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Innervated Reconstruction of Fingertip Degloving Injury Using a Dorsal Digital Perforator Flap Combined With a Cross-Finger Flap

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Background: The reconstruction of a fingertip degloving injury presents a functional and aesthetic challenge. We used a dorsal digital perforator flap combined with a cross-finger flap to reconstruct this type of injury. The purposes of this retrospective study were to evaluate the efficacy of the combined flaps and to present our clinical experience.

Methods: From November 2016 to October 2019, 16 patients (13 men and 3 women) with fingertip degloving injuries were treated with a dorsal digital perforator flap combined with a cross-finger flap for innervated reconstruction. We used an innervated dorsal digital perforator flap for the reconstruction of the dorsal defect of the degloved fingertip and an innervated cross-finger flap for the volar defect. The average size of the defect was 4.2×1.9 cm. The average sizes of the flaps were 2.3×2.1 cm (the dorsal digital perforator flap) and 2.5×2.1 cm (the cross-finger flap).

Results: All flaps and skin grafts survived completely without ischemia or venous congestion. All wounds and their donor sites healed primarily without exudation and infection. Patients were followed up for a mean time of 11.3 ± 1.9 months (range, 9–15 months). At the final follow-up, no significant difference was seen in the averaged total active motion between the injured fingers and the contralateral fingers. No significant difference was found in the averaged total active motion between the donor fingers and the contralateral fingers. All flaps obtained excellent or good sensory performance. All flaps had mild cold intolerance. Thirteen patients had no pain, 2 reported mild pain, and 1 experienced moderate pain. Ten patients were very satisfied with the appearance of the reconstructed finger.

Conclusions: The dorsal digital perforator flap combined with a cross-finger flap is an effective and reliable method for the reconstruction of fingertip degloving injuries.

Key Words: fingertip degloving injury, innervated reconstruction, dorsal digital perforator flap, dorsal branch of the digital artery, cross-finger flap

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The fingertips are an important part of the hand and play a significant role in the activities of daily life. Fingertip degloving injury is a common type of hand trauma accompanied by tissue defects and bone exposure, which should be reconstructed by large and innervated tissue flaps. The goals of the treatment are the restoration of physiological function, aesthetic efficacy, and sensation.

A dorsal digital perforator flap, first described by Bertelli and Pagliei[1] in 1994, is an axial fasciocutaneous island flap based on the dorsal branches of the digital artery (DBDAs), which uses the dorsal skin to provide soft tissue coverage for the injured finger. With the development of neuroanatomy and vascular anatomy, an increasing number of modified dorsal digital perforator flaps have been used for innervated reconstruction of fingertip defects,[2] and the reliability of this flap has gradually improved.[3] In addition, the application of innervated sensory cross-finger flaps also provides another encouraging method for the treatment of fingertip defects.[4] The aforementioned 2 flaps can provide reliable blood supply and sensation; nevertheless, the relatively small flap surface area of each flap alone restricts either flap completely covering fingertip degloving injuries.

We used a dorsal digital perforator flap combined with a cross-finger flap to reconstruct a fingertip degloving injury. The dorsal defect is recovered by the dorsal digital perforator flap, and the volar defect is recovered by the cross-finger flap. Combining flaps with neurorrhaphy can provide a large area of innervated flap, which is conducive to the reconstruction of fingertip shape and the recovery of finger physiological function. The purpose of this retrospective study was to evaluate the efficacy of the combined flaps for the reconstruction of fingertip degloving injuries and to present our clinical experience.

PATIENTS AND METHODS

Anatomical Basis

The location and distribution of the DBDAs are relatively constant. The DBDAs originate from the digital artery at the level of the proximal and middle phalanx and pass to the dorsum of the finger. The DBDA then sends out several secondary branches to supply soft tissue in the dorsal and lateral areas of the finger.[5] The 4 largest DBDAs are located at the middle and distal thirds of the proximal, middle of the

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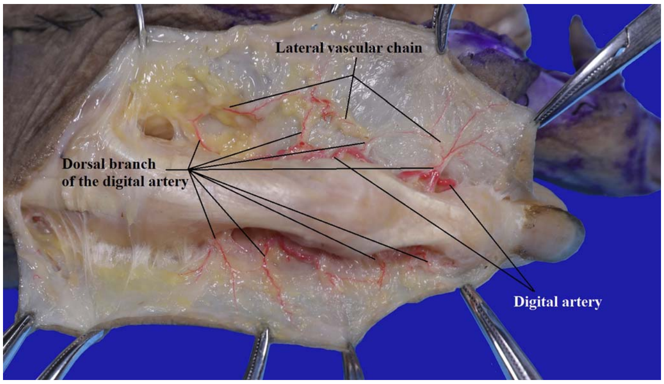

