Combined Bracing, Electrical Stimulation, and Functional Practice for Chronic, Upper-Extremity Spasticity

Kathleen Hardy, Kacia Suever, Amie Sprague, Valerie Hermann, Peter Levine, Stephen J. Page

KEY WORDS

- braces
- combined modality therapy
- electric stimulation
- muscle spasticity
- task performance and analysis
- upper extremity

OBJECTIVE. Conventional methods for managing upper-extremity (UE) spasticity are invasive, usually require readministration after a certain time period, and do not necessarily increase UE function. This study examined efficacy of combining two singularly efficacious modalities—UE bracing and electrical stimulation—with functional training to reduce UE spasticity and improve function.

METHOD. Two chronic stroke patients exhibiting UE spasticity were administered the Modified Ashworth Scale (MAS), the upper-extremity section of the Fugl-Meyer Impairment Scale (FM), the Box and Block Test (B&B), and the Arm Motor Ability Test (AMAT). They were then individually fitted for a brace and subsequently participated in treatment sessions occurring 2 days/wk for 5 wk, consisting of (1) 30-min clinical sessions, during which the UE was braced in a functional position while cyclic electrical stimulation was applied to the antagonist extensors of the tricep and forearm, and (2) 15-min, clinically based training sessions, occurring directly after the clinical session.

RESULTS. After intervention, participants exhibited 1-point reductions in MAS scores for the affected fingers, FM score increases, and increased ability to perform AMAT activities,. Three months later, both participants retained these changes.

CONCLUSION. Data point to a noninvasive, promising method of managing spasticity and rendering functional changes.

Kathleen Hardy, MS, OTR/L; Kacia Suever, MS, OTR/L; and **Amie Sprague, MS, OTR/L,** were Graduate Students, Master of Occupational Therapy Program, Xavier University, Cincinnati, OH, at the time of the study.

Valerie Hermann, MS, OTR/L, is Research Occupational Therapist, Department of Rehabilitation Sciences, University of Cincinnati Academic Medical Center (UCAMC), Cincinnati, OH.

Peter Levine, PTA, is Senior Research Assistant, Department of Rehabilitation Sciences, UCAMC, Cincinnati, OH.

Stephen J. Page, PhD, OTS, is Associate Professor, Departments of Rehabilitation Sciences; Physical Medicine and Rehabilitation; Neurology; and Neurosciences, UCAMC; Director, Neuromotor Recovery and Rehabilitation Laboratory, Drake Rehabilitation Center, Cincinnati, OH; and Member, Greater Cincinnati/Northern Kentucky Stroke Team, UCAMC, 3202 Eden Avenue, Suite 315, Cincinnati, OH 45267-0394; Stephen.Page@uc.edu. Page is also a student in the Occupational Therapy Program at The University of Findlay, Findlay, OH.

Stroke remains the leading cause of disability in the United States, and it causes upper-extremity (UE) impairments in >80% of survivors (Rosamond et al., 2007). Among the myriad stroke-induced impairments, UE spasticity may be one of the most devastating, because it can be painful, frequently compromises performance of activities of daily living (ADLs), and diminishes independence (Sommerfeld, Eek, Svensson, Holmqvist, & von Arbin, 2004). Consequently, treatments that decrease spasticity and increase functional ability are urgently needed (Gustafsson & McKenna, 2003, p. 205).

The most promising UE spasticity treatments involve pharmacologic management. For example, many studies have reported significantly reduced UE spasticity using selective chemodenervation with botulinum toxin A (BTX; see Cardoso et al., 2005, for a review). Others have reported spasticity reductions after injecting alcohol or phenol into a specific nerve (Kong & Chua, 1999) or administering antispastic medications intrathecally (Ivanhoe, Francisco, McGuire, Subramanian, & Grissom, 2006) or orally (Meythaler, Clayton, Davis, Guin-Renfroe, & Brunner, 2004). Although promising, these approaches are invasive and often require readministration, and the procedures and medications involved in these techniques are not always covered by patients' insurance. More important, spasticity reductions brought about by these techniques do not necessarily lead to functional improvements (Gallichio, 2004).

When accompanied by functional training, UE bracing and electrical stimulation have each shown independent promise in reducing UE spasticity (Alon, Sunnerhagen, Geurts, & Ohry, 2003). Work has also suggested that the combination of these promising modalities decreases UE spasticity and increases function in spastic cerebral palsy (Ozer, Chesher, & Scheker, 2006). As a next step, we examined the application of this combined technique on spasticity, disability, impairment, and function in 2 chronic stroke patients. We hypothesized that patients would exhibit modest spasticity reductions and increased ability to perform some valued activities. The study was important given the noninvasive nature of the intervention and the possibility of functional changes as a result of study participation.

