sample.

Interventions: CI therapy consisting of restraint of the unaffected upper extremity in a sling for 14 days combined with 6 hours of training per weekday of the affected upper extremity.

Main Outcome Measures: Actual Amount of Use Test (AAUT), Motor Activity Log (MAL), Wolf Motor Function Test (WMFT), and Arm Motor Ability Test (AMAT).

Results: There was a substantial improvement in the performance times of the laboratory tests (AMAT, WMFT, p < .01), and in the quality of movement (AMAT, WMFT, p < .04); especially in the use of the extremity in "real world" environments (AAUT, p = .02), supported by results of quantitative evaluation. The effect sizes were large and comparable to those found in previous studies of CI therapy.

Conclusions: CI therapy is an efficacious treatment for chronic stroke patients, especially in terms of real world outcome.

© 1999 by the American Congress of Rehabilitation Medicine and the American Academy of Physical Medicine and Rehabilitation

STROKE IS THE LEADING cause of disability in the adult population and is frequently accompanied by substantial loss of motor function. Although acute and postacute rehabilitation programs are available to stroke patients, substantial impairment and disability may persist for years. In a long-term follow-up study of stroke, it was found that 56% of the patients tested 5 years after stroke still had pronounced hemiparesis, which was the most common complaint at that time. The literature on the efficacy of rehabilitation programs targeting motor dysfunction (for a comprehensive review, see Duncan) suggests that few effective methods are available and that their effects on chronic motor disability after stroke may be especially weak and not permanent.

A possible explanation for the substantial remaining motor deficits in stroke patients might be the occurrence of learned nonuse, a phenomenon first described by Taub. Stroke patients who initially attempt to use the affected extremity find themselves unable to do so because the process of spontaneous recovery of function has not yet proceeded sufficiently far. This results in the experience of failure or punishment for attempts to move the extremity and in positive reinforcement for compensatory movements by the unaffected extremity—a learning process that might be supported by the teaching of compensatory activity during rehabilitation. This learned nonuse impedes attempts to further rehabilitate the affected extremity. Based on this theoretical account, constraint-induced (CI) movement therapy was developed. It is designed to overcome this learned disability by restraining the unaffected extremity and training the affected extremity, thereby leading to increased practice in the use of the affected extremity for a period of 2 weeks.

One uncontrolled and two controlled treatment outcome studies have tested CI therapy. A study by Wolf and associates used unaffected limb restraint without concurrent training for 25 subjects with hemiplegia that had resulted from stroke or head injury and observed them until 1 year after treatment. The main change occurred in speed of task execution. Taub and colleagues compared a group of four patients who received CI therapy to five subjects who served as attention controls. The treatment group carried out specified tasks under supervision for 6 hours per day for the 10 weekdays of the treatment period; the control group received instructions to focus attention on the affected limb, placebo physical therapy sessions, and self-motion exercises. After the 2-week intervention there were substantial decreases in performance speed, significant gains in quality of movement in the laboratory, and, in particular, very substantial increases in actual amount of use of the affected extremity in the life environment. Moreover, the therapeutic gains persisted at the 2-year follow-up. In a more recent study, 20 chronic stroke patients were treated with restraint of the unaffected, and training of the affected, upper extremity. The patients showed highly significant improvement of upper extremity function at the posttreatment assessment as well as at the 1-month follow-up. Table 1 contains the characteristics of the reported studies as well as their effect sizes (ESs). Effect sizes were computed by subtracting the posttreatment or follow-up mean of each individual variable from the pretreatment mean and dividing it by the posttreatment or follow-up standard deviation. The variable-specific ESs were subsequently averaged to obtain a studywise ES.
The purpose of this study was to (1) replicate the findings of Taub and coworkers in a different laboratory, and (2) compare the ESs of the CI treatment carried out in our laboratory to those reported previously.

