Application of a Volar Static Splint in Poststroke Spasticity of the Upper Limb

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Objective: To evaluate clinical and neurophysiologic effects of 3-month reflex inhibitory splinting (RIS) for poststroke upper-limb spasticity.

Design: Pretest-posttest trial.

Setting: Outpatient rehabilitation center.

Participants: Forty consecutive patients with hemiplegia and upper-limb spasticity after stroke that had occurred at least 4 months before.

Intervention: Patients wore an immobilizing hand splint custom-fitted in the functional position for at least 90 minutes daily for 3 months.

Main Outcomes Measures: Patients underwent measurement of (1) spasticity at the elbow and wrist according to Modified Ashworth Scale; (2) passive range of motion (PROM) at the wrist and elbow; (3) pain at the shoulder, elbow, and wrist using a visual analog scale; (4) spasms; and (5) comfort and time of splint application. The instrumental measure of spasticity was the ratio between the maximum amplitude of the H-reflex and the maximum amplitude of the M response (Hmax/Mmax ratio).

Results: A significant improvement of wrist PROM (F=8.92, P=.001) with greater changes in extension than in flexion, and a reduction of elbow spasticity (F=5.39, P=.002), wrist pain (F=2.89, P=.04), and spasms (F=4.33, P=.008) were observed. The flexor carpi radialis Hmax/Mmax ratio decreased significantly (F=4.2, P=.007), RIS was well tolerated.

Conclusions: RIS may be used as an integrative treatment of poststroke upper-limb spasticity. It can be used comfortably at home, in selected patients without functional hand movements, and in cases of poor response or tolerance to antispastic drugs.

Key Words: Arm; Hemiplegia; H-reflex; Muscle spasticity; Rehabilitation; Splints.

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REFLEX INHIBITORY SPLINTING (RIS) is commonly used by both physical and occupational therapists to prevent joint deformities and to reduce muscle hypertonia of hemiplegic upper limbs after stroke.4-6 Spastic hypertonia develops in some weeks after an acute stroke due to a combination of spasticity, thixotropy, and changes in muscle viscoelastic properties, which may ultimately lead to the development of fixed muscle contractures.7,8 Spasticity caused by an upper motoneuron syndrome is usually defined as a velocity-dependent increase in muscle resistance against passive lengthening because of a supraspinal disinhibition of both tonic and phasic stretch reflexes.9 This muscle overactivity may result in muscle imbalances and shortening, leading to abnormal postures.10 It may interfere with nursing care, rehabilitation potential, functional activities, and functional recovery of the patient.11 Pain in the hemiplegic upper limb is also widely reported to be a complication of spasticity.12-14

We reviewed the literature on splint effectiveness and found conflicting and nonconclusive data.12,15-17 Studies frequently relied on small populations,1-3,5,6,18-22 usually treated for short periods (2–8 wk).2,4,19,20,23 In fact, it is a common opinion that rigid splints are poorly tolerated when applied for long periods and that they could induce learned disuse by restraining motion.24 Most often, investigators used clinical scales to measure outcomes and few of them tried to objectively assess the effectiveness of RIS in reducing spastic hypertonia.3,6,21,25

Spasticity clinical scales, such as the Ashworth Scale or the Modified Ashworth Scale (MAS), have poor sensitivity to subtle changes26 and are unable to distinguish between resistance caused by biomechanic and neural factors, such as changes in soft-tissue length and spasticity, respectively.27 Instrumental evaluations, based on electromyographic or biomechanic techniques, may objectively quantify various clinical characteristics associated with spastic hypertonia and should be considered as an adjunct to clinical evaluation.28

This study evaluated the effect of RIS with the use of a custom static volar splint in poststroke patients with hemiplegia in terms of patient compliance, spasticity, passive range of motion (PROM), pain, spasms, and clonus. We used the MAS in combination with the ratio between the maximum amplitude of the H-reflex and the maximum amplitude of the M response (Hmax/Mmax ratio)29 to assess spasticity before RIS and during follow-up.

METHODS

Participants

We screened 250 poststroke patients from among the outpatients referred to the Rehabilitation Centre of S. Maria in Veli, Pozzolatico, Florence, between January 2, 2000 and December 30, 2001. Subjects were required to meet the following inclusion criteria: poststroke hemiparesis that occurred at least 4 months before the study; upper-limb spasticity (MAS score >1 at wrist and/or at elbow) without active functional...
movements; Medical Research Council (MRC)\textsuperscript{30} scale score of 2 or less; and age between 18 and 80 years. Exclusion criteria were: cognitive impairment, behavioral disturbances, or severe chronic disease likely to interfere with ability to give informed consent or to cooperate in the study; cutaneous or joint pathologic states in the upper limb not related to the hemiparesis (eg, previous fractures, severe articular blocks); previous splinting; and concurrent training and stretching exercises for the upper limb. Subjects taking oral antispastic drugs were included in the study only if the dosage had not been changed during the month before. All subjects signed an informed consent form approved by the institutional ethics committee.

