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RECOVERY OF FINGER SENSIBILITY AND SOMATOSENSORY EVOKED POTENTIALS FOLLOWING DIGIT-TO-DIGIT REPLANTATION IN MAN

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ABSTRACT. Recovery of finger sensation and digital nerve function following digit-to-digit replantation was studied in 14 patients by clinical sensory evaluation and somatosensory evoked potentials (SEP) to digital nerve stimulation. The mean interval between injury and surgery was 8 ± 3 h; that between surgery and study was 25 ± 7 months. Sensory examination revealed a mild hypersensitivity to cold. Pinprick, touch and hot sensations had nearly complete recovery, while vibration and two-point discrimination were impaired. In digital SEPs from the replanted side, the N9 component was present and normal in 8 patients (57%), whereas the N13 and N20 components had prolonged latency with normal central conduction time. Absence of the N9 component appeared to correlate with a more proximal level of injury and poor surgical outcome. The present data indicate that sensory recovery of the replanted digits was in general satisfactory but incomplete, and that over half of the patients had normal digital nerve conduction.

Key words: Digit-to-digit replantation, nerve regeneration, restorative neurology, sensory recovery, somatosensory evoked potential.

INTRODUCTION

Digit-to-digit replantation has been practiced for many years (16) and is an excellent model with which to study nerve regeneration and functional recovery. Previous reports on replanted digits have been concerned mainly with recovery of hand function and finger sensation (9, 10, 14, 22, 27). Sensory recovery is usually determined by the presence or absence of certain sensory modalities (1, 3, 11, 17). Yamauchi et al. (27) studied the time of appearance of various sensations following digit-to-digit replantation. Their data showed that pressure sensation appeared first, followed by touch, pain, cold, warm and perspiration, in that order. Another study reported that pain was the first sensation to return (8). However, eventual recovery of these sensations following digit-to-digit replantation has not been adequately described (9, 14, 22, 27).

Dellon has reviewed sensory recovery of replanted digits and concluded that functional recovery is related to age, level of injury, type of injury, interval from injury to surgery, length of ischemia time, skeletal shortening and sensory re-education (9, 10). Despite those studies, electrophysiological methods have not been utilized to investigate recovery of the replanted digits, although these methods have been used to study regeneration of larger nerves, such as the median, radial, ulnar, tibial and peroneal nerves (2, 3, 11, 17, 18, 20, 23). Therefore, our knowledge of regeneration of the small nerves, such as the palmar digital nerve, is inadequate.

In this report, somatosensory evoked potentials (SEP) to digital nerve stimulation following digit replantation were studied. The SEPs are capable of evaluating objectively not only peripheral nerve conduction but also central somatosensory pathway function. Furthermore, previous studies on nerve regeneration have usually dealt with motor nerves, and a few studies on sensory nerves have shown poor recovery (1, 3, 11, 17, 20, 23). Because digital nerves of the finger are comprised of sensory and autonomic nerve fibers, study of digital SEPs might provide some answers to the unresolved issue of sensory nerve regeneration.

PATIENTS AND METHODS

The study comprised 10 men and 4 women with a mean age of 33 ± 12 years (Table I). The mean interval between injury and surgery was 8 ± 3 h; that between surgery and study was 25 ± 7 months. The majority had sustained finger injury on the job. All patients had single digit mutilation. Six patients had lacerating injury, three had crushing injury, another three had cut injury, and two had avulsion injury. The

Table I. *Clinical data of 14 patients with digit-to-digit replantation*

Patient	Age/Sex	Interval from injury to surgery	Injured finger	Level of injury[1]	Type of injury	Surgical outcome[2]			
						Deformity	Immobility	Shortening	Atrophy
1	47/M	8 h	R-II	DIPJ	Lacerating injury by electric saw	–	–	–	–
2	27/M	5 h	L-I	MPJ	Lacerating injury by electric saw	–	–	–	–
3	18/F	10 h	L-II	DIPJ	Cut injury by machine	–	–	–	–
4	35/M	8 h	L-I	DIPJ	Cut injury by scissors	–	–	–	–
5	19/M	9 h	L-II	PIPJ	Crushing injury by machine	+	–	–	–
6	13/M	5 h	L-II	PIPJ	Lacerating injury by washer blade	–	–	+	+
7	41/M	8 h	L-II	DIPJ	Crushing injury by machine	–	+	–	+
8	34/F	12 h	L-II	DIPJ	Avulsion injury by machine	–	++	+	+
9	52/F	6 h	L-II	MPJ	Lacerating injury by electric saw	+++	–	+++	+
10	28/M	7 h	L-II	MPJ	Crushing injury by machine	++	+	+++	++
11	39/M	9 h	R-II	DIPJ	Lacerating injury by washer blade	+++	+	++	+
12	32/M	3 h	L-II	DIPJ	Cut injury by knife	++	+	–	+
13	47/F	6 h	R-II	MPJ	Lacerating injury by washer blade	++	++	+++	++
14	36/M	15 h	L-I	MPJ	Avulsion injury by machine	++	+++	+++	+++

