SENSORY OUTCOME OF FINGERTIP REPLANTATIONS WITHOUT NERVE REPAIR

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The sensory recovery outcomes of fingertip replantations without nerve repair were retrospectively studied. Between 2000 and 2006, 112 fingertip replantations with only arterial repair were carried out in 98 patients. About 76 of the replants survived totally, with a success rate of 67.8%. Evaluation of sensory recovery was possible in 31 patients (38 replantations). Sensory evaluation was made with Semmes–Weinstein, static and dynamic two-point discrimination, and vibration sense tests. Fingertip atrophy, nail deformities, and return to work were also evaluated. According to the Semmes–Weinstein test, 29.0% (11/38) of the fingers had normal sense, 60.5% (23/38) had diminished light touch, 7.9% (3/38) had diminished protective sensation, and 2.6% (1/38) had loss of protective sensation. Mean static and dynamic two-point discriminations were 7.2 mm (3–11 mm), and 4.60 mm (3–6 mm), respectively. Vibratory testing revealed increased vibration in 42.1% of the fingers, decreased vibration in 36.8%, and equal vibration when compared with the non-injured fingers in 21.1%. Atrophy was present in 14 (36.8%) fingers and negatively affected the results. Nail deformities, cold intolerance, return to work, and the effect of sensory education were investigated. Comparison of crush and clean cut injuries did not yield any significant difference in any of the parameters. Patients who received sensory education had significantly better results in sensory testing. The results were classified as excellent, good, and poor based on results of two-point discrimination tests. The outcome was excellent in 18 fingers and good in 20 fingers. Overall, satisfactory sensory recovery was achieved in fingertip replantations without nerve repair.
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Fingertip amputations are the most common type of amputation injury in the upper extremity.[1] Replantation at this level is technically challenging because of the decreased size of the digital arteries. With the advances in microsurgery, distal replantation today has become a common procedure, offering higher survival rates and excellent functional outcomes. Replantation has the advantage of reconstructing the lost segment with original tissue and without the expense of donor site morbidity. Preservation of fingertip sensibility is crucial to the success of reconstruction and use of the finger. Replantations distal to the proximal nail fold involve repair of only the digital artery in most cases. The digital nerves are branched at this level and often not repaired. Although the lack of neurorraphy may raise concern about the sensory recovery of the replanted segment, excellent sensory recovery was reported in previous studies,[2–5] especially in children.[6] In this series, the sensory outcomes of distal digital replantation are retrospectively analyzed in a mixed population of adults and children.

PATIENTS AND METHODS

Hospital ethics committee approval was obtained prior to the study. Patients with zone 1 (zone extending from the base of the nail to the fingertip) amputations according to the Tamai classification,[7] who underwent replantation without nerve repair were included in this study. Between 2000 and 2006, a total of 112 fingertip replantations were carried out in 98 patients, and the procedure was successful in 76 replantations (68 patients) with a 67.8% complete survival rate. Seven fingers survived partially (6.3%), and 29 replantations failed (25.9%). In patients with total survival of the replant, sensory testing was possible in 31 patients and these patients were included into the study. There were 27 males and 4 females, with mean age of 24.3 (6–40). Eighteen (58.1%) patients had injury in the right hand, and 13 (41.9%) in the left. The mechanism of injury was clean cut lacerations in 15 patients, crush injury in 15, and avulsion in 1. The injured fingers were thumb in 7 (18.4%), index in 9 (23.7%), middle finger in 17 (44.7%), ring finger in 3 (7.9%), and small finger in 2 (5.3%). Five patients had two fingers and one patient had three fingers amputations. Patient data is summarized in Table 1.