Method

Participants

Participants were referred to the pool of potential study participants from outpatient therapy clinics in the midwestern United States. A research team member screened volunteers using the following inclusion criteria: (1) stroke >6 mo before study enrollment (no upper limit was used, because motor changes have been reported in studies enrolling patients at various chronicities); (2) affected UE spasticity ≥2 on the Modified Ashworth Scale (MAS) at the wrist and fingers, because these were most likely to limit ability to perform valued activities; and (3) a minimum level of active, affected UE movement to ensure participation in the activity component of the study training regimen. We operationalized this level as the ability to actively flex the affected wrist a minimum of 10° and actively flex the MCP joints of the thumb and at least two additional MCP joints in two additional fingers ≥10°. We based this decision on studies showing that patients demonstrating these movement capabilities typically exhibit the largest response to motor interventions targeting the affected arm (Hendricks, van Limbeek, Geurts, & Zwarts, 2002). In addition, patients were required to (1) score >24 on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) and (2) be between ages 18 and 90 at the time of enrollment. Exclusion criteria were (1) currently receiving ongoing pharmacologic treatment of spasticity, (2) received any spasticity treatment within the 6 mo before consent (i.e., bracing, baclofen, phenol, BTX), (3) currently receiving occupational therapy treatment, and (4) current participation in any experimental rehabilitation or drug studies.

Three participants initially came forward for this study. All 3 had contacted the study team in response to advertisements placed in local outpatient therapy clinics. Although all 3 appeared eligible, 1 participant was excluded because of lack of transportation and ability to attend sessions. Thus, using the preceding study criteria, 2 participants were found eligible and agreed to participate. Both participants had experienced middle cerebral arterial strokes affecting their dominant arms. Demographics are shown in Table 1.

Apparatus: Description and Donning

The orthotic device incorporating electrical stimulation (ODES) was a dynamic brace that extended from the proximal upper arm to the digits (Ultraflex Inc., Pottstown, PA). Before donning the brace, electrical stimulation was applied to the affected UE via surface electrodes. Dual stimulation was elicited for simultaneous elbow, wrist, and finger extension by placing the electrodes on the antagonist extensors of the tricep and forearm (Figure 1A). Stimulation parameters were (1) pulse rate, 45 Hz; (2) stimulation phase, 7 s; (3) ramp up, 2 s; and (4) ramp down, 2 s. Stimulation was adjusted according to each participant's toleration of stimulation and the milliamps at which a muscle contraction was visible in the targeted muscle groups.

After electrode placement, a protective arm sleeve was donned to enhance orthotic comfort. The ODES was placed over the sleeve from the upper arm to the fingertips, with hinges placed at the elbow, wrist, and metacarpophalangeal joints with a lockable elbow hinge (Figure 1B). Once the orthotic was donned, the fingers were secured in a static digit pan, and the elbow hinge was locked. The brace donning protocol was as follows: (1) Place the pronated, flexed forearm in the middle segment of the orthotic device; (2) secure the wrist strap; (3) supinate forearm and extend elbow; (4) place upper segment of the orthotic device over biceps; (5) secure straps of upper and middle segments of the orthotic device; (6) place thumb in thumb segment of the orthotic device; (7) secure hand strap; (8) extend digits and place in digit segment of the orthotic device; (9) secure straps of digit segment; (10) reposition UE or orthotic device as needed; and (11) tighten straps of the orthotic device.

Outcome Measures

Because this study was the first to examine this regimen in people with stroke, we sought to assess its impact on