[1] DIPJ = distal interphalangeal joint; PIPJ = proximal interphalangeal joint; MPJ = metacarpophalangeal joint.
[2] + mild, ++ moderate, +++ severe.

injuries were near the level of interphalangeal joint in half of the patients. The reconstructive surgery consisted of an end-to-end nerve suture, anastomosis of arteries and veins, and reattachment of tendons.

Clinical sensory evaluation included pinprick, light touch, hot and cold sensations, vibration and two-point discrimination, as previously described (6). A toothpick was used for pinprick; cotton thread for light touch; a test tube filled with hot or ice-cold water for hot or cold sensation; 128 Hz tuning fork for vibration; a calibrated caliper for two-point discrimination. The temperature of the test tube for cold and hot sensations was 6–8°C and 70–75°C, respectively. These stimuli were applied to the palmar side of the fingertip. Sensation of the replanted digit was expressed as relative sensation to the contralateral corresponding normal finger. The patient was asked to quantify the sensation elicited from the replanted digit as a percentage of the sensation elicited from the normal finger. For two-point discrimination, the result was also expressed as a percentage of the normal finger. Each test procedure was repeated three times to obtain consistent results.

Recordings of SEPs to median and digital nerve stimulation have been described previously (5, 6). Nicolet Compact Four electromyograph (Nicolet, Madison, WI) was used to obtain averaged responses with the subject in a supine position. The room temperature was maintained at 22 to 24°C by a thermostat. The median nerve was stimulated at the wrist with a bipolar electrode with the cathode at the proximal end. Electric stimuli were constant current square pulses 0.1 ms in duration and 2.1 Hz in frequency. The stimulus intensity was adjusted to elicit minimal twitch of the thumb. Ring electrodes were used to stimulate the digital nerves distal to the surgical site, with the interelectrode distance varying from 0.5 to 1.5 cm depending upon the length of the replanted digit. The digital nerves of the normal finger were stimulated at the level comparable to that of the replanted digit. The stimulus intensity was suprathreshold but below the intensity which evoked discomfort. Evoked responses were recorded over the Erb's point, C-II spinal process, and the scalp area 2 cm posterior to C3 or C4 montage of the international 10–20 system and contralateral to the side of nerve stimulation (6). The linked-ears electrode was used as the reference while the ground electrode was placed around the forearm on the stimulation side. Evoked responses were amplified with a bandpass between 0.5 and 2K Hz. Usually 250–500 responses were averaged for median SEPs, and 500–1000 for digital SEPs. Student's *t*-test, paired or non-paired, was used for statistical analysis.

RESULTS

Fig. 1 shows four hands with digit replantation. The hands of two patients had achieved both functional and cosmetic purposes, while those of another two patients had deformity, shortening and atrophy. The surgery could result in deformity, immobility, shortening, atrophy or a combination of these deficits involving usually both proximal and distal stumps (Table I). These poor surgical results were absent in only four patients.

Table II summarizes recovery of sensation in replanted digits when compared to contralateral