FIGURE 1. Dorsal branches of the digital artery and the LVC are shown in the anatomic study. full color online

middle phalanx, and the distal interphalangeal joint.[6–9] The original diameters of the 4 dorsal branches are 0.1 to 0.5 mm.[10] The DBDAs divide into ascending and descending branches at the extensor tendon border. The ascending branch anastomoses with the descending branch to form a lateral vascular chain (LVC). A study confirmed the existence of continuous vascular networks between the dorsal branches, which constitute the vascular system over the dorsum of a finger.[11] We also performed anatomic studies on hand specimens, and the results confirmed the aforementioned conclusions about the origins of the DBDAs (Fig. 1). The retrograde dorsal digital perforator flap, which is supplied by the LVC, can be designed at the dorsum of the proximal phalanx to repair fingertip defects.

The dorsum of the proximal phalanx is innervated by the dorsal digital nerve (DDN), which originates from the superficial branch of the radial nerve and the dorsal branch of the ulnar nerve.[12,13] The dorsal digital perforator flap innervated by DDNs can be used for innervated reconstruction of the fingertip.

The dorsal branches of the digital nerves (DBDNs) originate from the digital nerves in the proximal third of the proximal phalanx and innervate the dorsum of the middle phalanx.[14] At the proximal phalanx, the diameter of the nerve branch is 0.9 to 1.3 mm, which is similar to that of the digital nerve at distal interphalangeal joint.[15] The cross-finger flap innervated by DBDNs can also be used for innervated reconstruction of the fingertip (Fig. 2).

Clinical Application

A retrospective study was performed after approval from the institutional review board and the ethical committee of our hospital. Written informed consent was obtained from all patients. All clinical investigations were conducted according to the principles expressed in the Declaration of Helsinki.

From November 2016 to October 2019, 16 patients (13 men and 3 women) with fingertip degloving injuries were treated with an innervated dorsal digital perforator flap combined with an innervated cross-finger flap for innervated reconstruction in our department. The average age of the patients was 35.4 ± 6.8 years (range, 21–49 years). The mechanism of injury was avulsion (n = 11), crush (n = 4), and roll (n = 1). The involved digits consisted of 8 middle fingers, 5 ring fingers, and 3 index fingers. The average size of the defect was 4.2 × 1.9 cm. The average sizes of the flaps were 2.3 × 2.1 cm (the dorsal digital perforator flap for the dorsal defect) and 2.5 × 2.1 cm (the cross-finger flap for the volar defect). The demographics of the patients are listed in Table 1.

The inclusion criteria were as follows: (i) one fingertip degloving injury with bone exposed, (ii) the length of the defects (volar and dorsal) was between 2.5 and 5.0 cm, and (iii) the necessity to preserve finger length and restore aesthetic appearance. The exclusion criteria were as follows: (i) the donor site of the flap was injured, (ii) the stump of the proper digital nerve was defective, (iii) the patient was older than 55 years, and (iv) the patient had a serious systemic disease.

Operative Technique

All operations were performed under axillary block with the aid of tourniquet control and operating microscopes. The recipient site was debrided, the stumps of the proper digital nerve were prepared, and the defect size was measured. The flap size was designed to be 10% to 15% larger than the defect size.

The dorsal digital perforator flap was designed and dissected on the dorsum of the homodigital proximal phalanx. A 1.0-cm-wide pedicle, designed retrograde on the LVS, was dissected to ensure the blood supply of the flap. The pivot point was often located at the middle of the middle phalanx. The radial and ulnar DDNs, which innervate the dorsum of the proximal phalanx, were harvested with the flap. The cross-finger flap was designed and dissected on the dorsum of the adjacent middle phalanx. The radial and ulnar DBDNs, which innervate the dorsum of the middle phalanx, were harvested with the flap[16] (Fig. 3).