Operative Technique

The amputate is examined first before the patient is admitted to the operating room. As the artery is tagged with a 10/0 suture, the patient is taken to the operating room and anesthesia is administered. 22 (71.0%) of the patients were operated under local anesthesia, 6 (19.4%) under brachial plexus block, and the remaining 3 (9.6%)

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Table 1. Data of Patients with Zone 1 Replantations Without Nerve Repair

Fingers	Case	Age	Sex	Injured finger	Type of injury	Distal interphalangeal joint, range of motion (%)	Semmes–Weinstein monofilament test	Static two point discrimination (mm)	Dynamic two-point discrimination (mm)	Vibration	Cold intolerance	Atrophy	Nail deformity	Return to work (months)	Outcome	Sensory education
1	Case 1	28	M	R3	Crush	100	Red	11	6	↓	+	+	−	4	G	
2	Case 2	29	M	R3	Crush	100	Purple	6	4	↑	−	+	+	3	E	
3	Case 3	40	M	R3	Clean cut	100	Blue	7	5	↓	−	−	−	3	G	+
4				R4	Clean cut	100	Blue	6	3	−	−	−	−	3	E	+
5	Case 4	24	M	R2	Clean cut	94	Blue	10	6	↓	−	+	−	3	G	
6	Case 5	14	M	L5	Clean cut	100	Green	5	5	↓	−	−	−		E	
7	Case 6	32	M	R1	Clean cut	80	Blue	10	5	↑	−	−	−	2	G	
8	Case 7	16	M	L1	Clean cut	100	Blue	6	5	↑	+	−	−		E	
9	Case 8	35	M	R3	Clean cut	100	Blue	10	6	↓	−	+	−	3	G	+
10				R4	Clean cut	100	Blue	9	5	↓	−	−	−	3	G	+
11	Case 9	26	M	L2	Clean cut	100	Green	5	3	−	−	+	−	4	E	
12	Case 10	22	M	L3	Clean cut	100	Green	6	3	↑	−	−	+	3	E	+
13	Case 11	6	M	R3	Avulsion	70 (flexion contracture)	Blue	6	5	−	−	+	−		E	
14	Case 12	40	M	R1	Clean cut	100	Blue	6	3	↑	+	−	+	3	E	+
15	Case 13	20	M	R3	Crush	100	Purple	10	6	↓	+	+	+	5	G	
16	Case 14	31	M	L3	Crush	100	Blue	7	5	↓	−	−	−	3	G	
17	Case 15	38	M	R2	Crush	100	Blue	6	4	↑	−	−	−	2	E	+
18	Case 16	18	M	L3	Crush	90	Blue	9	5	−	−	−	+	3	G	
19	Case 17	19	M	L3	Crush	100	Green	6	4	−	−	−	+	3	E	+
20	Case 18	29	M	L2	Clean cut	100	Blue	6	3	−	−	−	−	2	E	
21	Case 19	8	M	L1	Crush	100	Blue	7	5	↓	+	−	−		G	
22	Case 20	19	M	R3	Crush	100	Blue	7	5	↓	+	−	−	3	G	
23	Case 21	22	M	R3	Crush	100	Blue	9	6	↓	−	−	−	3	G	+
24				R4	Crush	90	Green	5	3	↑	−	+	−	3	E	+
25				R5	Crush	100	Blue	9	6	↑	−	+	−	3	G	+
26	Case 22	28	M	R1	Clean cut	90	Blue	8	5	↑	−	+	−	4	G	
27	Case 23	21	F	L2	Clean cut	100	Green	6	4	↑	−	−	−	3	E	+
28				L3	Clean cut	100	Green	6	4	↑	−	−	−	3	E	+
29	Case 24	25	M	R2	Clean cut	100	Green	3	3	↓	−	−	−	4	E	+
30	Case 25	22	F	L1	Crush	100	Blue	8	5	↑	−	+	−	4	G	
31	Case 26	18	M	R2	Crush	100	Green	4	3	↓	−	−	−	3	E	+
32				R3	Crush	100	Green	4	3	↓	−	−	−	3	E	+
33	Case 27	15	F	R1	Clean cut	100	Green	6	4	↑	−	+	+		E	
34	Case 28	37	F	L2	Crush	100	Blue	9	6	↑	+	−	+	3	G	
35	Case 29	24	M	R3	Crush	100	Blue	8	5	↑	−	+	−	3	G	
36	Case 30	19	M	R3	Clean cut	100	Blue	9	6	–	−	−	−	2	G	
37			M	R2	Clean cut	100	Blue	8	5	–	−	−	−	2	G	
38	Case 31	28	M	L3	Crush	100	Purple	10	6	↑	−	+	+	3	G	