METHODS

Subjects

Five patients (4 women, 1 man) participated in the study. Their ages ranged from 47 to 66 years, with a median age of 53 years. Time after stroke varied from 3 to 15 years, with a median time after stroke of 6 years. All subjects had hemiparetic right-arm dominance; four were hemiparetic on the right side and one, on the left. They were recruited from a Berlin stroke self-help group. Immediately poststroke, each patient participated in 6 to 8 weeks of rehabilitation; subsequently, they received conventional physical therapy once or twice a week for varying amounts of time. The following exclusion criteria were used: (1) stroke experienced less than 1 year earlier; (2) serious sensory, cognitive, or aphasic deficits (Mini-Mental State13 scores ranged from 26 to 30; Token Test14 scores, from -2 to 2) or severely depressed mood (CES-D Scale15 scores ranged from 6 to 22); (3) lesion in the primary sensory or motor areas of the cortex; (4) inability to extend at least 10° at the metacarpophalangeal and interphalangeal joints and 20° at the wrist; (5) ability to make extensive use of the involved upper extremity (Motor Activity Log score above 2.5) so that significant further improvement could not be expected; (6) left-arm dominance, and (7) age more than 80 years.

For all patients, magnetic resonance imaging (MRI) of the lesion was obtained at the time of the treatment (1.5-Tesla Siemens Magnetom Vision,16 T1 weighted scans, slice thickness 1mm, repetition time 22msec, echo time 10msec). Patient 1 showed a lesion in the posterior portion of the left internal capsule; patient 2 had an extended lesion in the left insula and the temporoparietal transition; patients 3 and 4 showed lesions in the left insula and left putamen; and patient 5 had a lesion in the right putamen and caudate nucleus (fig 1). The procedure of the study was approved by the local ethics review board and all subjects signed informed consent after receiving a detailed explanation of the study procedures.

Assessment

The Actual Amount of Use Test (AAUT) was developed by Taub as an implicit measure of actual use of an upper extremity. The test contains 21 items (eg, filling out a form). All patients signed informed consent for videotaping before the assessment phase but were not aware that they were being videotaped while performing AAUT activities. A rating scale with three categories (ranging from nonuse [0] to functional participation of the affected extremity in the activity at whatever level of proficiency [2]) is used by the observer to judge the frequency of use of the arm, and a six-category rating scale (ranging from nonuse [0] to normal [5]) is used to judge the quality of movement. The AAUT represents an objective and unobtrusive measure of motor function of the affected upper extremity.

A structured interview, the Motor Activity Log (MAL), was used to determine how often the patients used the affected extremity during the activities of daily life (ADL) outside the laboratory. For a specified time period, the patient had to indicate the amount of use of the affected arm for 20 individual
logic examination. Before and after the 2-week intervention procedure consists of 13 complex tasks that include one to three components each, with a total of 28 component tasks. Sample items are eating with a spoon, drinking from a cup, putting on a sweater, and buttoning it. Speed of task performance is recorded by a stopwatch, and functional ability and quality of movement; both were noted on separate 6-point scales.

Two laboratory motor tests were used. Performance on each was videotaped. The Wolf Motor Function Test (WMFT) was developed to quantify motor function after stroke and traumatic brain injury. A modified version of the test consists of 16 items ranging from simple movements, such as elbow extension and limb flexion for placing the hand on a table, to functional movements, such as lifting a soda can in simulated drinking or turning cards over; to ADL, such as folding a towel. Performance time is measured on 15 items; one item serves to determine the force. The quality and functionality of the test movements are evaluated by a separate 6-point rating from videotapes.

The Arm Motor Ability Test (AMAT) assesses the motor ability of the hand and arm during ADL tasks. The test consists of 13 complex tasks that include one to three components each, with a total of 28 component tasks. Sample items are eating with a spoon, drinking from a cup, putting on a sweater, and buttoning it. Speed of task performance is recorded by a stopwatch, and functional ability and quality of movement are rated on 6-point scales from video recordings of the patient’s performance (identical to the modified WMFT). The test has been found to have high reliability, internal consistency, and validity.

The videotapes of all motor tests were rated by an observer unaware of the pre- or posttreatment patient’s performance (identical to the modified WMFT). The patients kept a diary in which they recorded all the activities that were performed with the affected arm either with the sling and splint in place or removed. On weekends, the patients continued to wear the sling and practiced the tasks they had learned in the laboratory for at least 1 hour per day.