Table 1. Participant Demographics

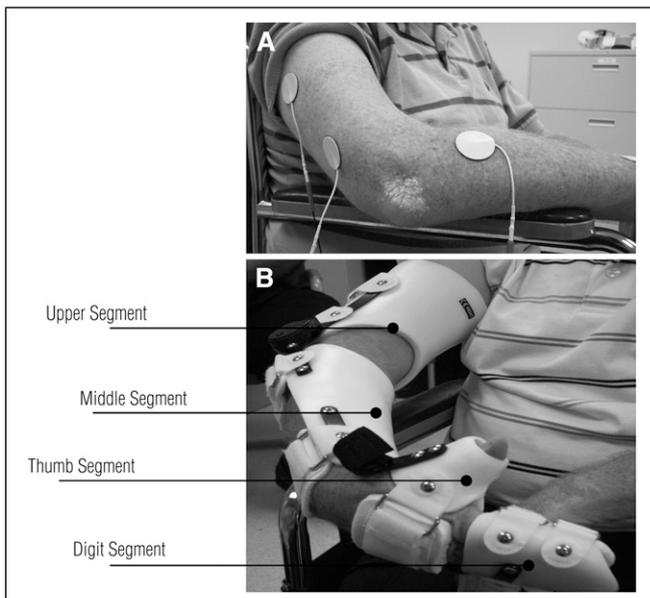| Participant	Months Since Stroke	Affected Side	Type of Stroke	Age	Gender
A	25	Left	Ischemic	76	Female
B	47	Left	Hemorrhagic	69	Female

Figure 1. The orthotic device incorporating electrical stimulation (ODES) electrode configuration (A) and brace (B).

a multitude of UE domains. Thus, the following battery of UE measures was administered 1 wk before intervention and 1 wk after intervention by a study team member with 8 yr experience administering the measures:

- The UE items of the Modified Ashworth Scale (MAS; Bohannon & Smith, 1987) are based on an ordinal-level scale (0–4) to assess spasticity at the elbow, wrist, fingers, and thumb.

- The UE section of the Fugl-Meyer Impairment Scale (FM; Fugl-Meyer, Jääskö, Leyman, Olsson, & Steglind, 1975) assessed isolated movement at each joint (UE impairment). Data are drawn from a 3-point ordinal scale (0 = *cannot perform;* 2 = *can perform fully*) applied to each item, and items are summed to provide a maximum score of 66.

- The Box and Block test (B&B) is used to measure disability and has been found to be both valid and reliable (Platz, Eichhof, Nuyens, & Vuadens, 2005). It is a timed grasp-and-release test in which participants are seated in front of a box with a large partition separating the box into two equal squares. Colored blocks are situated on one side of the partition, and participants are asked to move as many blocks as possible from one side to the other with the affected hand.

- The Arm Motor Ability Test (AMAT; Kopp et al., 1997) was used to determine whether changes occurred in activity limitation. The AMAT is a 13-item test in which ADLs are rated according to a functional ability scale that examines affected limb use (0 = *does not perform with affected arm;* 5 = *does use arm at a level comparable to unaffected side*) and a Quality of Movement Scale (0 = *no movement initiated;* 5 =

normal movement). ADLs, which are further subdivided into subactivities to be rated, included use of a knife and fork, eating with a spoon, combing hair, and tying shoelaces. Given the lack of distal movement among participants and the goals of the intervention, AMAT Items IV ("drink from mug"), IX ("wipe up spilled water"), XII ("prop on extended affected arm"), and XIII ("light switch/door") were omitted. In addition, a button-down shirt was substituted for a cardigan in Item X, because none of the participants had experiences with or owned cardigans, but all owned button-down shirs. Thus, use of a button-down shirt was more occupationally meaningful to our participants.

AMAT items are also often timed. However, this study's primary goal was to examine patients' ability to perform valued activities and the intervention's influence on these abilities. Given this goal, we elected not to time participants during AMAT item performance. We also felt that speed changes would be somewhat academic in a spastic sample when compared with new ability to perform the movements.

- We also administered the Canadian Occupational Performance Measure (COPM; Law et al., 1990) to measure perceptions of current task performance and satisfaction with that performance. Through a standardized interview, clients identify on a scale ranging from 1 to 10 the importance of, perception of, and satisfaction with their performance. Once the top five performance behaviors are determined, they are used to guide treatment and determine changes in client perception.

Intervention

After consent, screening, and testing, the participants visited the study laboratory for a single, 30-min brace measurement session conducted by a certified prosthetist–orthotist. Two weeks later, when the fitted orthoses were available, the study's intervention phase began.

Stroke rehabilitative efforts optimally incorporate both clinic-based treatments to allow for impairment management and progression of exercises and home-based treatments to enable reintegration into the patient's home environment (Low, Roderick, & Payne, 2004). This study's regimen consistently consisted of clinical treatments and home-based treatments.

Clinical Treatment Sessions

Clinical treatment sessions were administered in the laboratory, 2 weekdays/wk, over a 5-wk period. Each clinical session lasted 45–60 min and was administered by an

occupational therapist research team member. The sessions included two components. The first component consisted of wearing the brace with stimulation for 30 min. Specifically, once the orthotic device was donned, a passive, cyclic stimulation sequence began consisting of a cycle pattern of 10 s to obtain muscle contraction, followed by 7 s of no stimulation.