E, excellent; G, good. (↓) decreased; (↑) increased; (−) same.

under general anesthesia. Prophylactic antibiotic (Cephazoline sodium, 1 g, intravenously) and subcutaneous low molecular weight heparin (5,000 U) is administered and rheomacrodex 10% infusion at 500 cc/24 hours is initiated. Osteosynthesis is made with a single longitudinal K-wire. The nail bed, if injured, is repaired with 6/0 chromic sutures. The skin on the lateral aspect of the finger is repaired, and arterial anastomosis is carried out with 10/0 or 11/0 Ethilon sutures, using 4 or 5 sutures per anastomosis. Venous repair was not performed, and drainage was made with the application of heparin-soaked gauze on either the nail bed or a fish-mouth incision. External bleeding was continued for 7–10 days, and the patients were discharged after cessation of external bleeding. Mean operative time per finger was 95.0 ± 29.5 min (55–210).

Postoperative Evaluation

Patients with successful replantation were evaluated with respect to sensory recovery (measured with Semmes–Weinstein test, static and dynamic two-point discrimination, vibratory sense) cold intolerance, atrophy, nail bed deformities, range of motion in the distal interphalangeal joint, return to work in workers. Data from the Semmes–Weinstein monofilament testing were interpreted as follows: Green (filament marking 2.83) = normal; blue (filament marking 3.61) = diminished light touch; purple (filament marking 4.31) = diminished protective sensation; red (filament marking 6.65) = loss of protective sensation.[8] Excellent results were defined as moving two-point discrimination of 4 mm or less or static two-point discrimination of 6 mm or less; good results were moving two-point discrimination of 5–7 mm or static two-point discrimination of 7–15 mm; and poor results were defined as those with moving two-point discrimination of 8 mm or greater or static two-point discrimination of 16 mm or greater.[9] Statistical analyses were carried out using *t*-test for independent groups, Fisher's exact probability test, χ^2-square test, and independent samples tests to compare the outcomes in crush versus clean cut amputations, to test the effect of sensory education on sensory outcomes, and to compare the sensory status in patients with and without atrophy.

RESULTS

There were no perioperative complications. None of the patients required blood transfusion. The patient with three finger replantation showed a drop in hematocrit values from 38 to 27%. This patient was managed without transfusion since he did not develop symptoms of anemia or volume loss.

Mean follow-up, calculated according to the final visit, was 16 months (6–48). According to the Semmes–Weinstein test, 29.0% (11/38) of the fingers tested normal (green), 60.5% (23/38) had diminished light touch (blue), 7.9% (3/38) had diminished protective sensation (purple), and 2.6% (1/38) had loss of protective sensation (red) (Fig. 1). Mean static and dynamic two-point discriminations were 7.2 mm (3–11 mm) and 4.6 mm (3–6 mm), respectively. 16 (42.1%) fingers had increased vibration, 14 (36.8%) decreased vibration, and 8 (21.1%) had vibration equal to the non-injured fingers. Atrophy was present in 14 (36.8%) fingers. Nail deformity developed in 9 fingers (23.7%). Range of motion evaluations were calculated by comparing the total active range of motion of the replanted finger with the non-injured fingers as described by Matsuzaki et al.[5] and was found to be 98%. Mean time to return to work was 3.07 (2–5) months. The outcome of 38 fingers was excellent in 18 and good in 20. None of the patients reported chronic pain.