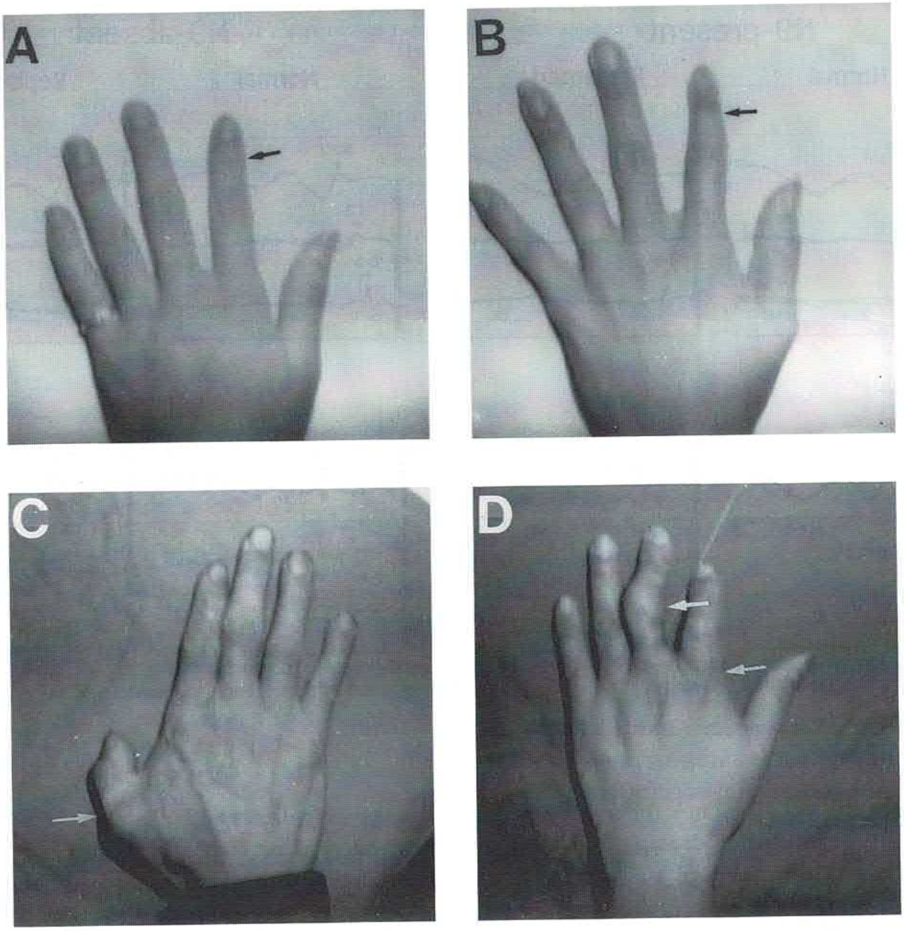

Fig. 1. Hands with digit-to-digit replantation. Arrow indicates the site of replantation.

corresponding normal fingers. Among six sensory modalities, pinprick, touch, and two temperature sensations achieved nearly complete recovery. The majority of the patients had mild hypersensitivity to cold. Vibration and two-point discrimination failed to achieve satisfactory results. Two-point discrimination was 3.0 ± 0.6 mm for normal fingers and 8.6 ± 3.8 mm for replanted digits ($p < 0.0001$). Using the upper normal limit of 4.8 mm (mean + 3 SD), normal two-point discrimination was seen in only two patients (nos. 2, 3).

Table II. *Sensory recovery following digit-to-digit replantation*

Sensory modality	Relative sensation ($\times 100\%$)
Pinprick	1.1 ± 0.4
Touch	1.0 ± 0.1
Temperature	
Hot	1.1 ± 0.5
Cold	1.3 ± 0.5
Vibration	0.64 ± 0.10*
Two-point discrimination	3.1 ± 1.3*

Values are mean ± SD.
Statistical significance: * indicates $p < 0.001$ when compared to normal finger.

Representative recordings of median SEPs are shown in Fig. 2A. Table III summarizes median SEPs in 14 patients with digit replantation. The stimulus intensity was 8 ± 3 mA for normal fingers and 8 ± 2 mA for replanted digits. The latencies and amplitudes of the N9, N13 and N20 components were not significantly different between normal and replanted sides. Nor was the central conduction time (N13 to N20 interpeak latency) between two sides.

Representative recordings of digital SEPs are shown in Fig. 2B, and Table III summarizes digital SEPs in 14 patients with digit replantation. The