**Experimental Procedure**

We used a pretest-posttest study design without a control group. To minimize the confounding influence of natural recovery, we included in the study only those patients with no MAS score changes, no more than a 5° change in wrist and elbow PROM, and no increase in MRC score between 2 consecutive evaluations 30 days apart.

Clinical and instrumental outcome measures were obtained at baseline (t0), and after the first (t1), second (t2), and third (t3) month of splint application. Patients were clinically evaluated by 3 of the authors (SV, CF, GC) who were blinded to both the previous clinical evaluation and the neurophysiologic results. All assessments were performed in a quiet room while the patient was sitting with arms resting comfortably on a pillow, at least 1 hour after splint removal. Upper-limb pain was measured by means of a visual analog scale (VAS).\textsuperscript{31,32} Spasticity of the upper limb was clinically assessed was measured by means of a vertical visual analog scale pillow, at least 1 hour after splint removal. Upper-limb pain the patient was sitting with arms resting comfortably on a pillow, at least 1 hour after splint removal. Upper-limb pain was assessed using the MAS.\textsuperscript{26,33} Goniometric measurements of elbow and wrist flexion and extension were obtained in degrees to calculate the PROM.\textsuperscript{34} For statistical analysis, we used the mean of 3 consecutive measurements to reduce possible measurement errors. Spasms, defined as sudden involuntary muscle contractions in the affected limb were assessed using the Penn Spasm Frequency Score (PSFS).\textsuperscript{35} Clonus, defined as repetitive muscle contraction evoked by brisk, forced, passive wrist extension, was rated on a dichotomous scale (present, absent).

The H-reflex was recorded, using a Sinergy electromyograph,\textsuperscript{a} by an author (AG) who was blinded to the clinical examination results. The band-pass filters were set at 2 and 10kHz, the sweep rate at 5ms/div, and sensitivity at 500V to 2mV/div (depending on signal size). We used a bipolar stimulus probe (interelectrode distance, 2cm; cathode proximal) to stimulate the median nerve at the elbow crease and the radial nerve in the lateral arm (\~\textasciitilde10cm above the lateral epicondyle where underlying tissue was thinnest). Pulse duration was preset at 1.0ms. To prevent habituation of reflex response, stimuli were repeated at least every 4 seconds. Surface electrodes\textsuperscript{b} were used. For all tests, the ground was on the dorsum of the hand and the common reference was on radial styloid. Active electrodes were placed on the bellies of the flexor carpi radialis (FCR) and extensor carpi radialis (ECR) at one third the proximal distance between the elbow and the radial styloid. The measurements were made with the forearm fully pronated for the ECR and fully supinated for the FCR. Each muscle was tested at rest so that changes of Hmax/Mmax ratio were not caused by the variability of the degree of muscle contraction. Subjects were seated comfortably with the shoulder slightly abducted and the elbow semiflexed. Stimulus intensity was increased gradually to obtain a typical series of H waves until a maximum H-reflex was observed. The maximum M response was recorded. Latencies were measured to the most reproducible onset of 4 responses; amplitude was measured from baseline to the largest negative peak in each series. The Hmax/Mmax ratio was calculated.

**Splint**

Static volar splints were made by experienced occupational therapists, using a low-temperature, nontoxic, biodegradable material produced from a strictly controlled cotton tissue and impregnated with a thermoplastic resin. The patient’s hand and wrist were in a functional resting position:\textsuperscript{25} wrist in 30° of extension, normal transverse arch, thumb in abduction and opposition with the pads of the 4 fingers, and metacarpal and proximal interphalangeal joints in 45° of flexion (fig 1). Autoadhesive straps were placed on the hand, wrist, and forearm dorsal face.

Written instructions were given to patients who were recommended to wear the splint for at least 90 minutes a day,\textsuperscript{12,37} at rest, in a sitting position. Each patient was given a diary to report daily wearing time and possible occurrence of skin breakdown and/or adverse reactions. Only patients who followed such instructions were admitted to the follow-up. At t3, a 3-grade scale on patients’ subjective impression of improvement (worse, no change, better) was administered.

