REEDUCATION OF SENSATION IN THE HAND AFTER NERVE INJURY AND REPAIR.

A. LEE DELLO, M.D., RAYMOND M. CURTIS, M.D., AND MILTON T. EDGERTON, M.D.

Baltimore, Md.

Without sensation, the hand is blind. Yet, even when highly trained surgeons, using the most modern techniques, repair a severed nerve, it is rare for an adult patient to recover normal functional sensation in the injured hand. We have reviewed the literature on sutured median and ulnar nerves completely lacerated at the wrist in adults (more than 14 years of age), for which age-specific results with long-term follow-up are given. Normal functional sensation (two-point discrimination of 3 to 5 mm) was recovered in less than two percent of such cases.1-4

It has been suggested that to improve these results, it is necessary to improve the technique of nerve suture.5, 6 Perineural (fascicular or funicular) suture, first suggested by Sunderland7 in 1958, and recently reported in cats8 and in humans,9 may provide this improvement. It is our impression, however, that the past failure to achieve recovery of functional sensation in the hand following nerve injury, and particularly nerve suture in adults, is more a failure of the patient to achieve his full sensory potential than a failure of the surgeon to achieve a technically good nerve suture.

This impression arose from repeatedly seeing patients improve their ability to localize a touch stimulus, or to discriminate two points, while in the very process of being examined. Although Wynn Parry10 had demonstrated the usefulness of sensory reeducation, rehabilitation techniques today continue to emphasize motor function to the virtual exclusion of sensory function.11

Based upon a clinical interpretation of recent neurophysiological evidence related to cutaneous sensibility,12 we have developed a sensory reeducation program in which patients are assigned specific sensory exercises at the appropriate time in their recovery process. This paper reports the results of our first year's experience with this program.

THE SENSORY REEDUCATION PROGRAM

The Sensory Reeducation Program is based upon the assumption that, in the patient undergoing regeneration of a peripheral nerve, there will be a time when he will begin to demonstrate less recovery of functional sensation than he is capable of demonstrating. The basis of this underachievement would be the failure of the patient to interpret correctly in his central nervous system the altered profile of impulses discharged when the sensory distribution of his regenerating nerve is stimulated. The Sensory Reeducation Program is designed to help the patient learn to interpret correctly these altered profiles of impulses, by assigning specific sensory exercises at the appropriate time in the recovery process—thereby enabling him to achieve his full sensory potential.

SPECIFIC SENSORY EXERCISES

The design of the specific sensory exercises and the selection of the appropriate time to institute these exercises developed from our clinical interpretation of recent neurophysiological evidence related to cutaneous sensibility.12 This evidence13-15

REFERENCE:

1. From the Division of Plastic Surgery of the Johns Hopkins Hospital.

297
has demonstrated that the large, myelinated sensory fibers (the group A-beta fibers) can be subdivided by their response to mechanical stimuli into quickly-adapting and slowly-adapting fibers. The quickly-adapting fibers can be subdivided again into a group maximally responsive to 30 cps vibratory stimuli, and a group maximally responsive to 256 cps vibratory stimuli. Clinically, the slowly-adapting fibers are interpreted to be those fibers mediating the perception of a constant-touch stimulus (as in the von Frey hair test or the Weber test) and the intensity of that stimulus. The quickly-adapting fibers are interpreted to be those fibers mediating the perception not only of flutter (30 cps) and vibration (256 cps), but also of a moving-touch stimulus (such as finger stroking).

**EXERCISES**

Exercises were chosen to be simple, repetitive, and capable of being performed at home by the patient himself.

*Early Phase, Slowly-Adapting Fibers*

In the Early Phase of the Sensory Reeducation Program (before the perception of moving-touch and/or constant-touch has been recovered at the distal phalanx) the exercise to reeducate the perception mediated by the slowly-adapting fibers consists of touching the eraser end of a pencil (or any blunt object, like another finger) on the given area with varying pressure.

*Early Phase, Quickly-Adapting Fibers*

The exercise to reeducate the perception mediated by the quickly-adapting fibers consists of moving the eraser end of a pencil (or any blunt object, like another finger) across the given area.

*Late Phase*

In the Late Phase (when the perception of constant-touch and moving-touch has been recovered distally) the exercises consist of utilizing various sized and shaped nuts and bolts, such as are available at any hardware store (Figs. 1, 2).

For constant-touch, the patient attempts to discriminate whether he is feeling the larger (16 mm diameter) or the smaller (11 mm diameter) of a pair of hexagonal nuts; the similarity in size and, therefore, the degree of difficulty of the task, is increased as the patient improves.