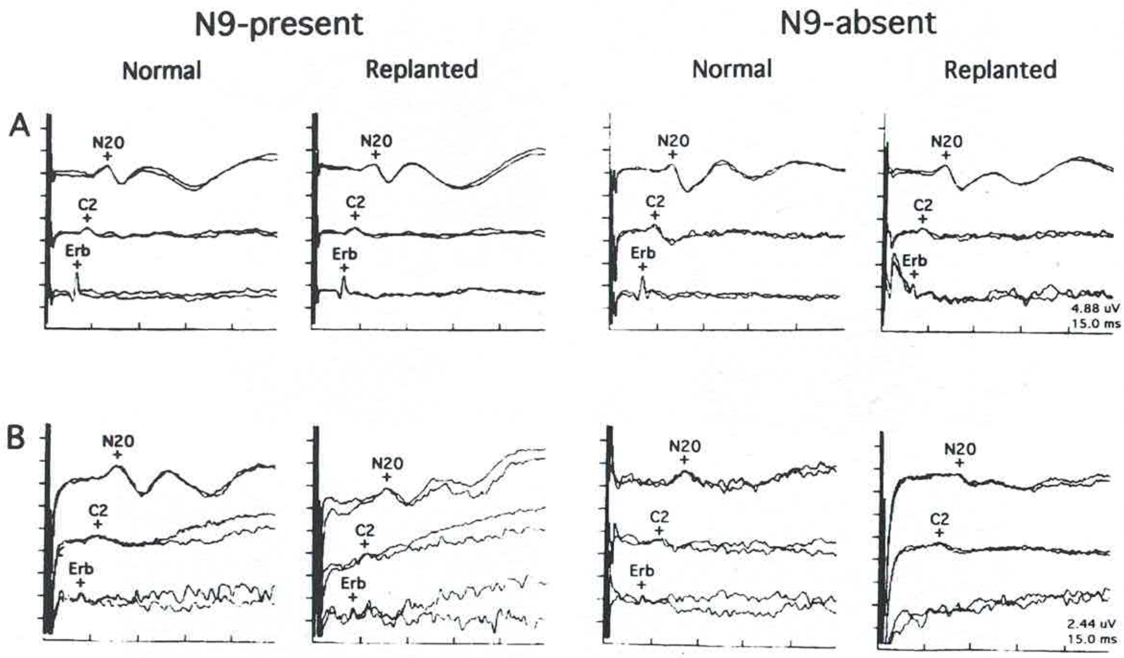

Fig. 2. Representative median (A) and digital (B) SEPs from two patients with presence and absence of the N9 component, respectively.

stimulus intensity was 10 ± 2 mA for normal fingers and 13 ± 3 mA for replanted digits ($p = 0.0011$). In digital SEPs from the replanted side, the N9 component was absent in six patients (nos. 5, 8, 9, 10, 12, 13) and the N13 component in two (nos. 3, 12). Five of six patients with absent N9 component had poor surgical outcome. In those patients with the N9 component absent, latencies of N13 and N20 components were prolonged, but the central conduction time was still normal (Table IV). However,

Table III. *Median and digital SEPs following digit-to-digit replantation in 14 patients*

SEP component	Median SEP Latency (ms)	Median SEP Amplitude (uV)	Digital SEP Latency (ms)	Digital SEP Amplitude (uV)
A. Erb's (N9)				
Normal	9.6 ± 0.6 (14)	6.02 ± 2.77	12.2 ± 1.0 (14)	1.15 ± 0.68
Replanted	9.3 ± 0.6 (14)	5.87 ± 3.14	12.9 ± 0.8(8)	0.84 ± 0.44
B. Cervical (N13)				
Normal	12.6 ± 0.9 (14)	2.49 ± 0.93	16.1 ± 0.9 (14)	0.81 ± 0.32
Replanted	12.5 ± 0.8 (14)	2.32 ± 0.99	17.3 ± 1.4*(12)	0.49 ± 0.21
C. Scalp (N20)				
Normal	18.4 ± 1.1 (14)	3.96 ± 2.51	21.9 ± 1.3 (14)	1.34 ± 0.82
Replanted	18.1 ± 1.3 (14)	3.38 ± 2.55	23.4 ± 2.0*(14)	1.26 ± 0.98
D. CCT (N13-N20)				
Normal	5.8 ± 0.6 (14)		5.8 ± 1.0 (14)	
Replanted	5.6 ± 0.7 (14)		5.8 ± 0.9 (12)	

Values are mean $\pm$ SD; number of patients is given in parentheses.
CCT = central conduction time.
Statistical significance : * indicates $p < 0.01$ when compared to normal.

Table IV. *A comparison of digital SEPs between two groups with presence and absence of the N9 component, respectively*

	N9 present		N9 absent	
SEP component	Latency (ms)	Amplitude (uV)	Latency (ms)	Amplitude (uV)
A. Erb's (N9)				
Normal	12.1 ± 0.9 (8)	1.40 ± 0.81	12.3 ± 1.2 (6)	0.82 ± 0.29
Replanted	12.9 ± 0.8 (8)	0.84 ± 0.44	–	–
B. Cervical (N13)				
Normal	16.0 ± 1.0 (8)	0.74 ± 0.32	16.2 ± 0.7 (6)	0.89 ± 0.33
Replanted	16.8 ± 1.5 (7)	0.54 ± 0.16	18.0 ± 0.9* (5)	0.42 ± 0.25
C. Scalp (N20)				
Normal	22.0 ± 1.3 (8)	1.34 ± 0.73	21.7 ± 1.4 (6)	1.49 ± 1.37
Replanted	23.2 ± 2.5 (8)	1.07 ± 0.50	23.7 ± 1.5* (6)	1.33 ± 1.00
D. CCT (N13-N20)				
Normal	6.0 ± 0.7 (8)		5.5 ± 1.1 (6)	
Replanted	5.8 ± 0.7 (7)		5.6 ± 1.2 (5)	

