The Effects of Exercise on Finger Extension of CVA Patients

(electromyography, flexor digitorum profundus, flexor digitorum superficialis, extensor digitorum communis)

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Lee A. Quintana

The choice of activity to improve finger extension of post-CVA patients is based on untested assumptions and hypotheses. In this study, using electromyography of the extrinsic finger muscles and electrogoniometry of wrist and finger joints, the effects of five types of exercise on the finger extension of post-CVA patients were documented.

Results indicated that resisted and rapid exercises recruited high percentages of output of all three muscles. Slow, unresisted extension exercises preferentially recruited the extensor digitorum. No exercise caused significant immediate changes in range of motion (ROM), flexor/extensor balance, time required to open the hand, or level of activity of the extensor digitorum during opening of the hand. Resisted grasp did not limit the patients' ability to extend the fingers. Variability in percent of motor output among the subjects of this study indicates the need to monitor each patient during therapy.

The ability of some post-cerebral vascular accident (CVA) patients to do functional activities is severely limited by lack of finger extension. In treatment, occupational therapists choose activities that are expected to preferentially recruit the finger extenders and avoid activities that may facilitate the flexors. The flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) are usually considered as a unit.

This descriptive study used electronic instrumentation to document the actual effects of five types of exercises that are basic components of occupational therapy activities on post-CVA patients' ability to extend their fingers: 1. finger extension maximally resisted by rubber bands placed around the distal phalanges of the fingers and thumb, a pure exercise; 2. and 3. rapid and slow unresisted extension to flick ping pong balls toward a target (rapid extension is used whenever an object is released as it is being thrown, or during typing, playing the piano, etc. Slow extension is similar to opening the hand in preparing to pick up large objects); 4. maximally resisted grasp of a 2.5-cm cylinder, such as used to hold a hammer, broom, or tools; and 5. grasp and release of a lightweight 6-cm cylinder, similar to grasp and release of cones or other large objects often used in therapy (see Figures 1-5).
A case can be made for each type of exercise studied to be potentially advantageous or disadvantageous with regard to the restoration of finger extension of the hemiparetic hand. It was hypothesized that resisted extension would recruit the highest level of motor neurons in the extensor digitorum (ED) and axiomatically result in improved extensor function, defined as increased range of motion, carryover of muscle output during rhythmic opening of the hand, improved flexor/extensor balance, and increased speed of extension.

This hypothesis that a high level of motor unit recruitment would occur was based on the following ideas: During resisted extension, concentration and attention are directed toward extension. Tanji and Evarts showed that attention activated pyramidal tract neurons (PTNs) in monkeys (1). Attention has also been shown to cause a change in motor unit recruitment in humans (2). Activation of PTNs (corticomotoneurons) is a mechanism for recruitment of motor neurons of the muscles responsible for a movement prior to the initiation of actual movement (1, 5). Brinkman and Kuypers determined that finger extension is a highly cortically controlled movement largely dependent on corticomotoneurons (4); therefore, attention is expected to contribute to recruitment of the ED.
From a biomechanical point of view, resistance recruits many motor units on a subcortical level and, over time, strengthens the muscle (5). It has been shown that in normals, resistance also causes cocontraction of the antagonists (6-8), which would be unwanted if the flexors were already hyperactive; however, this may be different for the spastic patient. Levine and Kabat found that, in spastic patients, maximum contraction of a muscle inhibited its antagonist (8).

It was hypothesized that rapid unresisted extension would put stretch on the flexors resulting in facilitation of the flexors, reciprocal inhibition of the extensors (9-11) and loss of extensor function. On the other hand, large phasic motor units, which are known to become activated during rapid, ballistic movement (12), and the attention focused on extension may result in beneficial effects of motor unit recruitment of the ED without loss of function.

Slow unresisted extension, although not expected to recruit many motor units of the ED, was chosen for study to contrast with rapid, unresisted extension to determine the relative importance of rapid stretch of the flexors. It was expected that, as a result of this slow unresisted exercise, extensor function would be unchanged or perhaps improved.

Using the results of an earlier clinical study (13), the authors hypothesized that resisted grasp would not impair extensor function. Resisted grasp is frequently avoided in both therapeutic and functional activities in the treatment of hemiparetic patients with poor finger extension since resistance is expected to heavily recruit flexor motor units and impair extensor function. Motor unit recruitment of the flexors may also be enhanced through the effects of attention/effort that are greatly directed toward flexion; however, inhibition of flexion could occur as the result of the sensory input offered by the pressure of the hard surface of the dynamometer on the flexor tendons, as proposed by Rood (9), and as a result of maximum activation of the golgi tendon organs due to maximum contraction (10). In addition, extension could be facilitated since the weak ED would be recruited at a higher level than during unresisted extension (14).