For moving-touch, the patient attempts to discriminate whether he is feeling the 4 sides (sharp) of a square nut or the 6 sides (dull) of a hexagonal nut being rolled across his finger.

To reeducate areas on single fingertips, the exercises are administered with the other (normal) hand.

To reeducate pinch areas, assuming motor function is sufficient, the patient attempts to discriminate whether the rounded or the flat side of the cap nut (11 mm diameter) is in contact with his thumb. The patient proceeds to the smaller cap nut (6 mm diameter) as he improves. Ability to detect which side of a small button is grooved is the most difficult exercise.

**Fig. 1.** The pattern of recovery of sensation in Case 3. (●●●) represents level at which there was perception of pin prick; (●) represents perception of 30 cps stimuli; (●▬) represents perception of finger-stroking; (●×●) represents perception of constant-touch stimuli; (●●●●) represents perception of 256 cps stimuli. Note the distal progression of the pattern with time (from left to right) until we finally see recovery of sensation clear out to the fingertips for both the median and ulnar nerves.
The "appropriate time" is determined from the pattern of recovery of sensation. Utilizing pinprick, constant-touch, finger-stroking, and tuning forks of 30 cps and 256 cps, it has been demonstrated that a typical pattern of sensory recovery occurs prior to the return of 2 PD (Fig. 1).

First to return distally is the perception of pinprick, then the perception of 30 cps stimuli (either concurrently or just ahead of the perception of moving-touch), then the perception of constant-touch, and finally, the perception of 256 cps stimuli. If the 30 cps stimulus is perceived at some distal level, but moving-touch is perceived only at a more proximal level, it is the appropriate time for the patient to enter the Early Phase of sensory exercises specific for moving-touch (in that area to which the pattern of recovery has progressed). Similarly, if the 256 cps stimulus is perceived at some distal level, but constant-touch is perceived only at a more proximal level, it is the appropriate time for the patient to enter the Early Phase of sensory exercises specific for constant-touch (in that area to which the pattern of recovery has progressed) (Fig. 3). The basis for this must be that...
the 30 cps and 256 cps stimuli have not been encountered before. Consequently, their perception does not have to be relearned, and therefore they reflect more precisely than the constant-touch or moving-touch stimuli the level to which the fibers for which they are specific have regenerated.

The 256 cps stimulus does not test for the fibers that mediate constant-touch, but the fibers for which it does test return distally after the return of those for constant-touch. Thus, if the 256 cps stimulus is perceived more distally than constant-touch, we assume that the constant-touch fibers are regenerated distally but the patient has not learned yet to interpret their altered profile of impulses; hence, he is ready to be reeducated.

When the perception of moving-touch and/or constant-touch has progressed to the tip of the distal phalanx, the Late Phase of sensory exercises for that specific sensation may begin. At this point, testing the recovery of functional sensation begins, using the Weber test for two-point discrimination (2 PD). As the sensory threshold is highest early in the course of regeneration, the blunted compass points should be pressed more firmly in the early testing periods to stimulate the given threshold level that exists at that time; otherwise that patient’s ability will be underestimated. (Almquist’s data would support this approach.)

Eight correct responses out of 10 trials (of being touched with both points simultaneously) are taken as a positive response—with the patient’s perception that the “two” is really two points being monitored frequently by giving a one-point test.

It is critical for the interpretation of this test that the two points be perceived as two points and not one broad area—or the patient’s two-point discrimination will be overestimated and a true reflection of his peripheral innervation density of slowly-adapting fibers at the point tested will not be obtained.

Several seconds must elapse between test repetitions to avoid fingertip fatigue and mental fatigue. Even areas with slight paresthesias may be tested by the careful and critical examiner. Late Phase exercises are stopped when the 2 PD shows no further improvement and plateaus—when normal functional sensation is recovered (3 to 5 mm 2 PD at the fingertip).

**PATIENT POPULATION**

The Sensory Reeducation Program functions as a service provided by the Occupational Therapy group (at Johns Hopkins Hospital) to the Division of Plastic Surgery. At the time the program had completed its first year, 19 patients had been referred for evaluation.

Patients were referred either because they had had a nerve repair or injury in the past and had recovered less than adequate functional sensation—or because they had had a nerve repair or injury recently and were to beevaluated and reeducated during their recovery of sensation. No initial selection was made by age, site of injury, type of injury, type of repair, or by the patient’s education, job, or motivation for recovery.