The second study component occurred immediately after the bracing–electrical stimulation. Participants were administered 15–20 min of repetitive, task-specific, purposeful activities incorporating the affected UE without the brace on. Specifically, using the COPM, each participant identified motor behaviors that he or she wanted to relearn (e.g., writing, drinking from a favorite coffee cup). The therapist assisted in behavior selections, ensuring that each patient would be challenged, because this challenge appears to be a major factor in facilitating cortical plasticity (see Kleim et al., 2002). Therapy sessions then focused on performance of successive activities that collectively constituted the final desired task. The basic or most primitive version of the task was first addressed, and sequential movements were incrementally added to increase the challenge. Frequent verbal encouragement and hands-on assistance were provided. This regimen was based on recent, successful work that included this practice regimen (Page, Levine, Leonard, Szaflarski, & Kissela, 2008).

Home-Based Treatment Sessions

Home-based treatment sessions consisted of two 30-min sessions of the aforementioned bracing–electrical stimulation regimen occurring every weekday and followed by overnight wearing of the orthotic device without stimulation. Because patients were participating in a portion of the intervention while at home, logs were provided for documentation of device use time and nighttime wear. Although shorter in duration, the format of the home-based ADL exercises was also based on Page et al.'s (2008) home-based regimen.

Posttesting

One week after the final therapy session, each participant returned to the laboratory, at which time posttesting took place. The MAS, FM, B&B, and AMAT were again administered by the same examiner who administered the pretests. The examiner was unaware of whether participants had participated in a rehabilitative intervention.

A research team member contacted the participants by telephone 3 mo after intervention phase completion. At that time, they and their caregivers were asked about their current movement abilities and about how participation in the intervention had influenced their ability to perform valued activities. Because the participants had sometimes experienced transportation difficulties during the study, this was their preferred method of follow-up.

Results

During the course of the intervention, the participants complained of difficulty donning the ODES and reported occasional diminished desire to wear their braces as assigned. However, no persistent complaints, limitations in movement, or diminished compliance were observed, perhaps because the therapists addressed and adjusted needs associated with complaints. Home program compliance was 100% for both patients, as measured by home use logs; both participants attended all clinical sessions. Both patients donned their braces with assistance from their caregivers when at home.

After intervention, participants exhibited no MAS changes at their affected elbows or wrists. However, both exhibited 1-point reductions in their MAS scores for the affected fingers, reflecting reductions in finger spasticity levels (Table 2). Both participants exhibited FM score increases, reflecting reduced UE impairment, and Patient B exhibited a notable increase in her B&B score (Table 2). Both participants exhibited new or improved ability to perform AMAT items (Table 3).

At the 3-mo follow-up call, both participants indicated that they continued to retain these levels of

Table 2. Participants' Modified Ashworth Scale, Fugl-Meyer, and Box and Block Scores Before and After Intervention

	Score	
Test	Participant A	Participant B
Elbow[a]		
Pretest	1	3
Posttest	1	3
Wrist[a]		
Pretest	3	3
Posttest	3	3
Fingers[a]		
Pretest	3	4
Posttest	2	3
Fugl-Meyer		
Pretest	14	24
Posttest	18	26
Box and Block[b]		
Pretest	0	1
Posttest	0	8

[a]Modified Ashworth Scale score; elbow measurement was taken during elbow extension.
[b]Score denotes number of blocks transferred in 1 min.

Table 3. Participants' Arm Motor Ability Test Scores Before and After Intervention

Task	Participant A	Participant B
I. Cut meat/knife and fork task		
(1) Pick up utensils		
Pretest	0	2
Posttest	1	1
(2) Cut meat		
Pretest	1	1
Posttest	1	4
(3) Fork to mouth		
Pretest	0	2
Posttest	1	4
II. Foam "sandwich"		
(4) Pick up foam sandwich		
Pretest	2	3
Posttest	2	2
(5) Bring sandwich to mouth		
Pretest	1	3
Posttest	2	4
III. Eat with spoon		
(6) Pick up spoon		
Pretest	1	2
Posttest	0	0
(7) Pick up dried kidney bean with spoon		
Pretest	0	2
Posttest	1	4
(8) Bring spoon to mouth		
Pretest	0	2
Posttest	1	4
V. Comb hair		
(11) Pick up comb		
Pretest	1	2
Posttest	0	1
(12) Comb hair (120-s limit)		
Pretest	0	1
Posttest	1	2
VI. Open jar		
(13) Grasp jar top (bilateral task)		
Pretest	0	1
Posttest	1	1
(14) Screw jar top open (bilateral task)		
Pretest	1	1
Posttest	3	2
VII. Tie shoelace		
(15) Use both hands to tie the laces on the board in a bow (120-s limit, bilateral task)		
Pretest	0	1
Posttest	0	2
VIII. Use telephone		
(16) Bring phone receiver to ear		
Pretest	0	1
Posttest	1	1
(17) Dial phone number		
Pretest	1	1
Posttest	1	1