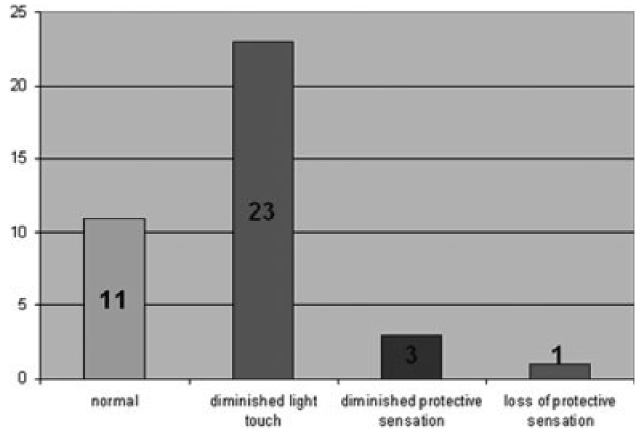

Figure 1. The results of the Semmes–Weinstein test.

Comparison of Crush and Clean-Cut Injuries

The results were compared between crush and clean cut injuries, and none of the sensory parameters measured in this study showed a statistically significant difference between the two injury types. Cold intolerance, nail deformity, atrophy rates, return to work, and the outcomes were also similar.

Atrophy and Sensory Recovery

The only patient who had loss of protective sensation and all patients with diminished protective sensation had atrophy. Patients without atrophy performed significantly better in monofilament testing ($P = 0.042$). Mean static two-point discrimination test was 8.15 ± 2.08 mm and 6.71 ± 1.81 mm in patients with and without atrophy, respectively, which was significant ($P = 0.034$). Dynamic two-point measurements in patients with and without atrophy were 5.00 ± 1.16 mm and 4.38 mm ± 1.06 mm in patients with and without atrophy, however, this difference was not significant ($P = 0.11$). The type of injury did not affect the development of atrophy ($P = 0.248$).

The Effects of Sensory Education

The possible beneficial effects of sensory education were also investigated. Sensory education was suggested to all patients; however, only 12 patients accepted treatment, and the characteristics of the patients who received sensory education and who did not were similar. In Semmes–Weinstein testing, among 22 fingers, which did not undergo education, 3 were normal, 15 had diminished light touch, 3 had diminished protective sensation, and 1 had loss of protective sensation. In patients who received sensory education (16 fingers), 8 were normal and 8 had diminished light touch. Mean static and dynamic two-point discriminations were 7.83 ± 1.78 and 5.04 ± 0.88 mm in patients without education and 6.20 ± 1.94 and 3.93 ± 1.10 mm in patients with education, respectively. This difference was statistically significant in favor of sensory education, both in Semmes–Weinstein tests ($P = 0.018$) and static and dynamic two-point discrimination tests ($P = 0.011$ for static and $P = 0.001$ for dynamic).