Five patients were lost to follow-up prior to completion of their initial evaluation; 4 patients were lost to follow-up after being evaluated and followed for some time, but prior to entering the Sensory Reeducation Program. One patient is excluded from this report because he underwent a neurolysis after entering the Sensory Reeducation Program.

Nine patients have entered the Sensory Reeducation Program and are reported in this study (Table I).

**RESULTS**

**Early Phase**

Five patients entered the study early enough in their recovery to be in the Early Phase (Table II). In there, when examination demonstrated that perception of 30 cps and 256 cps stimuli had pro
CONSTRUCTIVE SURGERY, March, 1971

Sensory Reeducation Program as a service provided by the Division of Physical Therapy (at Johns Hopkins Hospital) to the Division of Plastic Surgery. Late Phase reeducation was begun after proximal phalanges for 3 weeks without further distal progression, Early Phase sensory reeducation was begun. The reeducation enabled the patients to recover these perceptions to the fingertip in 4 to 5 days (Fig. 3). No difference in response to reeducation was noted between nerve palsy and nerve suture patients, or between median and ulnar nerve lesions.

Three patients completed the Early Phase early enough in the course of this study to proceed into the Late Phase. One patient was lost to follow-up (Case 7), however, returned to work and was lost to follow-up at this point.

Six patients entered the Late Phase of the Sensory Reeducation Program (Table III). Two patients (Case 7 and Case 8) were seen at the beginning of this study and received Late Phase reeducation until they recovered normal functional sensation (4 and 6 weeks, respectively) and were discharged. Case 7 returned to truck driving, and Case 8 returned to work at a steel mill.

Case 3 and Case 6 entered the Late Phase after completing the Early Phase, and Case 5 and Case 9 entered the Late Phase directly. In these 4 patients, 8 fingers (thumb and index for each of 3 median nerves, and the little finger for each of two ulnar nerves) had received a 3-week course in sensory reeducation when this study terminated. Each of the ulnar nerve distributions recovered two mm 2 PD (normal functional sensation) after the 9 weeks of reeducation. At the end of this same period, each of the median nerve distributions had recovered to less than 15 mm 2 PD. In one patient, from essentially no 2 PD, the thumb improved to 15 mm and the index to 7 mm PD.

For Case 6 and Case 9 this pattern was reversed, with the thumb recovering the better 2 PD. In both

TABLE II

<table>
<thead>
<tr>
<th>Patient</th>
<th>Time from Nerve Repair to Early Phase Entry</th>
<th>Perception Recovered Initially After Reeducation</th>
<th>Time Required for Recovery of the Reeducated Sensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>11 weeks</td>
<td>constant-touch moving-touch and constant-touch</td>
<td>5 days</td>
</tr>
<tr>
<td>Case 2</td>
<td>28 weeks</td>
<td>moving-touch and constant-touch</td>
<td>4 days</td>
</tr>
<tr>
<td>Case 3</td>
<td>26 weeks</td>
<td>moving-touch and constant-touch</td>
<td>4 days</td>
</tr>
<tr>
<td>Case 6</td>
<td>24 weeks</td>
<td>moving-touch and constant-touch</td>
<td>4 days</td>
</tr>
<tr>
<td>Case 7</td>
<td>21 weeks</td>
<td>constant-touch</td>
<td>5 days</td>
</tr>
</tbody>
</table>

* For nerve palsy patients this time interval is from the date of injury to Early Phase entry.

TABLE I

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Injury</th>
<th>Nerve</th>
<th>Date Injured</th>
<th>Date Repaired</th>
<th>Type of Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>29</td>
<td>hand crushed by wood piles, no skin avulsed</td>
<td>M&amp;U</td>
<td>2/5/70</td>
<td>-</td>
<td>none</td>
</tr>
<tr>
<td>Case 2</td>
<td>36</td>
<td>barbiturate overdose, full weight of head rested on wrist 8 hrs</td>
<td>M&amp;U</td>
<td>10/1/69</td>
<td>-</td>
<td>none</td>
</tr>
<tr>
<td>Case 3</td>
<td>50</td>
<td>tire jack slipped, hit into arm above elbow</td>
<td>M&amp;U</td>
<td>7/21/69</td>
<td>-</td>
<td>none</td>
</tr>
<tr>
<td>Case 4</td>
<td>58</td>
<td>elbow hit by barrel</td>
<td>U</td>
<td>7/23/68</td>
<td>2/13/69</td>
<td>neurolysis</td>
</tr>
<tr>
<td>Case 5</td>
<td>18</td>
<td>steel; complete cut</td>
<td>U</td>
<td>2/14/69</td>
<td>2/14/69</td>
<td>suture</td>
</tr>
<tr>
<td>Case 6</td>
<td>20</td>
<td>glass; complete cut</td>
<td>M</td>
<td>9/10/69</td>
<td>9/10/69</td>
<td>suture</td>
</tr>
<tr>
<td>Case 7</td>
<td>29</td>
<td>glass; complete cut</td>
<td>M</td>
<td>9/19/69</td>
<td>9/19/69</td>
<td>suture</td>
</tr>
<tr>
<td>Case 8</td>
<td>47</td>
<td>steel; complete cut</td>
<td>D</td>
<td>3/7/68</td>
<td>11/3/68</td>
<td>suture</td>
</tr>
<tr>
<td>Case 9</td>
<td>40</td>
<td>razor; complete cut</td>
<td>D</td>
<td>1/5/70</td>
<td>1/5/70</td>
<td>suture</td>
</tr>
</tbody>
</table>

