Use of Early Tactile Stimulation in Rehabilitation of Digital Nerve Injuries

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Key Words: finger injuries • neural pathways • sensorimotor therapy

Objective. Digital nerves are the most frequently injured peripheral nerve. To improve the recovery of functional sensibility of digital nerve injuries, a prospective randomized controlled study was conducted to see the effect of using early tactile stimulation in rehabilitation of digital nerve injuries.

Method. Two specific tactile stimulators were made and prescribed for patients with digital nerve-injury. Twenty-four participants with 32 digital nerve injuries received the prescribed tactile stimulators (experimental group), and another 25 participants with 33 digital nerve injuries received only routine conventional therapy (control group).

Results. A significant difference (p < .05) was seen in the experimental group, although there were some variations between the different classes of associated injuries, with least benefit observed in the combined nerve, tendon, and bone injury class.

Conclusion. Use of early tactile stimulation as described in this study can be considered an effective way to improve both quality and quantity of recovery of functional sensibility in digital nerve injuries without combined nerve, tendon, and bone injuries.


Peripheral nerve injury is a common upper-extremity injury. In Hong Kong, about 11.4% of total patients in the Department of Orthopaedics and Traumatology of Prince of Wales Hospital are peripheral nerve injuries of the upper extremity. Among them, 44% are digital nerve injuries. Although the use of microsurgical nerve suturing technique, especially perineurial repair, can enhance nerve repair (Tupper, Crick, and Matteck, 1986), functional sensibility recovery of a repaired nerve is still unpredictable. Hunter, Shneider, Mackin, and Callahan (1990) defined functional sensibility as the ability of the hand to engage in full activities of daily living, including those activities in which vision is essentially occluded while the hand manipulates and identifies an object. Good functional sensibility relies on sufficient innervation density of slowly and quickly adapting fibers and their corresponding mechanical receptors, Merkel cell-neurite complex, Meissner corpuscle, and Pacinian corpuscle, which is explicit in cutaneous pressure threshold (CPT), static 2-point discrimination (S2PD), and moving 2-point discrimination (M2PD). Poor functional sensibility after surgery is attributed to factors classified as preoperative, intraoperative, or postoperative. Preoperative factors include the age of the patient (Al-Ghazal, McKiernan, Khan, & McCann, 1994; Goldie, Coats, & Birch, 1992; Rosen, Lundborg, Dahlin,
Holmberg, & Karlson, 1994), associated injuries (Mailander, Berger, Schaller, & Ruhe, 1989), level of injury (Glickman & Mackinnon, 1990), and mechanism of injury (Altissimi, Mancini, & Azzara, 1991). Intraoperative factors include the surgeon's experience in choosing a suturing technique (Nakatsuchi, Matsui, & Handa, 1980) and the time of surgery (DeMedinaceli & Seaber, 1989). Postoperative factors refer to rehabilitation (Hung, Cheng, & Leung, 1986; Shieh, Chiu, Lee, & Hsu, 1995; Vitkus, Vitkus, & Krivulin, 1989) or to factors that relate to patients themselves, such as their cooperation in rehabilitation programs and habits. An insensate fingertip, unilaterally or bilaterally, can be annoying, especially for those who frequently engage in fine hand manipulative tasks such as picking up and holding small objects. Consequently, hand function, work capability, or even skill in daily living are affected by peripheral nerve injury.

**Tactile Stimulation**

The theoretical rationale for using early tactile stimulation in this study is based on evidence of somatosensory cortex plasticity. Studies have shown that the adult mammalian somatosensory system is capable of major functional reorganization after peripheral nerve injury. Microelectrode mapping studies carried out in monkeys by Merzenich and Kaas (1982) and Merzenich et al. (1983a, 1983b) showed that with tactile stimulation, a new sensory map appeared in the somatosensory cortex. Kidd, Lawes, and Musa (1992) determined that if the median nerve was cut, there would be a change in the cortical representation. Because the cortical cells have no tactile input from the median nerve, instead of dying or doing nothing, they began to respond to the input from the radial nerve or ulnar nerve. Merzenich and Kaas explained that this reorganization of the somatosensory cortex resulted from axonal sprouting from the neighboring normal territory, that is, crossover innervation. Jones (1981) labeled this process reactive synaptogenesis: a reaction to some stimulus rather than part of the normal developmental process.