Grasp and release of a large, lightweight object is the type of activity used for re-education of the function of the hand. Resistance and stretch are not usually factors in this exercise. Unless release is simply relaxation of the flexors, attention is directed alternately toward both flexion and extension. Whether this type of exercise would recruit motor units of the finger extensor or relax spastic flexors was questionable, and therefore was studied in this experiment.

### Table 1

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Age</th>
<th>Involved Side</th>
<th>Brunnstrom Hand Stage</th>
<th>Months Post</th>
<th>Sensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>66</td>
<td>Right*</td>
<td>5-6</td>
<td>8</td>
<td>Intact</td>
</tr>
<tr>
<td>2 &amp; 3</td>
<td>19</td>
<td>Left</td>
<td>5</td>
<td>12</td>
<td>Intact</td>
</tr>
<tr>
<td>4</td>
<td>56</td>
<td>Left</td>
<td>3-4</td>
<td>7</td>
<td>Intact</td>
</tr>
<tr>
<td>5</td>
<td>65</td>
<td>Right*</td>
<td>5</td>
<td>8</td>
<td>Intact</td>
</tr>
<tr>
<td>6</td>
<td>56</td>
<td>Right*</td>
<td>5</td>
<td>12</td>
<td>Absent</td>
</tr>
<tr>
<td>7</td>
<td>70</td>
<td>Right*</td>
<td>4</td>
<td>19</td>
<td>Intact</td>
</tr>
<tr>
<td>8</td>
<td>67</td>
<td>Left</td>
<td>4</td>
<td>3</td>
<td>Intact</td>
</tr>
<tr>
<td>9</td>
<td>50</td>
<td>Left</td>
<td>5</td>
<td>35</td>
<td>Sharp/dull diminished</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
<td>Right*</td>
<td>5</td>
<td>36</td>
<td>Absent</td>
</tr>
</tbody>
</table>

*Indicates that the involved side is the dominant side.

### Method

Ten post-CVA patients who met specific criteria were recruited from the outpatient population of Brantree Hospital, Braintree, Massachusetts, and were paid for participating in this study (see Table 1 for patient characteristics). Criteria included diagnosed CVA; ability to understand directions; sitting tolerance of 3 hours; freedom from significant contractures, pain, and skin allergies in the affected extremity; and return of hand function between Levels III and V of Brunnstrom's classification (15), as determined by the investigators.

The electrical output of the FDP, the FDS, and the ED was recorded, from indwelling electrodes, using electromyography (EMG). Movement of the proximal interphalangeal (PIP), metacarpophalangeal (MP), and wrist joints was monitored using electrogoniometers (elgons) and recorded simultaneously with the electrical activity from each muscle. The finger elgon was mounted on the dorsum of the hand and middle finger. The wrist elgon,
a simple hinge type, was mounted on the ulnar side of the wrist joint and measured only flexion and extension.

Strength of grasp was recorded by use of an electronic grasp dynamometer. The details of method and instrumentation have been described elsewhere (16).

Subjects were randomly assigned to one of four groups. Each group assignment represented an order of exercises and thereby controlled for order effects. A brief practice period preceded the experiment. The experiment followed this sequence: unresisted opening (extension) of the fingers from whatever position they were in, unresisted closing (flexion) to full range, unresisted opening to full range, three repetitions of the first exercise in that subject's assigned sequence, unresisted opening, closing, opening, repeated. A 2-minute rest followed. Then the sequence was repeated for each of the remaining four exercises. A check of EMG activity preceding the start of any sequence ensured that the subject started from a relaxed state, defined as an absence of or constant low level of EMG activity. The forearm was pronated for the rapid, slow, and resisted extension sequences, and was in midposition for grasp and grasp/release sequences; no effort was made to hold the subjects in these postures beyond initially positioning them to start the sequence.

Data Reduction

EMG. Samples for analyses included isometric portions of the resisted exercises and the entire movement of all concentric contractions. Average wrist position was noted and no sample was selected if wrist movement occurred. In addition, if artifact (electrical activity generated by factors other than muscle activity) was noted in the raw EMG signal, the sample was not used.

Integrated electromyograms (IEMG) were normalized both as to time, since the duration of each exercise varied, and also in relation to maximum voluntary contractions (MVC) in order to control for the effects of differences between subjects (17). Each person acted as his or her own control. The MVC for the flexor muscles for each subject was the averaged millimeter/second score of the experimental trial of resisted grasp that generated the highest reading on the dynamometer, whereas the MVC for the ED was the first experimental trial of resisted extension. The normalized scores of all other movements and exercises were then calculated and reported as percentages of MVC (17).