DISCUSSION

The decision making process in the treatment of amputations at or distal to the distal interphalangeal joint may be challenging because of the presence of numerous options for reconstruction. When the amputated part is not replanted, distal tip amputations can be repaired by bony shortening and primary repair, skin or composite grafts, local, regional, and free flaps. These techniques may have drawbacks, such as non-aesthetic appearance, the need to shorten the finger, persistent pain, hypersensitivity, cold intolerance, paresthesia, soft tissue atrophy, absence of nail or nail deformity, joint stiffness, and decreased grip power. Some of these techniques also require a second operation and are also associated with donor site morbidity. Goldner et al. listed the advantages of replantation in distal amputation: it is a single stage procedure giving good distal soft tissue coverage, adequate sensibility without painful neuroma, good metacarpophalangeal, and proximal interphalangeal joint motion and it preserves the nail, maintains digit length, is cosmetically pleasing, and the patient is satisfied.[10] Fingertip replantation is a technically demanding operation that requires microsurgical expertise, and the operative time is significantly longer when compared with other alternatives. The postoperative follow-up is even more demanding since the replanted segment must be under close supervision of the medical staff. The fingertip must be drained continuously through the nail bed or a fish-mouth incision, or by using leeches. Bloodletting necessitates frequent dressing changes and follow-up of hemodynamic parameters, especially in multidigit replantations. Although other reconstructions can often be carried out in outpatient settings, replantation requires hospitalization for ~1 week. All these factors increase the costs of replantation. Therefore, replantation in distal digital amputations must be justified with long term outcomes that are superior or at least equivalent to other alternatives. Hattori et al. published their series of 46 patients, where 23 patients had replantation and 23 patients had amputation closure.[11] They found that replantation not only serves to give the best appearance, but also the best functional outcome. Although the existence of paresthesia and cold intolerance were not statistically different between the two groups, pain in the affected fingers was more frequent in the amputation closure group. The average Disabilities of the Arm, Shoulder, and Hand score of the successful replantation group was statistically better. In a previous study, we found that replantations in zones 1 and 2 yielded satisfactory cosmetic and functional outcomes, and the success rates in zone 1 replantations were higher.[12]

One of the main requirements of pulp reconstruction is satisfactory sensory recovery. In most replantations distal to the nail bed, the digital nerves are not repaired because the nerves are already branched at this level. Despite this fact, good sensory outcomes were reported in numerous series where the digital nerves were not repaired. Hirase found no difference at 1 year after surgery between cases, in which the digital nerves were sutured and which were not.[13] Yamano reported that in zone 1 injuries in which nerve repair was impossible, sensory recovery was as good as instances where one or two nerve branches were sutured.[2] In our study, all patients except for one achieved protective sensation, and most (34/38) had either diminished light touch (blue) or were normal (green) in Semmes–Weinstein test. Dubert et al. compared the results of replantation versus reposition flap repair in very distal amputations, and in replanted fingers they reported that there was no significant difference whether or not the nerve has been sutured.[3] However, they concluded that this lack of difference was a reflection of the limitations of their investigative methods and was not sufficient to question the need for nerve sutures. Agreeing with their conclusion, we do not state that nerve repair is unnecessary in zone 1 replantations, rather we emphasize that the results are good in zone 1 repairs without nerve repair.

Despite significant improvements over the years, quantitative measurement and documentation of sensory function remains difficult.[14,15] There are two types of fibers involved in the perception of touch: slowly and quickly adapting fibers.[16] Slowly adapting fibers are responsible for the results in static two point discrimination and Semmes–Weinstein tests. Rapidly adapting fibers are responsible for moving two-point discrimination test and vibration sensation on the skin. Based on these data, we measured all these four parameters for the sensory assessments in this study. When the vibratory sense was compared with the neighboring non-injured fingers, it was seen that 16 (42.1%) fingers had increased vibration, 14 (36.8%) had decreased vibration, and 8 (21.1%) had vibration equal to the non-injured fingers. Dellon showed that vibratory perception is a valuable tool in the assessment of nerve injury and regeneration.[17] The vibratory sense measurements in our study showed variability, and it was even increased in some patients. The small size of the replanted segments made vibratory sense evaluation difficult in some patients, and we believe that increased vibratory sense is due to either hypersensitivity encountered during regeneration or a result of the patients' inability to accurately recognize the vibration sense in the small replanted segment. Moving two-point discrimination measurements were also difficult, especially in patients with small or atrophic fingertips as the distance that the disc travels is small. The difficulties in achieving accurate results in moving two-point discrimination and vibratory sense tests decrease the accuracy of these tests in fingertip replantations, and based on our experience we suggest that sensory assessments in fingertip replantations preferentially should be made with static two-point discrimination and monofilament tests.