In digital nerve injuries, collateral sprouting of the sensory nerve has been well demonstrated. Chow, Luk, Ngai, and Hwang (1980) showed that collateral innervation after a digital nerve division is a dynamic process. According to some authors, the sensibility recovery following digital repair is due to collateral innervation (Calder & Allister, 1993; Chow & Ng, 1993; Tadjalli, McIntyre, Dolyunchuk, & Murry, 1996; Tupper et al., 1986). On the other hand, tactile stimulation in the form of stroking over the striped patterns will strongly excite both Meissner corpuscles and Pacinian corpuscles to transduce mechanical impulses (Palmer & Gardner, 1990), and the brain will take these changing patterns of motion and skin pressure into account in analyzing peripheral input to produce a perceptual constancy of texture (Sinclair & Burron, 1991). This tactile stimulation is extremely important in the early period after nerve repair because of the sparse innervation density of mechanoreceptors. Wei and Ma (1995) concluded that there is an improvement in measured sensibility after nerve surgery. The most likely explanation for the observed effect is cortical reorganization due to increased neural activity in the post-central gyrus during tactile stimulation.

To improve the recovery of functional sensibility of digital nerve injuries, a prospective randomized controlled study was conducted. The effect of using early tactile stimulation in the rehabilitation of digital nerve injuries was investigated.

**Method**

**Participants**

Sixty volunteer participants with digital nerve injuries who were scheduled for nerve resuture surgery were recruited from Prince of Wales Hospital of Hong Kong with written consent. All participants had complete lacerations of digital nerves distal to the metacarpophalangeal joint of the finger. Data were excluded from analysis from those who did not comply with the reassessment procedures for 6 months after surgery or with the rehabilitation protocol. Data were also excluded if skin grafting or skin flaps were required for skin closure, if painful neuroma developed after surgery, and if there was a history of diabetes or skin disease (e.g., scleroderma) that could affect assessment.

The participants were randomly divided into two groups: the experimental group (n = 32) received conventional therapy program plus early tactile stimulation program; the control group (n = 33) received conventional therapy only. Among these two groups, the participants were further classified into one of four different injury classes: Class 1 (digital nerve injuries); Class 2 (digital nerve injuries with tendon injury); Class 3 (digital nerve injuries with bone injuries) and Class 4 (digital nerve injuries with combined tendon and bone injuries, but not a complete amputation).

**Measure of Functional Sensibility**

Commonly, evaluation of sensibility is measured by CPT as well as by M2PD and S2PD. CPT quantifies the course of nerve regeneration of the slowly adapting fibers because CPT was measured as the smallest perceivable force in grams using Semmes-Weinstein monofilaments. M2PD and S2PD quantifies the innervation density of slowly adapting nerve fibers and the innervation density of quickly adapting nerve fibers and their corresponding mechanoreceptors (Dellon, Mackinnon, & Crosby, 1987; Dellon & Munger, 1983; Herold, 1993). For this study, M2PD and S2PD were measured as the shortest perceivable distance in millimeters using a disk-criminator (a standardized two-point discrimination test instrument [Crosby & Dellon, 1989]). The evaluations were classified according to suggestions by Mackinnon and Dellon (1988), Tajima and Imai (1989), and Glickman and Mackinnon (1990) (see Table 1).
Sensibility was evaluated at 3 weeks after surgery, which was before the study intervention, and at 6 months after surgery, which was before the intervention ended. Evaluations were performed by two independent evaluators, both of whom were occupational therapists. Interrater reliability was calculated to examine any variation between raters and dependability of the data collected.

Because a patient’s own appraisal is paramount in assessing the results of a nerve repair (Nishikawa & Smith, 1992; Van Boven & Johnson, 1994), participants were asked to subjectively evaluate the return of sensitivity in the area supplied by the injured digital nerve. This self-evaluation was expressed as a percentage of sensibility recovery of the deficit area compared with the equivalent area of the uninjured digit on the contralateral hand.

**Instruments**

Two types of tactile stimulators were designed for use in the study. One was made of a rotating disc, 15-cm in diameter, with 20 wedge-shaped structures (18° each) with alternating raised portion (1 mm) and depressed flat surface (see Figure 1). The disc was attached to a motor that rotated at the rate of 1 revolution per sec according to the tactile stimulus delivery device developed by Jenkins, Merzenich, Ochs, Allard, and Guic-Robles (1990). The disc and the motor were housed in a metal box with a window through which a portion of the rotating disc protruded.