The flexor/extensor balance was estimated by calculating two ratios from IEMG scores: FDP/ED and FDS/ED. These ratios were calculated for the opening motions before and after each exercise in order to determine whether any of the exercises affected these balances.

Range of Motion Data. The scores for active range of motion of finger extension were determined by adding together the degrees of movement of the PIP and MP joints of the middle finger during opening from full flexion.

Data Analysis

The data were analyzed using one- and two-way analyses of variance (ANOVA) for repeated measures (18). Significance level was set at .05. If an F ratio was significant, Tukey’s procedure (q) was calculated to locate the difference (19).

Results

Percentage of motor recruitment during the exercises was analyzed from two points of view. First, it was of interest to determine which muscle was significantly recruited by each of the five exercises (see Table 2). The ED was recruited significantly more during rapid extension than during grasp of the lightweight cylinder (p < .05), but no other comparisons produced significant differences. The FDP was recruited significantly more during resisted grasp when compared to any other exercise (p < .01), and more during rapid extension than during either slow extension or grasp/release (p < .05). There was no significant difference in level of recruitment of this muscle during rapid or resisted extension.

The FDS was recruited more during resisted grasp than slow extension or release of the lightweight cylinder (p < .05) but no other comparisons were significantly different.

The standard deviations shown on Table 2 indicate the variability of response between subjects as has been seen in normals (16, 20).

The other point of view of analysis was to look at the synergistic relationships of the three muscles during each exercise (see Table 3).

During resisted extension, the ED was recruited at a significantly higher percentage than the FDP, but not significantly more than the FDS (F2, 14 = 4.78, p = .03). Rapid extension (mean contraction time = 0.4 seconds) recruited a significantly higher percentage of the ED than the FDS, but not more than the FDP (F2, 12 = 4.73, p = .03). Slow extension (mean contraction time = 2.0 seconds) recruited a significantly higher percentage of the ED than either of the flexors (F2, 14 = 19.13, p = .0001). During resisted grasp all three muscles were highly recruited, none significantly more than the others (F2, 12 = 58, p > .57). Grasp of
Table 2
Mean Percentage of IEMG during the Exercises

<table>
<thead>
<tr>
<th>Muscle/Exercise</th>
<th>Mean %</th>
<th>SD</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexor Superficialis (N = 4*)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resisted Grasp</td>
<td>98.0</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>Resisted Extension</td>
<td>59.5</td>
<td>67.8</td>
<td></td>
</tr>
<tr>
<td>Unres. Grasp/Release</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unres. Grasp</td>
<td>49.3</td>
<td>39.4</td>
<td></td>
</tr>
<tr>
<td>Unres. Release</td>
<td>24.8</td>
<td>27.8</td>
<td></td>
</tr>
<tr>
<td>Unres. Rapid Extension</td>
<td>63.8</td>
<td>72.7</td>
<td></td>
</tr>
<tr>
<td>Unres. Slow Extension</td>
<td>23.5</td>
<td>19.6</td>
<td></td>
</tr>
<tr>
<td>Flexor Profundus (N = 7*)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resisted Grasp</td>
<td>94.7</td>
<td>17.4</td>
<td></td>
</tr>
<tr>
<td>Resisted Extension</td>
<td>33.9</td>
<td>14.3</td>
<td></td>
</tr>
<tr>
<td>Unres. Grasp/Release</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unres. Grasp</td>
<td>29.1</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td>Unres. Release</td>
<td>28.3</td>
<td>21.7</td>
<td></td>
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<tr>
<td>Unres. Rapid Extension</td>
<td>52.9</td>
<td>29.2</td>
<td></td>
</tr>
<tr>
<td>Unres. Slow Extension</td>
<td>18.7</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td>Extensor Digitorum (N = 8*)</td>
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<tr>
<td>Resisted Grasp</td>
<td>97.5</td>
<td>64.1</td>
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<tr>
<td>Resisted Extension</td>
<td>90.5</td>
<td>38.1</td>
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<td>Unres. Grasp</td>
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<td>Unres. Release</td>
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<tr>
<td>Unres. Rapid Extension</td>
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<tr>
<td>Unres. Slow Extension</td>
<td>63.9</td>
<td>29.5</td>
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</table>

*SMDP ANOVA for repeated measures includes only those cases with complete data, therefore no record with missing data was included.