Task	Participant A	Participant B
X. Put on button-down shirt		
(20) Put affected arm in sleeve, shirt over affected shoulder (120-s limit, bilateral task)		
Pretest	0	1
Posttest	1	1
(21) Button two lower buttons (bilateral task)		
Pretest	1	3
Posttest	0	2
XI. Put on t-shirt		
(22) Arms in t-shirt sleeves (120-s limit, bilateral task)		
Pretest	0	1
Posttest	1	0
(23) Head through neck hole (120-s limit, bilateral task)		
Pretest	0	1
Posttest	0	0
(24) Pull down and straighten shirt (bilateral task)		
Pretest	0	1
Posttest	0	0

Note. Functional ability scores range from 0 to 5.

movement, which their caregivers corroborated. Both participants indicated that participation positively influenced their ability to perform valued activities, and both Patient B and her caregiver indicated that the patient was attempting many more activities (i.e., increased affected arm use) since the intervention, such as combing her hair with a brush and using eating utensils.

Discussion

The most promising UE spasticity treatments are invasive and tend to rely on pharmacologic inhibition of the spastic reflex. This study examined a noninvasive approach that combined management of the patient's current UE spasticity (bracing) with techniques thought to reduce spasticity (electrical stimulation) and increase cortical input (task-specific functional training). Although existing techniques offer limited functional gains, we hypothesized that this combined regimen would reduce UE spasticity at several joints as well as UE impairment, disability, and functional limitation.

Before intervention, neither participant reported being capable of using the affected UE for functional activities. Both patients were able to actively extend the affected wrist 10° and two digits minimally (required for study inclusion) but exhibited little ability to perform functional movements with their arms, as their AMAT scores show. Preintervention FM scores reflected a moderate level of UE impairment in both participants, and

MAS scores showed rigidity in the distal areas of their affected UEs.

After intervention, both participants exhibited 1-point MAS score reductions in their affected fingers, the clinical significance of which differed for the 2 participants. Patient A exhibited increased isolated movement at several proximal joints, including the shoulder and the elbow (reflected by a 4.0 change in FM score), that was concurrent with the reduced MAS score. She was now able to grasp small objects in her fingers and transport them using new elbow extension and supination. However, she still required the less affected arm to remove the objects from the affected fingers. Nonetheless, she was extremely pleased that she was now able to grasp objects independently, and this new flexion constituted an incremental increase in independence for her.

By contrast, Patient B exhibited less initial UE impairment than Patient A. Her impairment level was further reduced after intervention, as reflected by a 2-point FM increase (from 24 to 26). Her primary change was increased grip in the fingers, such that she was markedly better able to perform the B&B after intervention. She and her caregiver also reported—and showed the team—that she was now able to more quickly perform AMAT activities. However, Patient B's spasticity remained more dense than that of Patient A throughout the UE. Because of her residual spasticity, Patient B continued to compensate with her torso during performance of AMAT movements.

In short, each participant displayed different but clinically significant changes that were not curative. Indeed, at times, assistance from the unaffected arm was required during functional activities. However, participation in the intervention enabled better performance of isolated movements at certain joints and improved functional performance.

Although additional study of this intervention is warranted, we also note several study limitations. First, although the case series design was beneficial in examining how different people responded to the intervention, a group design with participants who are better matched on impairment and plasticity levels is needed. Ultimately, researchers also need to compare the effect of this intervention with that of stand-alone, noninvasive interventions (e.g., stimulation or bracing only) and to pharmacologic strategies. In doing so, future researchers would also be better served if they brought participants in for follow-up evaluations. The data collected from follow-up evaluations in this study were valuable but would have been more substantive and objective had they been accompanied by readministration of the outcome measures by our rater.

Our combined intervention likely has a place in the spasticity management milieu; however, whether its administration optimally precedes, accompanies, or follows other spasticity management strategies will be influenced by outcomes of future studies. ▲

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