The second device was a portable pocket tactile stimulator, essentially a plastic card 4.5 cm length × 3 cm width × 3.2 mm thick. On the card was one row of staples 1 cm long and 1 mm wide, which were raised 1 mm above the surface of the plastic and spaced at 2 mm intervals. A second row of staples of equal dimensions was spaced at 5 mm intervals. This difference in groove intervals was designed to provide two gradations of tactile stimulation for the hand when the fingers stroked and pressed the staples. The intervals 2 mm and 5 mm were chosen on the basis of the worldwide accepted normal values of M2PD (2 mm) and S2PD (5 mm). This tactile stimulator was intentionally made to look like a key holder to be easy and convenient to carry around (see Figure 2).

**Intervention: Tactile Stimulation Program**

All participants received a conventional therapy program, including splinting, active and passive range of motion, pressure therapy to control swelling and scarring, and strengthening activities according to their associated injuries. The experimental group also received early tactile stimulation. This intervention started at 3 weeks after surgery, which was considered a safe time to remove protective splintage and start mobilization activities of the injured fingers. The intervention involved (a) sitting in front of the rotating stimulation disc and using the injured finger to maintain contact with the disc through the window for 20 min twice a week (see Figure 3) and (b) using the injured finger to stroke and press over the staples on the pocket tactile stimulator for 1.5 hr every day as a home program (see Figure 4). During the tactile stimulation

<table>
<thead>
<tr>
<th>Test or Grade</th>
<th>Poor</th>
<th>Fair</th>
<th>Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static and moving 2-point discrimination</td>
<td>&gt; 15 mm</td>
<td>11 mm–15 mm</td>
<td>7 mm–10 mm</td>
<td>2 mm–6 mm</td>
</tr>
<tr>
<td>Cutaneous pressure threshold</td>
<td>279.4 g–4.19 g</td>
<td>0.235 g–0.445 g</td>
<td>0.217 g–0.172 g</td>
<td>0.080 g–0.008 g</td>
</tr>
<tr>
<td>(6.65–4.56)</td>
<td>(4.31–3.48)</td>
<td>(3.61–3.22)</td>
<td>(2.83–1.65)</td>
<td></td>
</tr>
<tr>
<td>Self-appraisal</td>
<td>0%–25%</td>
<td>26%–50%</td>
<td>51%–75%</td>
<td>76%–100%</td>
</tr>
</tbody>
</table>

*Numbers in parentheses indicate the corresponding filament making on Semmes-Weinstein monofilaments.*
intervention, these participants were instructed to observe and feel the action for 5 min, to close their eyes to feel the stimulus for 5 min, and then to reopen their eyes to integrate this tactile experience with vision for 5 min. The intervention ended 6 months after surgery.

Statistical Analysis

Descriptive statistics were used to describe the data. Then data were analyzed by interrater agreement (Kappa, $k$) and interrater association (Spearman, rank order correlations, $r$) to determine interrater reliability. The Mann Whitney $U$ test was used to test for statistical differences and interclass differences between the experimental and control groups. Multiple regression was used to determine the contribution of different variables, both independent variables (experimental and control group) and confounding variables (mechanism of injury, level of injury, associated injuries, smoking habit, age of participant), on the prediction of sensibility recovery (determined by CPT, M2PD, and S2PD). All of the statistical tests were computerized by STATISTICA for Macintosh\(^1\) and significance was set at $p < .05$ level.

Results

Of the 60 participants recruited, eleven were excluded because they defaulted follow-up; 4 (9 digital nerve) were excluded because they had not complied with the rehabilitation protocol; and 1 (1 digital nerve) was excluded due to the development of a painful neuroma 1 month after surgery. As a result, data from 49 participants remained. Twenty-five (18 men, 7 women) were in the control group. They had 33 digital nerve injuries among them (19 digits sustained single nerve injury, 7 digits sustained injury to both nerves) and an age range of 19 to 51 years ($M=37.8$ years). Twenty-four (20 men, 4 women) were in the experimental group. They had 32 digital nerve injuries (22 digits sustained single nerve injury, 5 digits sustained injury to both nerves) and an age range of 20 to 64 ($M=42.1$ years). The confounding variables are summarized in Table 2.

High interrater reliability was obtained between the two raters (CPT: $k = .89$, $r = .975$; M2PD: $k = .96$, $r = .941$; S2PD: $k = .92$, $r = .934$).

The distribution of sensibility recovery in the different injury classes at 3 weeks and 6 months after surgery are summarized in Table 3. Generally, participants in the experimental group recovered better S2PD and M2PD than the control group (28% vs. 9%). The experimental group also recovered more cutaneous pressure than did the control group.