A lightweight cylinder recruited none of the three muscles significantly more than any other ($F_2, 8 = 1.04, p > .39$); all were at relatively low levels. Release of the cylinder did recruit a significantly higher percentage of the ED output than either flexor ($F_2, 10 = 6.03, p < .02$).

No significant differences were found in the analysis of the immediate effects following three trials of any of the exercises. There were no significant changes in range of motion of extension, carryover of muscle output during rhythmic opening of the hand, balance of FDP/ED or FDS/ED, nor the amount of time required to open the hand as a result of the exercises. Neither were there significant differences in these effects across exercises. It must be concluded that none of these exercises caused any immediate effect—beneficial or detrimental—not did any one exercise cause effects different from another. The trends are interesting, however, since they do differ for each exercise. These trends are listed in Table 4. Whether these trends are indicative of changes that may occur following long-term use of any of these exercises needs to be studied.

Discussion
Both positive and negative symptoms have been implicated as the major reason for motor deficits in patients with upper motor neuron (UMN) lesions. After their study of 16 patients, Sahrmann and Norton concluded that only the negative symptoms—that is, the inability to generate a normal level of motor unit recruitment in muscles affected by the UMN lesion—result in deficits of dynamic range and the inability to contract and relax the muscles reciprocally as normals do during reversing movement (21). Mizrahi and Angel refute this conclusion on the basis of examination of one patient (22). They concluded that the positive symptoms—hyperactive stretch reflexes—were the basis for their subject's deficits in dynamic range.

If inability to recruit motor neurons is considered the primary deficit of post-CVA patients, an important treatment for improving finger extension would be the use of exercise/activity that recruits high percentages of the available motor units. There were no significant differences in percent of motor unit recruitment of ED among the exercises used in this study with the exception of grasp of the lightweight cylinder, which recruited significantly less output. The means indicate that especially high percentages were recruited during rapid unresisted extension, resisted grasp, and resisted extension (see Table 2).

If hyperactive stretch reflexes of the flexor muscles are considered the primary deficit of the post-CVA patient's ability to extend the fingers dynamically, then activities that call for rapid extension would...
be avoided. The FDP was recruited significantly more during rapid extension when compared to slow extension. The mean percentage of output of the FDS was also higher during rapid extension than slow extension but not significantly so, probably because of the high variability of response during rapid extension (see Table 2). One indication of flexor hyperactivity would be that the movement was arrested prematurely (21). When range of motion was examined during either rapid or slow extension and compared to the rhythmical openings that immediately preceded the periods of exercise, there was a loss of range of movement in both cases. However, there was no significant difference in these losses between slow (mean = 2.0 seconds) and rapid (mean = 0.4 seconds) extension (t = 1.26, N.S.). This observation warrants further controlled study since it has implications for emphasis of therapeutic programs.

The synergistic comparisons of level of muscle recruitment during each of the exercises indicated certain patterns. During resisted grasp or grasp of the lightweight cylinder, no muscle was recruited significantly more than another; the mean outputs increased as demands of resistance increased. During unrestricted extension (slow extension and release of the lightweight cylinder) a higher percentage of the ED was recruited than either of the flexors. There was no significant difference in ED recruitment between these two exercises, a fact supporting the idea that the release of the cylinder was an active use of the ED rather than relaxation of the flexors or tenodesis effect.

Although there were no significant immediate effects of the three repetitions of each exercise, a discussion of the trends may be fruitful in identifying directions for future research.

**Resisted Grasp**

Resisted grasp did recruit maximum percentages of output from the flexors, but also recruited the antagonistic extensor. This finding is contrary to the finding of Levine and Kabat that maximum contraction resulted in inhibition of the antagonist in spastic patients (8).
The fear that resisted grasp would overly recruit the flexors to the point that patients would be unable to open the hand was not realized. On the contrary, as it was hypothesized, this exercise did not jeopardize extensor function. There was neither a loss of overall range of motion of extension nor an increase in time required to open the hand afterward, as would be expected if the flexor tone increased. In addition, during opening after the exercise, the level of ED recruitment increased, and the flexor/extensor balances shifted toward extension. The FDS’s output decreased, but the output of the FDP increased during opening after grasp, indicating that the flexors do not act as a unit.

It is impossible to determine whether these results occurred because of recruitment of the ED or inhibition of the FDS because of pressure on the tendons. Since the FDP was not inhibited, although presumably also affected by pressure, and since examination of each subject’s record shows a mean loss of range at the PIP and an increase at the MP, it appears that ED recruitment made the difference. The loss of range at the PIP could have been caused by the hyperactivity of the FDP, which prevented the lumbrical from contacting to put slack on the FDP to allow full finger extension (20).