Values are mean ± SD; number of patients is given in parentheses.
CCT = central conduction time.
Statistical significance : * indicates $p < 0.01$ when compared to normal.

patients with the N9 component present had normal digital SEPs.

DISCUSSION

With the exception of two-point discrimination, the present sensory tests have been criticized as being subjective and difficult to quantify. Interpretation of the present results of sensory recovery therefore has to be cautious. These sensory findings should be considered only as approximate. Similar to previous reports (9, 14, 22, 27), replanted digits exhibited mild intolerance to cold. The perception of pinprick, light touch and hot sensations appeared to be normal. However, vibration and two-point discrimination were impaired.

Unsatisfactory recovery of vibratory sensation following peripheral nerve repair has been reported (1, 8–10, 20). High frequency vibratory perception is usually the last sensation to recover, while the vibratory threshold is also elevated (8, 17, 18). The vibratory sensation is presumably mediated by the quickly adapting receptors of the Pacinian corpuscles located subcutaneously (4, 18, 19, 21), and the Pacinian corpuscles are probably not reinnervated after Wallerian degeneration in man (18, 19) and only to a minor extent in the primates (24). The vibratory responses following nerve injury with or without nerve repair might originate from the Meissner rapidly adapting end organs (2, 19).

Recovery of two-point discrimination has also been reported to be unsatisfactory following nerve repair (1, 2, 18, 20), digit-to-digit replantation (9, 14, 22, 27), and toe-to-digit transplantation (6). With the exception of the Pacinian corpuscle mechanoreceptor, another three types of mechanoreceptors, including rapidly adapting (RA), slowly adapting type I (SAI) and slowly adapting type II (SAII) units, are reinnervated following peripheral nerve repair (2, 18, 19). In human glabrous skin, the reinnervated mechanoreceptors are predominantly located in the palm and the proximal finger, with few in the fingertip, and the reinnervated SAI units usually have smaller receptive fields (18). These reinnervation patterns of cutaneous mechanoreceptors might be one important factor in the poor recovery of two-point discrimination. Another important factor was likely an incomplete regeneration of the large myelinated nerve fibers following digit replantation. Our previous study has shown that sensory nerve action potentials following stimulation of the digital nerves distal to the replanted site had reduced amplitude (7). In the present study, the N9 component was absent in six patients. These findings suggest unsatisfactory regeneration of large myelinated fibers which convey information on vibration and localization.

Besides the possible peripheral mechanisms for the poor recovery of two-point discrimination, central mechanisms might also be involved. In the present study, although the N9 component was absent in some patients, the N20 component was present in all patients and the central conduction time was normal, suggesting that processing of somatosensory impulses to the cerebral cortex was not particularly impaired in digit replantation. A study from Schady et al. (21) has indicated that, following nerve transection in man, the somatosensory system remains able to process information from the nerve and the function of somatosensory localization is retained, but the central adaptation may be poor. But studies of the primates suggest that the CNS is capable of compensatory reorganization following nerve injury, and establishing preinjury skin-to-cortex somatotopic correspondences following regeneration (25, 26). Whether such reorganization may occur in man remains to be further studied.

The present data demonstrate that surgical outcome and level of injury appeared to be crucial in determining the eventual recovery of repaired digital nerves. The N9 component of the digital SEPs was usually absent in patients with poor surgical outcome. Furthermore, the latter group also had more proximal finger amputations than patients who had the N9 component. Surgical complications such as deformity, immobility, atrophy, and shortening appeared to be as important as the nerve repair per se in the eventual recovery of digital nerve function.

In conclusion, digit-to-digit replantation is an excellent model for studying nerve regeneration and sensory recovery in man. This model has the advantage of eliminating anomalous innervation and crossover innervation. The present study indicates that recovery of sensation in replanted digits was in general satisfactory but incomplete. The incomplete recovery was mainly restricted to vibration and two-point discrimination, and appeared to correlate with digital SEP abnormalities. Severity of injury causing poor surgical outcome also appeared to be important in the eventual recovery of digital nerve conduction.

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