Figure 3. Tactile stimulation by contacting the rotating disc.

Figure 4. Stroking and pressing the pocket tactile stimulator as home program.

Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experimental Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thumb</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Index</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>Middle</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Ring</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Little</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Digital nerve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radial</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Ulnar</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>Mechanism of injury</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut</td>
<td>23</td>
<td>28</td>
</tr>
<tr>
<td>Crush</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Level of injury</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal phalanx</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Distal interphalangeal joint</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Middle phalanx</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Proximal interphalangeal joint</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>Proximal phalanx</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Associated injury</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1 (nerve only)</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Class 2 (nerve + tendon)</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Class 3 (nerve + bone)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Class 4 (nerve + tendon + bone)</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Smoking habit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>No</td>
<td>21</td>
<td>21</td>
</tr>
</tbody>
</table>

Note: $n = 32$ for experimental group; $n = 33$ for control group.

\(^1\)Developed by StatSoft, Inc., 2300 East 14th Street, Tulsa, Oklahoma, 74104.
When examining sensibility recovery of all the digits among participants with single digital nerve injuries, those in the experimental group showed better recoveries (M2PD: \( p = .0023 \), S2PD = .0037) than those in the control group. When examining the sensibility recovery of the different injury classes, the results on the experimental group were better than those of the control group, although not all reached significance. M2PD was significant (\( p = .0485 \)) in Class 1; S2PD was significant (\( p = .04521 \)) in Class 2; CPT (\( p = .0339 \)) and S2PD (\( p = .0339 \)) were significant in Class 3. No significant difference was drawn from any sensibility submodalities in Class 4. Moreover, a higher percentage of subjective sensibility recovery was reported by those in the experimental group.

When the contribution of different variables on the prediction of sensibility recovery of CPT, M2PD, and S2PD for digital nerve injuries was analyzed by multiple regression analysis (see Table 4), the age of the participant and the tactile stimulation intervention program were found to be the two main statistically significant determinants in predicting sensibility recovery.

### Discussion

The purpose of this study was to investigate the effect of using early tactile stimulation (3 weeks after surgery) in promoting the recovery of functional sensibility in terms of CPT, M2PD, and S2PD in digital nerve injuries. The results provide evidence that early tactile stimulation via active stroking and pressing a ridged pattern can improve the recovery of M2PD and S2PD in persons with digital nerve injuries, despite variations between classes of associated injuries. The least benefit was observed in the combined nerve, tendon, and bone injury class.

That no significant difference was found in the recovery of CPT between the experimental and control groups.
may be explained by the ability of a single axon to regenerate and innervate proper sensory end organs sufficiently to support normal threshold sensory end organs. The results of such a study have been published previously. For that reason, functionally engaging the sensory injured hand in activities early after surgery can cause the cortical cells to receive tactile input from another territory. This crossover innervation explains why participants in the experimental group showed more significant improvement in M2PD and S2PD than those in the control group.

In digital nerve injuries, crossover innervation is thought to be the main attribute in improving sensibility. For that reason, functionally engaging the sensory injured hand in activities early after surgery can cause the cortical cells to receive tactile input from another territory. This crossover innervation explains why participants in the experimental group showed more significant improvement in M2PD and S2PD than those in the control group.

In addition to the tactile stimulation program, the age of the participant was found to be a determinant in sensibility recovery, which verifies Young, Wray, and Werks's (1981) finding that age correlated most closely with the return of sensory function after digital nerve repair. Young et al. observed that the chance of achieving useful 2-point discrimination was 80% in patients younger than 20 years of age at the time of the repair and that this ability declined with age. Many authors have concluded that normal sensibility can never be regained after repair of a divided digital nerve and that complete recovery is to be expected only in children (Al-Ghazal et al., 1994; Altissimi et al., 1991; Goldie et al., 1992; Sullivan, 1985). The superior capacity to relearn sensation is better in children than in adults because of brain plasticity (Rosen et al., 1994).

The results also indicated that participants with nerve injury and either a tendon or bone injury benefited from the early tactile stimulation program, unlike the participants with all three injured systems. Undoubtedly, an extensive scarred, fibrotic area with variable blood perfusion will have a different degree of adversity to nerve regeneration. To conclude, use of early tactile stimulation is an effective way to improve the functional sensibility of digital nerve injuries without severe associated injuries.

References


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