* U = ulnar nerve, M = median nerve, both at wrist level except where indicated; D = digital nerve to the radial side of the index finger sutured at the PIP joint.

Injury classification for evaluation was made by the patient's education, job, and their recovery to be in the normal functional sensation range (3 to 5 mm 2 PD at the fingertip).
TABLE III

<table>
<thead>
<tr>
<th>Patient</th>
<th>Time from Nerve Repair* to Late Phase Entry</th>
<th>Finger Tested</th>
<th>2 PD (mm)</th>
<th>Time Required for Recovery of the Reeducated Sensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 3</td>
<td>31 weeks</td>
<td>thumb</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td>Case 4</td>
<td>13 weeks</td>
<td>index</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>Case 5</td>
<td>56 weeks</td>
<td>little</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Case 6</td>
<td>27 weeks</td>
<td>little</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Case 8</td>
<td>30 weeks</td>
<td>index</td>
<td>35</td>
<td>13</td>
</tr>
<tr>
<td>Case 9</td>
<td>14 weeks</td>
<td>index</td>
<td>45</td>
<td>6</td>
</tr>
</tbody>
</table>

* For nerve palsy patients this time interval is from the date of injury to Late Phase entry.

The Sensory Reeducation Program:

The Sensory Reeducation Program ideally would apply specific sensory exercises, known to reeducate specific sensations, as early as possible in the recovery process to accomplish recovery of normal sensation as soon as possible. The exercises employed, however, had not been previously validated. It was not possible, therefore, to apply them as soon as possible in the recovery process, because to do so would have made it impossible to determine whether any observed improvement in the recovery of sensation was due to regeneration, or to reeducation, or to both. Each patient, therefore, was evaluated continuously prior to entering the program, until his recovery of sensation appeared to have stopped progressing and had remained without further improvement for at least 3 weeks. This "stable" period indicated that the effects of the regenerating fibers had reached a plateau or had slowed greatly. At this point, the patient entered the program.

This method enabled each patient to serve as his own age-and-lesion-matched control. Whatever change occurred now in his recovery of sensation during the short period of sensory reeducation had to be the result of the program and not of his regeneration process.

This year's operation of this Sensory Reeducation Program strongly support the propositions that (1) in the regeneration of a peripheral nerve there will come a time when the patient will begin to demonstrate less recovery of functional sensation than he is capable of demonstrating, and (2) that specific sensory exercises assigned at the appropriate time will then help the patient to achieve the full potential given to him by surgery as quickly as possible.

Although we believe that our nerve palsy patients would have achieved a good result without therapy, we think they achieved this sooner than if they had been left to recover without therapy. For example, our 47-year-old digital nerve patient might have regained 11 to 19 mm 2 PD in 5 years; his recovery of 5.5 mm 2 PD within 9 months after repair was almost certainly due to his sensory reeducation.

It would have been rare, also, if one of our median or ulnar nerve suture patients, being adults, had regained even 20 mm 2 PD 5 years after surgery. Yet all 3 regained normal (or near normal) 2 PD within 3 weeks of sensory reeducation. (This occurred in 3 weeks.)
The practice of not evaluating the final results of nerve sutures for at least two years, and preferably longer, probably has prevented the observation (made here) that patients in the early part of their recovery often improve in their tested results as they are being tested. The latter is probably responsible for the seemingly remarkable rapidity with which our patients recovered normal functional sensation.

**Comparison with Other Series**

The value of making this sensory reeducation program an integral part of the management of peripheral nerve injuries becomes more apparent when our results are contrasted with the experience in the literature. In 600 cases of repaired distal median and ulnar nerves in British soldiers after World War II, normal sensation was recovered in only about 0.2 percent.