**Data Analysis**

Descriptive statistics for clinical and instrumental parameters were calculated at each recording time. Changes of dependent variables (spasticity, PROM, pain, spasm, Hmax/Mmax ratio), were tested by 1-way analyses of variance (ANOVs) for repeated measures using the different times of the study (follow-up, 4 levels: t0, t1, t2, t3) as the within-subject factor. In addition, to test if patient subgroups may benefit from splinting, we performed 2-way ANOVAs using as between-subject factors the time elapsed from stroke (time, 2 levels: subacute, <6mo; chronic, >6mo from stroke onset), nature (nature, 2 levels: ischemic, hemorrhagic), and site of lesion (site, 2 levels: cortical, subcortical). Use of oral antispastic drugs was assessed as a possible confounding factor (drugs, 2 levels: yes, no). Univariate solution was taken with the Greenhouse-Geisser correction factor, used whenever appropriate to protect against type I errors associated with nonsphericity of data.\textsuperscript{35} Those variables that showed significant main effects or significant interactions (\(P<.05\)) were subjected to post hoc test (Fisher) using an \(\alpha\) level of less than .05.

**RESULTS**

Forty patients were included in the study. The remaining 210 eligible patients were excluded from the study because of...
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stroke onset less than 4 months before (n=70), presence of active functional hand movements (n=68), absence of upper-limb spasticity (n=43), cognitive impairment (n=10), or pathologic joint (n=1).

Table 1 lists the main demographic and clinical features of the enrolled patients. Ten patients were taking oral antispastic therapy at the time of inclusion in the study (baclofen, 25–75mg/d); no patient changed drug dosage during follow-up. Of the patients initially included, 1 had a recurrent stroke, 1 had a cardiovascular event, 1 refused to continue the study for personal reasons, and 1 patient dropped out from the 4-week follow-up because of poor tolerance to the splint. Thus, 36 patients were eligible for the complete follow-up period.

The splint was well tolerated and its daily use time increased significantly, from a mean of 110 minutes (range, 90–240min) at t1 to a mean of 150 minutes (range, 120–300min) at t3

**DISCUSSION**

This study found that patients with upper-limb spasticity who wore, without discomfort, a custom volar splint for 2 to 3 hours a day for up to 3 months, had improvement in elbow spasticity and wrist PROM. The increase in wrist PROM was higher in chronic than in subacute patients. This finding could be attributable to the fact that the splinting effects were more evident in chronic patients because they had a lower baseline range of motion than subacute patients. The occurrence of adaptive articular changes, which require time to develop after stroke, could be responsible for the progression of articular limitation over the time. RIS reduced pain at the wrist and limb spasms. The Hmax/Mmax ratio was significantly reduced in the FCR.

There was an increase in joint PROM after RIS. 1,3,23,39 In the present sample, the increase in wrist PROM was mainly attributable to greater extension. This increase was not associated with a reduction in spasticity, when we clinically assessed it by means of the MAS. However, when we used the Hmax/Mmax ratio as a neurophysiologic measurement of spasticity, we detected a significant reduction of it in the FCR muscle and no changes in the ECR muscle. These data confirm a reduction in flexor spasticity at the

<table>
<thead>
<tr>
<th>Time</th>
<th>Wrist</th>
<th>Elbow</th>
<th>PROM</th>
<th>Extension</th>
<th>Flexion</th>
<th>PROM</th>
<th>Wrist</th>
<th>Elbow</th>
<th>PROM</th>
<th>Wrist</th>
<th>Elbow</th>
<th>Shoulder</th>
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<tbody>
<tr>
<td>t0</td>
<td>42 ± 19</td>
<td>81 ± 9.8</td>
<td>123 ± 25</td>
<td>-4 ± 3</td>
<td>133 ± 9</td>
<td>129 ± 13</td>
<td>1.4 ± 0.5</td>
<td>1.7 ± 0.6</td>
<td>1.62</td>
<td>1.53</td>
<td>1.31</td>
<td>2.37</td>
</tr>
<tr>
<td>t1</td>
<td>48 ± 26</td>
<td>82 ± 11</td>
<td>130 ± 26</td>
<td>-3 ± 2</td>
<td>129 ± 10</td>
<td>126 ± 14</td>
<td>1.3 ± 0.6</td>
<td>1.5 ± 0.6</td>
<td>1.21</td>
<td>0.84*</td>
<td>1.53</td>
<td>2.03</td>
</tr>
<tr>
<td>t2</td>
<td>51 ± 18</td>
<td>83 ± 11</td>
<td>134 ± 24</td>
<td>-3 ± 3</td>
<td>130 ± 10</td>
<td>127 ± 16</td>
<td>1.6 ± 0.5</td>
<td>1.4 ± 0.4*</td>
<td>1.03</td>
<td>0.71*</td>
<td>0.90</td>
<td>2.28</td>
</tr>
<tr>
<td>t3</td>
<td>56 ± 21</td>
<td>87 ± 13</td>
<td>143 ± 29</td>
<td>-4 ± 3</td>
<td>130 ± 8</td>
<td>126 ± 14</td>
<td>1.2 ± 0.7</td>
<td>1.3 ± 0.3*</td>
<td>0.90</td>
<td>1.01</td>
<td>0.84</td>
<td>1.81</td>
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</table>