Then, the 2 flaps were transferred to wrap the exposed bone. The dorsal defect was covered by the dorsal digital perforator flap through an open tunnel, and the volar defect was covered by the cross-finger flap (Fig. 4). A 1-cm-wide subcutaneous tissue margin surrounding the LVC was included in the pedicle to improve venous drainage. Dissection and ligation of the dorsal veins contained in the pedicle were not necessary, but the preservation of a skin bridge over

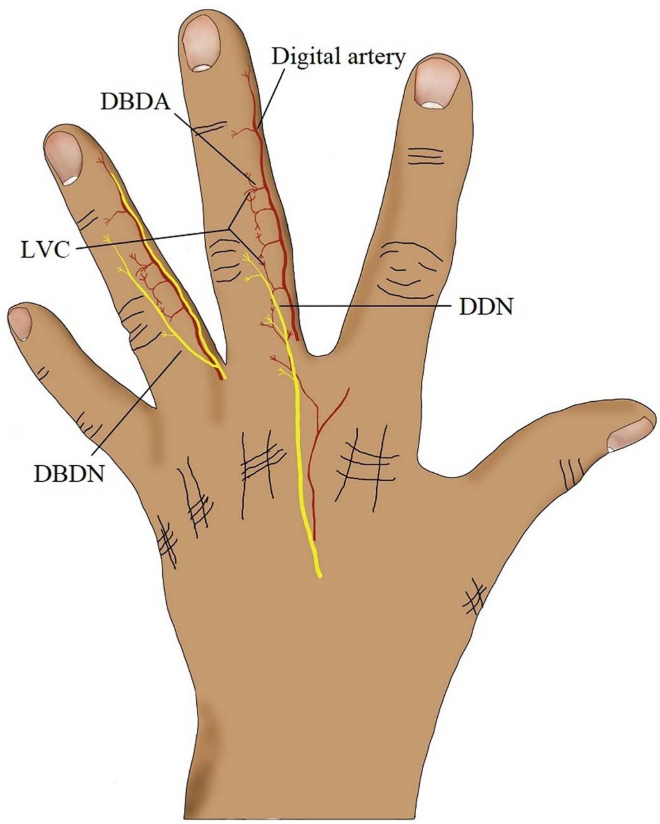

FIGURE 2. Lateral vascular chain originates from the DBDAs. The dorsum of the proximal phalanx is innervated by the DDN, and the dorsum of the middle phalanx is innervated by the DBDN. full color online

TABLE 1. Demographics of the Patients

Case	Age, y	Sex	Mechanism	Injury Finger	Defect Size, cm	Flap Size, V/D, cm	Follow-up, mo
1	32	M	Avulsion	Middle/R	4.9 × 2.1	2.7 × 2.3/2.5 × 2.3	14
2	21	M	Avulsion	Middle/L	4.8 × 2.0	2.7 × 2.2/2.4 × 2.2	10
3	40	F	Avulsion	Index/L	3.3 × 1.8	2.0 × 2.0/2.0 × 1.8	9
4	26	M	Roll	Ring/R	4.6 × 2.1	2.6 × 2.3/2.4 × 2.3	15
5	44	M	Crush	Middle/L	4.7 × 1.9	2.7 × 2.2/2.5 × 2.2	11
6	31	M	Avulsion	Ring/L	4.6 × 1.9	2.7 × 2.2/2.5 × 2.1	13
7	38	M	Avulsion	Middle/L	4.4 × 2.0	2.5 × 2.2/2.5 × 2.2	10
8	33	M	Crush	Middle/L	4.0 × 1.9	2.4 × 2.1/2.3 × 2.1	12
9	29	M	Avulsion	Middle/R	4.7 × 2.0	2.7 × 2.2/2.5 × 2.2	14
10	36	F	Avulsion	Ring/R	3.5 × 1.9	2.2 × 2.1/2.1 × 2.0	11
11	40	M	Avulsion	Index/L	4.6 × 2.0	2.7 × 2.2/2.5 × 2.2	11
12	49	M	Avulsion	Ring/R	4.5 × 1.8	2.7 × 2.0/2.3 × 2.0	10
13	34	M	Crush	Middle/R	4.1 × 1.9	2.5 × 2.1/2.1 × 2.1	13
14	37	M	Avulsion	Ring/R	4.3 × 1.9	2.6 × 2.1/2.2 × 2.1	9
15	43	M	Avulsion	Middle/L	4.2 × 1.8	2.7 × 2.0/2.5 × 2.0	9
16	34	F	Crush	Index/R	2.6 × 1.7	2.0 × 1.7/1.9 × 1.6	10
Mean	35.4 ± 6.8				4.2 × 1.9	2.5 × 2.1/2.3 × 2.1	11.3 ± 1.9

D, dorsum; L, left; R, right; V, volar.

the pedicle was necessary. With the aid of an operating microscope, neurorrhaphy was performed between the stumps of the digital nerves and the DDNs and DBDNs. The edge of the flaps was sutured together. The donor sites were resurfaced by a full-thickness skin graft from the medial forearm with pressure bandaging.