For the cleaner, less extensive, and earlier repaired civilian nerve injuries a comparison of the results obtained in children (14 years of age or less) versus adults is revealing. Compilation of the data from all reported series with age-specific results—either expressed in mm of 2 PD or convertible to mm of 2 PD (94 equals 3 to 5 mm, S3+ equals 3 to 12 mm 2 PD)—with long-term follow-up (90 percent of the cases followed more than two years, 75 percent of the cases more than 5 years, and 55 percent of the cases more than 5 years) reveals that 70 percent of 180 children recovered 3 to 5 mm 2 PD, and 97 percent recovered 3 to 12 mm 2 PD, while only two percent of 625 adults recovered 3 to 5 mm 2 PD, and 5 percent recovered 3 to 12 mm 2 PD.1-4, 10, 13-20

Larsen and Posch,21 who do not mention using sensory reeducation, obtained results significantly different from these. (45 percent of 140 adults recovered 3 to 10 mm 2 PD) but very similar to those of Wynn Parry.10

Wynn Parry10 employs a form of nonspecific sensory exercise, administered shortly after recovery of protective sensation (pain and temperature). The blindedfolded patient tries to recognize a common object (key, coin, bottle opener) placed into his hand by the therapist. Progress is noted by the number of seconds required for recognition. If no recognition is initially possible, the patient is switched to large wooden blocks of various weights and shapes. Wynn Parry notes that in 3 to 4 weeks there is an improvement in hand function; at his evaluation two years following repair, no patient had regained normal 2 PD but 25 percent of his ulnar nerve suture patients and 50 percent of his median nerve suture patients had recovered "some" 2 PD. In 25 percent of his median nerve patients, this "feeling was little short of perfect."

The literature contains many examples of the results of sensory reeducation—they just are not identified as such. For example, following suture of the ulnar or median nerve at the wrist, it is generally agreed one can expect useful sensation ("superficial pain and tactile sensation with some degree of two-point discrimination") to return by 3 years—with some small but definite improvement continuing until 5 years.1-8, 10, 17, 19-22 The basis for this "small but definite improvement" (which Hakstian calls "the drop-off in recovery towards completion of regeneration that characterizes all peripheral nerve sutures") surely cannot be due to the continuing regeneration of axons, which occurs at from one to 4.5 mm/day.22 We suggest it is due to the "subliminal" reeducation that attends the daily, though guarded, use of an injured hand. Fragiadakis's23 observation (that results of nerve suture were better in patients who were dextrous, rather than heavy manual laborers or clerical workers) supports this suggestion.

One wonders if the success of children in recovering their functional sensation is not at least partially due to their continual curious investigation of their environment with their hands, rather than to some supposed superior ability of their
central nervous system to compensate for misdirected axons. An example of this subliminal reeducation may be found in Onne's work. To establish norms for 2 PD he tested for it twice in each of a series of patients with normal hands. One patient's 2 PD decreased by 6 mm from one determination to the next. (Indeed, 2 PD in the corresponding areas of the normal hand of our patients, which was measured at each session, "improved" from 6 mm to 3.5 mm for Case 4, from 4 mm to 2 mm for Case 3, from 3 mm to 2.5 mm for Case 8, and from 4 mm to 2 mm for Case 5. This is analogous to the change from normal 2 PD [3 to 5 mm] to 1.5 mm found in nondiabetic blind persons who have been trained to read Braille.)

SUMMARY

A sensory reeducation program for the hand, after nerve injury and repair, is described in detail. During its first year in operation, 6 adults with essentially no two-point discrimination recovered normal (or near normal) functional sensation, within two to 6 weeks of entering the program.

We suggest that sensory reeducation, which can be administered effectively by an occupational therapist, be made an integral part of the postoperative management of peripheral nerve injuries.

A. Lee Dellon, M.D.
Surgery Branch
National Cancer Institute
National Institutes of Health
Bethesda, Md. 20014

Dr. Dellon is Clinical Associate, Surgery Branch, at the National Cancer Institute, NIH, in Bethesda, Md., Dr. Curtis is in private practice in Baltimore, Md. Dr. Edgerton is now Head of the Department of Plastic Surgery at the University of Virginia School of Medicine in Charlottesville, Va.

ACKNOWLEDGMENTS

We appreciate the cooperation of the Johns Hopkins Department of Occupational Therapy in this study. We especially thank Janice Maynard, M.A.O.T., O.T.R., for her expert assistance in evaluating these patients.

REFERENCES


REFERENCES