The results of sensory assessment of distal replantations were reported previously by numerous authors. Matsuzaki et al. retrospectively examined 10 patients with zone 1 replantations with artery only repair and measured sensory recovery with Semmes–Weinstein test and static two-point discrimination, and found that 4 fingers had diminished light touch and 8 fingers had diminished protective sensation, and found an average two-point discrimination of 5.9 mm (3–11).[5] Hahn and Jung examined 432 patients and measured static two-point discrimination [average 7 mm (range 5–9 mm)] and mean active range of motion.[18] Yamano reported the results of two-point discrimination in 74 finger replantations, however, he did not separate zone 1 replantations without nerve repair from zone 2 replantations without nerve repair.[2] Dubert et al. measured sensibility in 10 replants, using static and dynamic two-point discrimination and Semmes–Weinstein tests, and found the static and dynamic two-point discriminations to be 6.5 and 4 mm, respectively.[3] Static and dynamic two-point discriminations in our study were 7.2 mm (3–11 mm) and 4.6 mm (3–6 mm), respectively. Faivre reported the results of distal replantation in 8 children, who had excellent outcomes without nerve repair.[6] Mean static two-point discrimination was 4.6 mm (3–6 mm), and mean Semmes–Weinstein testing measurement was 3.3, which corresponded to a mildly diminished light touch sensation. The superior results in his study can be explained by the greater degree of spontaneous neurotization in children. In our study, we aimed to demonstrate the results of sensory recovery, using a multitude of parameters for quantitative sensory assessment in a selected group of patients who had replantations in zone 1 without nerve repair. This study also aimed to compare the results in crush versus clean cut amputations, to evaluate the effects of atrophy and sensory education on sensory outcomes.

Atrophy of the replanted segment was seen in 14 of the replants (36.8%) and did not interfere with usage of the finger. All fingers with loss of protective sensation (red) or diminished protective sensation (purple) on Semmes–Weinstein test had atrophy. When the results of monofilament testing are compared between patients with and without atrophy, the difference was significant. Static two-point discriminations were significantly better in patients without atrophy. Dynamic two-point discriminations were also better in patients without atrophy; however, the difference was statistically insignificant. Therefore, the presence of atrophy was found to be a negative factor with respect to sensation. Also, there were two fingers in this series, in which we observed reversal of atrophy with the improvement of sensation (Fig. 2). Therefore patients who complain of atrophy may be told that there is a small possibility of improvement in atrophy. The largest series in the literature regarding distal replantations is by Hahn et al., where the atrophy rate was 10%.[18] Their recommendation to minimize soft tissue atrophy is to anastomose as many veins as possible, however, this is rarely possible in zone 1 amputations.

Nails have more than esthetic significance, they enhance pulp sensitivity, increase pulp stability, are necessary for fine prehension, and the best way to keep a normal nail after distal amputation is to replant the fingertip.[19] Blunt or crush injuries distal to the lunula do not interfere with nail growth if the injury does not involve the germinal matrix. Amputations proximal to the lunula may cause nail problems, such as hook nail or cleft nail.[20] In this series, 5 patients (14.7%) had nail deformity in follow-up. Nail deformities did not interfere with work or daily life therefore no secondary surgery was applied. Seven patients (22.5%) complained about cold intolerance, and they tried to solve this problem by wearing gloves. Mean period before returning to work in adult workers was 3.7 (2–5) months. Although return to work is significantly longer in replantations when compared with primary repair or local flap coverage, replantation gives the best functional outcomes in long term.