ANOVA

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<tr>
<th>F</th>
<th>P</th>
<th>NS</th>
<th>NS</th>
<th>NS</th>
<th>NS</th>
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<td>5.14</td>
<td>&lt;.002</td>
<td>&lt;.01</td>
<td>&lt;.001</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Abbreviations: NS, not significant; SD, standard deviation.

1Significantly different from t0 and t2.

Table 1: Demographic and Clinical Data of the Study Population

<table>
<thead>
<tr>
<th>Clinical Data</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n)</td>
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</tr>
<tr>
<td>Mean age (range) (y)</td>
<td>62 (39–72)</td>
</tr>
<tr>
<td>Male/female (n)</td>
<td>26/14</td>
</tr>
<tr>
<td>Time from stroke: mo (range)</td>
<td>17 (4–168)</td>
</tr>
<tr>
<td>Subacute/chronic</td>
<td>21/19</td>
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<tr>
<td>Affected upper limb (R/L)</td>
<td>20/20</td>
</tr>
<tr>
<td>Lesion on CT scan (n)</td>
<td>23/17</td>
</tr>
<tr>
<td>Ischemic/hemorrhagic</td>
<td>23/17</td>
</tr>
<tr>
<td>Wrist clonus (n)</td>
<td>17</td>
</tr>
</tbody>
</table>

Abbreviations: CT, computed tomography; L, left; R, right.

Table 2: PROM, MAS, VAS, and Statistical Significance Computed by ANOVA for Repeated Measures in the Study Population (n=36)

DISCUSSION

This study found patients with upper-limb spasticity who wore, without discomfort, a custom volar splint for 2 to 3 hours a day for up to 3 months, had improvement in elbow spasticity and wrist PROM. The increase in wrist PROM was higher in chronic than in subacute patients. This finding could be attributable to the fact that the splinting effects were more evident in chronic patients because they had a lower baseline range of motion than subacute patients. The occurrence of adaptive articular changes, which require time to develop after stroke, could be responsible for the progression of articular limitation over the time. RIS reduced pain at the wrist and limb spasms. The Hmax/Mmax ratio was significantly reduced in the FCR.

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with chronic hemiplegia. Assuming that transjoint projections, the Hmax/Mmax ratio recorded from the FCR after palmar RIS was judged to be uncomfortable by our patients and only in 1 case was it not tolerated at all, in contrast with the previously reported poor tolerance of rigid splints.24 In a recent systematic review, Lannin and Herbert17 found insufficient evidence either to support or to refute the effectiveness of hand splinting for adults following stroke, mainly because of the small sample sizes and the heterogeneity of the studies.1,3,5,6,18,22

The present sample is the largest observed for a 3-month follow-up. Both primary and secondary outcome measures, with the exception of pain, changed significantly after t2. The temporal pattern of improvement observed in study patients suggests that the discordant findings of previous researches could be the result of short periods of RIS (<2mo).4,23,50 Unfortunately, because of the methodologic limitation of this study—that it was not designed in a randomized controlled fashion—we cannot show a clear effectiveness of splinting for poststroke spasticity of the upper limb.

**CONCLUSIONS**

Daily use of RIS over an extended period is associated with reduction of spasticity and pain and with an increase in wrist PROM. Its use is proposed even when the hemiplegic upper limb is not expected to gain further relevant motor recovery and/or improvement. Results of the present study suggest that RIS should be considered as part of an integrative approach rather than as part of an alternative to other treatments. It can be used at home for long periods of time while resting. It is recommended in selected patients without functional hand movements, to avoid possible interference with motor recovery, and in cases of poor response or tolerance to antispastic drugs. RIS prescription should be reserved for those patients who have not yet developed tendon retractions and have an expected good compliance with treatment. The need for randomized controlled trials in this area appears evident.

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**References**