Postoperative Management

After surgery, the hand was elevated to reduce possible venous congestion of the flap. A splint was used to protect the pedicle and nerve coaptations for 2 weeks. The pedicle of the cross-finger flap was divided 3 weeks after the operation, and then the patients started active range of motion exercises with the help of a physical therapist for a mean time of 50 days (range, 42–60 days). Tactile stimulation was applied to the flap and continued until the patient returned to work.

Evaluation

At the final follow-up, total active motion (TAM) of the injured and donor fingers was measured with a goniometer, and the sensation of the flaps was measured using the static 2-point discrimination (2PD) test. Then, the results were compared with the contralateral fingers.[17] Two-point discrimination was classified using the modified American Society for Surgery of the Hand guidelines (excellent, <6 mm; good, 6–10 mm; fair, 11–15 mm; poor, >15 mm).[18] Cold intolerance of the flaps was assessed using the Cold Intolerance Severity Score (CISS) questionnaire.[19] The score was grouped into 4 ranges: mild (0–25), moderate (26–50), severe (51–75), and extreme severity (76–100). A 10-cm line visual analog scale (VAS), which was categorized into mild (0–3 cm), moderate (4–6 cm), and severe (7–10 cm), was used to evaluate the pain sensations of the injured fingers. The satisfaction of patients with the appearance of the injured finger was assessed using the Michigan Hand Outcome Questionnaire (MHQ), which was based on a 5-point response scale.[20] All of the aforementioned evaluations were performed by the same surgeon who was blinded to the procedures.

SPSS Statistics 26.0 software (IBM SPSS, Chicago, Illinois) was used for statistical analyses. Quantitative variables are described as the mean ± SD. The *t* test was applied to compare the injured fingers and their contralateral sites in relation to the quantitative outcomes. The

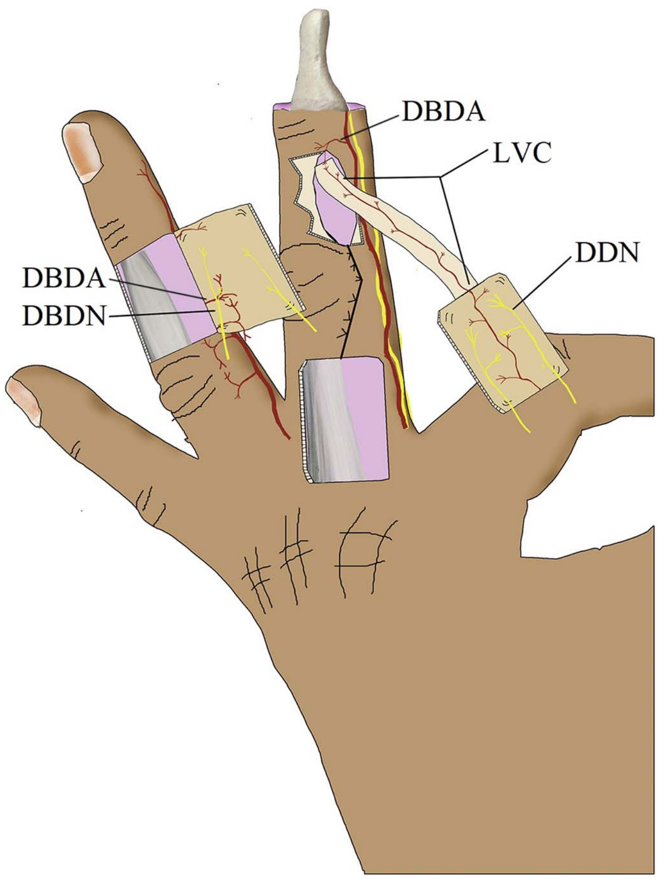

FIGURE 3. The cross-finger flap receives its blood supply from the DBDAs, and the terminal DBDNs is included in the flap. The dorsal digital perforator flap receives its blood supply from the LVC, which stems from the DBDAs, and the terminal DDNs are included in the flap. full color online