Rehabilitation after replantation requires experience and special attention.[21] Wiberg et al. investigated the results of sensory recovery after sensory re-education in 18 fingers of 10 patients, and compared the results with 7 fingers in 4 patients who did not receive sensory

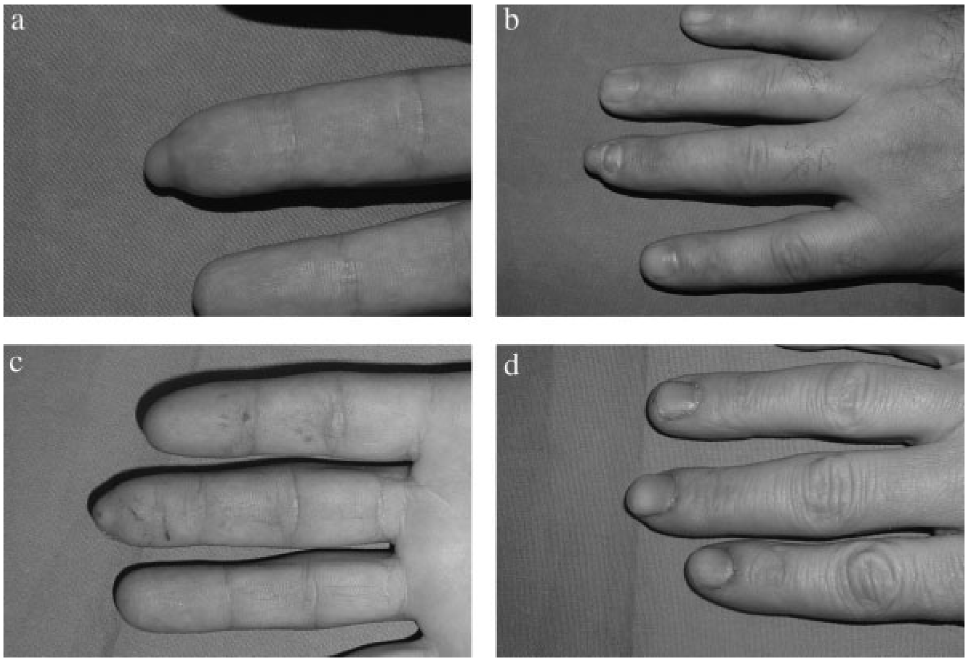

*Figure 2. Case 29: a 24-year-old male worker sustained a crush injury to his right middle finger. The atrophy that developed in the replanted finger significantly decreased over the months along with a recovery in sensation. (**a**,**b**): Postoperative 6 months. (**c**,**d**): Postoperative 40 months.*

re-education.[22] Two-point discrimination was seen to be better in the sensory educated group, and Semmes–Weinstein test did not show a significant change. Shieh et al. evaluated the effectiveness of sensory reeducation after digital replantation and revascularization, and found that the group, which received sensory reeducation, had significantly better results in Semmes–Weinstein and two-point discrimination tests.[23] Follow-up control of 16 fingers in 12 patients in our group who received sensory education revealed normal values (green) in 8 (50%), and diminished light touch (blue) in 8 (50%), and these results were significantly better when compared with the rest of the patients. Rehabilitation also significantly decreases stiffness that may occur following immobilization to achieve bone union. Sensory reeducation and daily use of the digits in fine pinch will improve functional sensibility after complete nerve regeneration, but immobilization will deteriorate it.[24] Since the repair is distal to all joints, amputations distal to the distal interphalangeal joint often have excellent range of motion.

One of the drawbacks of this study is the high number of replanted patients who do not have sensory testing. Only 38 patients out of 68 were available for analysis. There was no selection bias in these patients, and all patients with successful replantation were tried to be recruited for postoperative evaluation. Because of reimbursement issues however, the evaluations in this study had to be performed in a separate physiotherapy unit, and this decreased the number of patients who volunteered for the measurements. The number of patients who accepted sensory education was even lower. Six patients were lost to follow-up due to changes in personal contact information.

In conclusion, distal tip replantations yield excellent cosmetic and functional outcomes and sensory recovery is accomplished even in the absence of nerve repair. Therefore, the lack of nerve repair in fingertip replantation should not be regarded as a negative factor in the decision making process. The type of trauma does not affect the degree of recovery once the replantation is successful. Sensory education positively affects the outcomes.

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