In addition to the unaffected arm restraint, the patients were given behavioral training of the affected limb for 6 hours per day on each of the 10 weekdays of the 14-day treatment period. Based on the results of the pretreatment motor assessment, 12 to 16 specific exercises were chosen for training (shaping) that were focused on improving movements involving the maximum deficit. Shaping tasks included such activities as flipping dominos or stacking blocks. In the five patients trained in this study the deficits ranged from abduction and flexion at the shoulder, pronation/supination of the forearm, extension of the wrist or elbow, isolated finger movements, and fine motor skills. Each shaping task was repeated 10 times in a block of trials, and blocks of trials for each task and for different tasks were repeated throughout the day, with appropriate rest intervals between blocks. The difficulty of the tasks was continuously increased in small steps and contingent verbal reinforcement was given for the slightest improvement in performance time or quality of movement.

### Data Analysis

For all the variables in the study Friedman one-way analysis of variance (ANOVA) was used to determine the overall change from pretreatment to posttreatment and to follow-up. These ANOVA procedures were followed by pretreatment to posttreatment and pretreatment to follow-up one-sided Wilcoxon rank sign tests. Since four dependent variables were used in the study, we refrained from Bonferroni corrections in order not to further reduce the power of our tests. In addition, ESs were computed for each individual variable for both the pretreatment to posttreatment and the pretreatment to follow-up comparisons. Table 2 contains the means and standard deviations of all the variables used in the study and the ESs.

### Results

#### Efficacy of the Intervention

The AAUT, which is considered to reflect real world behavior, showed very substantial improvements in the use of the affected extremity after the training period. Amount of use of the affected extremity in the laboratory situation almost doubled (increase of 98%), and quality of movement increased by 124% in the pretreatment to posttreatment comparison (both Wilcoxon tests: Z = -2.02, p = .020; table 2). The MAL showed a 166% increase in quality of movement of the affected extremity at posttreatment and 165% at follow-up (Friedman test: χ² = 6, p = .049; individual subject pretreatment to posttreatment and pretreatment to follow-up comparisons, all p values < .05). A similarly strong improvement occurred on the...
The most striking finding of this study was the dramatic improvement in the amount of use of the affected extremity in real-world environments, as shown by the more than 100% increase in use and the large ESs on both the MAL and the AAUT. The agreement of the objective measure (AAUT) and the patients' subjective report (MAL) indicated that the improvement in the amount of use of the affected limb is transferred from the clinic to the real world situation.

Smaller but significant improvements were found on the AMAT and the WMFT tests with respect to speed of task performance, quality of movement, and functional ability. The increased use of the affected arm in the real-world environment is the more interesting because quality of movement, although substantially improved, still exhibited a substantial deficit. The gap between the moderate improvement in motor function on the laboratory tests and the massive improvement in actual amount of use of the limb in the life environment is the area within which CI therapy operates and produces therapeutic effects. There is often a very large difference between what a stroke patient can do and what she or he does; CI therapy reduces this difference. As noted above,6,8 the disparity between the motor capacity of many stroke patients and their actual use of the limb may be due to learned nonuse that develops in the early poststroke period but which can be overcome by the application of an appropriate technique, such as CI therapy.

It is unlikely that the current results are based on spontaneous improvements in motor function. All the patients in this study were several years poststroke, and their condition had not improved for many months to years. Although some (nonsignificant) regression took place, the improvements were retained at the 3-month follow-up, suggesting that the therapy had produced a long-term treatment effect, as noted in previous research.8 Taken together, the results from the previous studies and this experiment suggest that CI therapy is a powerful technique for the modification of motor deficit late after stroke for the substantial number of patients for whom it is applicable.

This independent replication in another laboratory of CI therapy proved to be as successful as the original study. Larger sample sizes with corrections for multiple tests used to be used in further research to substantiate the findings of this initial replication study. Based on the large effects produced by CI therapy in chronic stroke patients, there is a need for application of CI therapy with acute and subacute stroke patients where it...
might be possible to avoid completely the development of a portion of the chronic motor deficit that would otherwise develop.

References

Supplier
a. Siemens AG, Nürnberger Str. 74, D-91050 Erlangen, Germany.