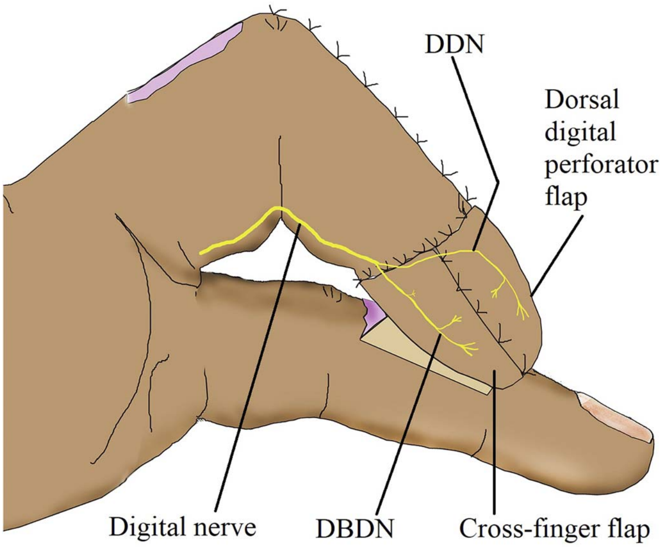

FIGURE 4. An innervated dorsal digital perforator flap was harvested for the reconstruction of the dorsal defect of the degloving fingertip, and the innervated cross-finger flap was harvested for the volar defect. full color online

level of significance was set at 5%, where $P < 0.05$ was considered statistically significant.

RESULTS

All flaps and skin grafts survived completely without ischemia and venous congestion. All wounds and their donor sites healed primarily without exudation and infection. Patients were followed up for a mean time of 11.3 ± 1.9 months (range, 9–15 months).

At the final follow-up, the average TAM of the injured fingers and donor fingers was 256.4 ± 15.2 (range, 215–273) and 258.2 ± 14.6 (range, 223–277), compared with 263.8 ± 15.3 (range, 217–275) and 264.8 ± 14.4 (range, 225–276) of the contralateral fingers (Table 2). No significant difference was seen in the averaged TAM between the injured fingers and the contralateral fingers ($P = 0.196$). In addition, no significant difference was found in the averaged TAM between the donor fingers and the contralateral fingers ($P = 0.221$; Table 3).

The averaged static 2PDs on the cross-finger flaps and the dorsal digital perforator flaps were 6.1 ± 1.1 mm (range, 5–9 mm) and 7.3 ± 1.0 mm (range, 6–10 mm), compared with 3.6 ± 0.6 (range, 3–5 mm) and 5.4 ± 0.7 (range, 4–6 mm) on the contralateral fingers (Table 2). There were significant differences in the averaged static 2PD between the cross-finger flaps and the contralateral fingers and between the dorsal digital perforator flaps and the contralateral fingers ($P < 0.001$; Table 3). The averaged static 2PD on the cross-finger flaps and the dorsal digital perforator flaps reached 59% and 74% of those of the contralateral fingers, respectively. According to the modified American Society for Surgery of the Hand guidelines, all flaps obtained excellent or good sensory performance (scored <10).

According to the CISS questionnaire, all flaps scored less than 25 and had mild cold intolerance. According to the VAS, 13 patients had no pain, 2 reported mild pain, and 1 experienced moderate pain. A positive Tinel sign was found in only one reconstructed finger. According to the MHQ, 10 patients were very satisfied (score 5) with the appearance of the reconstructed finger, and the remaining patients were satisfied (score 4). Color matching of the skin graft in the donor defect was normal in 13 patients, hypopigmented in 1 patient, and hyperpigmented in 2 patients.

Case Reports

Case 1 (Patient 5)

A 44-year-old man suffered from a fingertip degloving injury of his left middle finger, resulting in distal phalanx bone exposure and nail bed defects. After debridement, the defect was 4.7 × 1.9 cm (volar and

TABLE 2. Assessment of 2PD, TAM, CISS, and Appearance (MHQ)