Gellhorn stated that, if one muscle (or muscles) is paralyzed, it cannot be exercised by voluntary movement; however, if the antagonist motion brings into action the partially paralyzed muscle as synergist, adequate flow of impulses could be provided until new connections were made (for direct control) (7). This statement seems to support the idea that it would be reasonable to include activities that incorporate resisted grasp in a therapy program to improve hand function of post-CVA patients in Brunnstrom stages III to V, insofar as it was done in this study to activate the extensors through synergy.

Resisted Extension

The hypothesis that resisted extension would recruit a significantly higher level of motor output of the ED than that generated during any other exercise was not supported. Higher levels were seen during resisted grasp and rapid, unresisted extension.

Following resisted extension, no change in percent of motor output was seen for the FDP, whereas the FDS showed a decrease, again indicating that the flexors do not operate as a unit.

The FDP/ED balance shifted toward flexion because of a decrease in extensor output, while the FDS/ED balance did not change. Contrary to expectations, as a result of repeated resisted extension, the largest mean loss in ROM of extension was noted, although this was not statistically significant. The percent of motor output of ED during opening also tended toward a decrease.

Although the time required to extend the fingers after the exercise decreased, indicating no increase in flexor tone—at least in the short term—this exercise appeared to have undesirable effects.

Rapid Extension

The facilitation of the flexors because of stretch was not clearly apparent; that is, ROM decreased, the FDP/ED ratios shifted toward flexion during opening after the exercise, and the percentage of output of the FDP increased. However, the FDS/ED ratio and the percentage of FDS output during opening after the exercise did not change, again indicating the independence of these two flexors. A decrease was found in the time required to open after the exercise; this would be expected to increase if both of the flexors were facilitated. As proposed, this exercise recruited a significant percentage of ED activity, although a facilitation effect was not seen since a small decrease was noted in opening after the exercise.

Unresisted Slow Extension

As an alternative to rapid extension, slow unresisted extension is chosen since it is thought that the stretch reflex is not elicited while concentration on the extensor movement is still offered. This study failed to support this expectation. As a result of the slow extension exercise, changes indicative of evocation of the stretch reflex—increased time to open, decreased ROM, shift of flexor/extensor balance toward flexion, and increased output of flexors during opening after the exercise—were seen for this exercise. However, the increased time to open after the exercise could have been because of the subjects’ perseveration of the timing of the exercise rather than facilitation of the flexors.

The level of motor unit recruitment was less during this exercise when compared to rapid or resisted exercise: however, the level of output of the extensor during opening after the exercise increased, thereby indicating facilitation of this muscle. This exercise needs further study.

Unresisted Grasp/Release

Unresisted grasp/release recruited a relatively low level of output of all three muscles when compared to the rapid or resisted exercises; however, neither in this activity nor in the rhythmical opening and closing
of the hand before and after each activity, which generated low levels of muscle output, was total inhibition of antagonists seen. The average time required for grasp was 1.2 seconds, and release was 0.9 seconds. ROM, level of FDP and ED during opening, and FDP/ED ratio essentially did not change as a result of this exercise. Time required to open the fingers decreased after the exercise when compared to the previous time. The percentage of motor output of the FDS decreased, and the FDS/ED balance shifted toward extension during opening after the exercise.

There is a need to test the assumption that underlies many therapeutic procedures: that is, if motor unit recruitment is increased through some method of facilitation, a concomitant improvement in the ability to move will occur. We observed increased motor unit recruitment of extensors during attempts at rapid extension with concomitant reduction of extensor movement or even flexion instead of the intended movement.

Since it is thought that effort (resistance and/or concentration) shunts the neural activity to spastic muscles (23), it would be expected that, following these five resisted and goal-directed exercises, the flexors would be more active. There was no significant change in the relative percentage of output after any exercise for either flexor muscle, nor was there a consistent trend of increased flexor tone following these exercises.

It is concluded that the extensor digitorum ED can be maximally recruited by use of slow, unresisted extensor activity or release of large objects. The intersubject variability suggests the need to monitor patient responses using biofeedback devices and/or careful measurement of change as a result of therapy. This study needs to be replicated on another group of subjects for validation. The long-term effects of the exercises require clinical testing.

Acknowledgments
Appreciation is expressed to Anne G. Fisher, M.S., OTR; Charles Long, II, M.D.; Barbara Myers, Ph.D., statistician; Magdalen Koehler, R.N., and the administration of Braintree Hospital for their assistance. We are also grateful to the occupational therapists for allowing us the use of space and for help in patient selection.

This research was supported by grant #1RO1NS15758-01 from the National Institute of Neurological and Communicative Disorders and Stroke.

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