	TAM				2PD, V/D, mm				
Case	Injured Finger	Opposite Finger	Donor Finger	Opposite Finger	Injured Finger	Opposite Finger	CISS V/D	VAS	Appearance (MHQ)
1	263	270	264	268	6/7	4/5	0/10	0	4
2	273	277	275	276	6/8	3/5	10/0	0	4
3	232	240	235	243	6/6	4/6	10/10	0	5
4	265	274	267	272	5/7	3/6	20/0	0	5
5	260	267	262	270	5/7	4/4	0/0	0	5
6	266	275	265	277	5/6	4/6	10/20	3	5
7	251	256	254	260	6/8	3/6	0/0	0	5
8	265	270	268	270	7/7	4/5	10/0	0	4
9	262	272	260	275	7/6	3/6	0/10	0	5
10	264	275	268	275	5/7	5/6	10/0	0	4
11	242	248	246	250	6/7	3/5	0/0	0	5
12	215	223	217	225	5/8	4/6	10/20	2	4
13	268	275	270	275	6/7	3/4	0/0	0	5
14	270	280	267	280	7/9	4/5	0/0	0	5
15	262	267	265	266	8/7	3/5	20/10	4	4
16	245	252	248	255	8/10	4/6	0/10	0	5
Mean	256.4 ± 15.2	263.8 ± 15.3	258.2 ± 14.6	264.8 ± 14.4	(6.1 ± 1.1)/ (7.3 ± 1.0)	(3.6 ± 0.6)/ (5.4 ± 0.7)			

D, dorsum; V, volar.

TABLE 3. Result of Comparisons of the Injured Finger and the Opposite Finger

Variable		Injured Hand	Opposite Hand	P
TAM of finger	Injured finger	256.4 ± 15.2	263.8 ± 15.3	0.196 (>0.05)
	Donor finger	258.2 ± 14.6	264.8 ± 14.4	0.221 (>0.05)
2PD of flap, mm	Volar	6.1 ± 1.1	3.6 ± 0.6	<0.001
	Dorsal	7.3 ± 1.0	5.4 ± 0.7	<0.001

A *P* value of <0.05 was set as statistically significant.

dorsal). A dorsal digital perforator flap combined with a cross-finger flap was designed and harvested to reconstruct the fingertip. The sizes of the flaps were 2.7 × 2.2 and 2.5 × 2.2 cm, respectively. The nerves of the flaps were stitched with the stump of the proper digital nerve. At the 11-month follow-up, the TAM of the injured finger was 260 compared with 267 of the contralateral finger, and the static 2PDs were 5 mm on the volar flap and 7 mm on the dorsal flap compared with 4 and 4 mm of the contralateral finger. The patient was satisfied with the appearance and function of the injured finger. The finger had no cold intolerance (Fig. 5).

Case 2 (Patient 14)

A 37-year-old man suffered from a fingertip degloving injury of his right ring finger, resulting in distal phalanx bone exposure and nail bed defects. After debridement, a cross-finger flap was raised from the dorsum of the middle finger, and a dorsal digital perforator flap was raised from the dorsum of the ring finger to resurface the defect. Neurorrhaphy was performed between the nerves of the flaps and the stump of the proper digital nerve. Both flaps survived completely. At the 9-month follow-up, the reconstructed finger showed a good appearance and function with static 2PDs of 7 mm on the cross-finger flap and 9 mm on the dorsal digital perforator flap. The patient was satisfied with the appearance of the injured finger and had no cold intolerance (Fig. 6).

DISCUSSION

The reconstruction of a fingertip degloving injury presents a functional and aesthetic challenge. Numerous techniques have been reported in the literature. However, most present some drawbacks. The volar V-Y flap or lateral V-Y flap can be used for a fingertip defect and results in good sensory recovery. However, the flap cannot be used for defects greater than 1.5 cm.[21–25] Coverage of the fingertip defect with an abdominal flap, an arm flap, or a chest wall flap is a simple technique. However, the flap is bulky, which affects motion and cannot restore sensation.[26,27]

The sensate dorsal homodigital island flap can be an alternative but is limited by the size that can be harvested.[28–30] The conventional cross-finger flap lacks tactile gnosis, and its wide pedicle restricts it from wrapping the entire exposed bone.[31,32] Although the modified sensate cross-finger flap can be used to reconstruct a fingertip degloving injury and results in good sensation, donor site morbidity is significant with poor appearance and function owing to the large harvest.

Although transfer of a free partial toe flap can restore both aesthetic efficacy and sensation of the fingertip, it requires microsurgery techniques and a prolonged operating time. Moreover, it carries a risk of anastomotic failure, and donor site morbidity is significant.[33–35] Bone shortening and terminalization, with a short recovery time, may be a good choice for patients older than 55 years. However, it is not suitable for young patients, as the results are less favorable in esthetics, gripping activities, dysesthesias, and pain.[36,37]

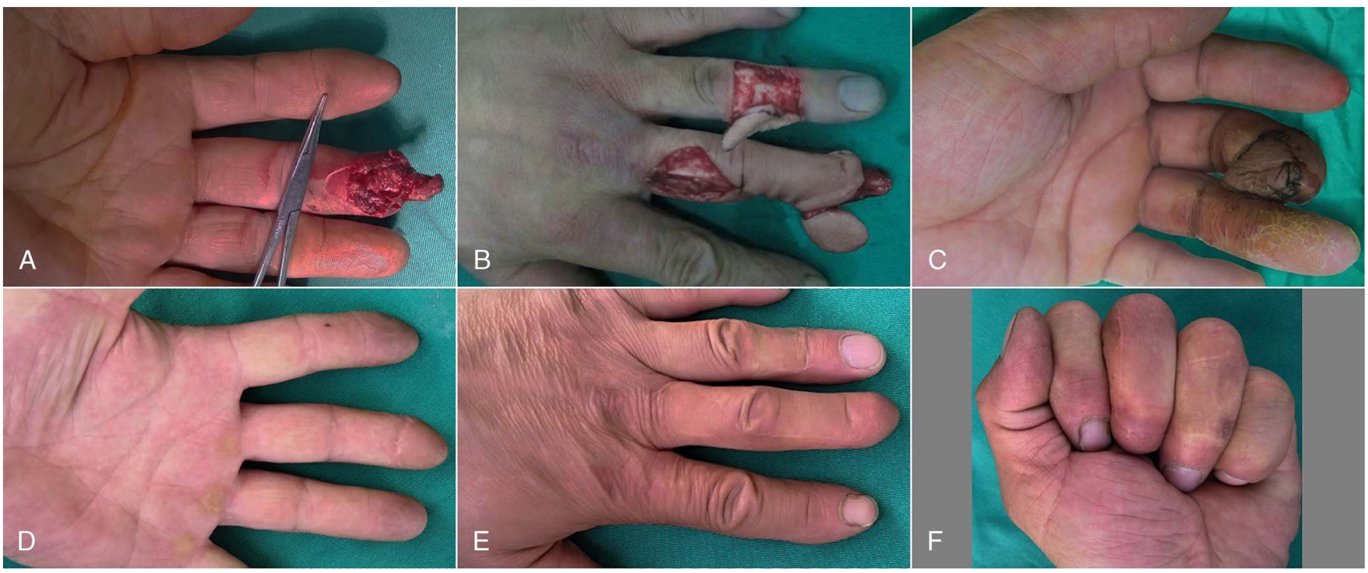

FIGURE 5. A, Fingertip degloving injury of the left middle finger. B, A cross-finger flap was dissected on the dorsum of the middle phalanx of the ring finger, and a dorsal digital perforator flap was dissected on the dorsum of the proximal phalanx of the injured finger. C, The volar and dorsal defects of the injured fingertip were reconstructed by the cross-finger flap and the dorsal digital perforator flap, respectively. D and E, Volar and dorsal appearance of the reconstructed fingertip at 11 months postoperatively. F, Function of the reconstructed fingertip at 11 months postoperatively. full color online

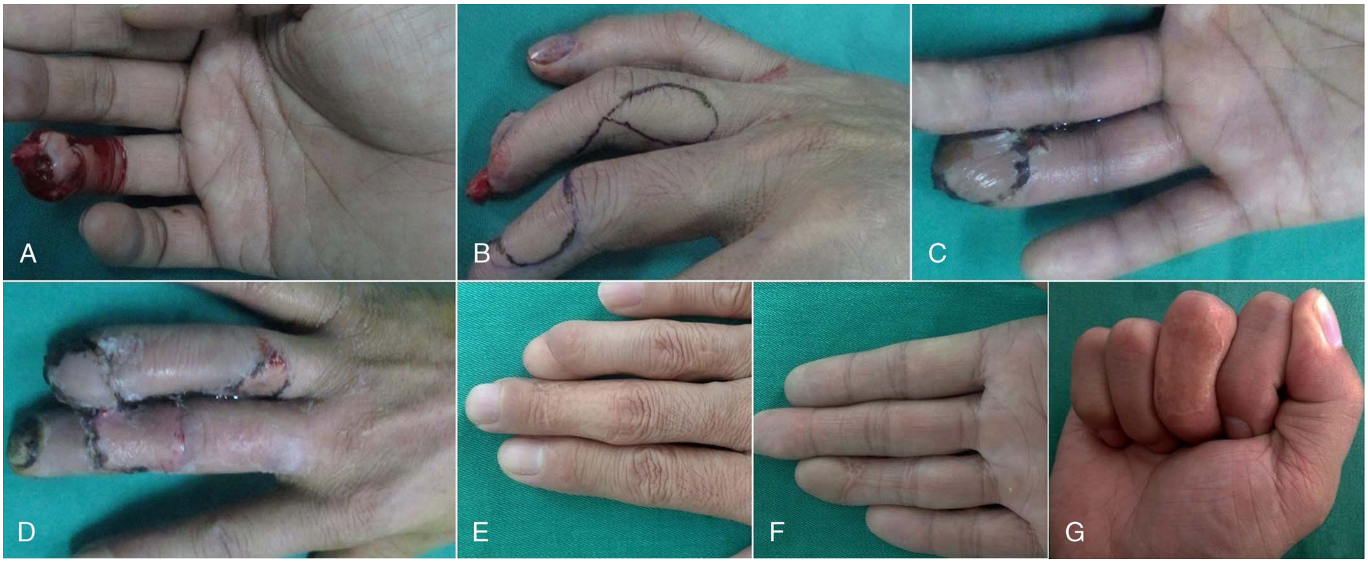

FIGURE 6. A, Fingertip degloving injury of the right ring finger. B, A cross-finger flap was designed on the dorsum of the middle phalanx of the middle finger, and a dorsal digital perforator flap was designed on the dorsum of the proximal phalanx of the injured finger. C and D, The volar and dorsal defects of the injured fingertip were reconstructed by the cross-finger flap and the dorsal digital perforator flap, respectively. E and F, Dorsal and volar appearance of the reconstructed fingertip at 9 months postoperatively. G, Function of the reconstructed fingertip at 9 months postoperatively. full color online

We used an innervated dorsal digital perforator flap for reconstruction of the dorsal defect of the degloving fingertip and an innervated cross-finger flap for the volar defect. The sufficient flap size provided by the combination of the 2 flaps is conducive to restoring the aesthetic form of the fingertip. According to the MHQ, all of the patients in our series were satisfied with the appearance of the reconstructed finger.

Because of nerve anastomoses, the sensation of the flaps can be restored, which is conducive to functional reconstruction and can prevent neuroma and pain. In our series, the averaged static 2PD on the cross-finger flaps and the dorsal digital perforator flaps reached 59% and 74% of those of the contralateral fingers, respectively. The CISS questionnaire scores of all flaps were less than 25 (mild), and most patients had no pain.

Our technique divides the necessary soft tissue requirements for the injured finger between 2 fingers. Two fingers each contribute a smaller flap, thereby leading to each finger having less donor morbidity, such as skin graft contracture and extensor tendon adhesion. Thus, the total donor site morbidity is minimized.[38] In our series, no significant difference was seen in the averaged TAM between the injured or donor fingers and the contralateral fingers. Meanwhile, early rehabilitation with the help of a physical therapist is also very important.[39]

To avoid potential injury to the donor site at the original trauma, a homodigital flap should be designed on the proximal dorsum instead of the middle dorsum, which is adjacent to the wound. There is no need to use a Doppler probe to locate the digital artery perforator because of its anatomical consistency.

It has been reported that flap venous congestion is a common postoperative complication.[40] In our series, a 1-cm-wide subcutaneous tissue margin surrounding the LVC was included in the pedicle to improve venous drainage, but dissection and ligation of the dorsal veins contained in the pedicle were not performed. The preservation of a skin bridge over the pedicle was necessary, as it could prevent the tiny venules from compression after flap transfer.[41] None of our flaps showed venous congestion.

During flap elevation, proper incisional extension was conducive to harvesting a longer flap nerve, which was helpful for tension-free neurorrhaphy. Burying the proximal ends of the severed DDNs and DBDNs into healthy soft tissues might make any hypersensitivity or symptomatic neuroma less symptomatic.[42,43]

The disadvantages include 3 weeks of immobilization and a 2-stage procedure. The new volar fingertip with a cross-finger flap lacks the soft tissue stability, because the fibrous septum is no longer there (as the pulp of the finger is missing). The instability may interfere the activities such as picking up objects. The limitations of this study are the small sample size and the lack of a control group, and the results may vary in larger or other cohorts. Therefore, future studies will ideally be prospective, randomized, and blinded to better ascertain the efficacy of our technique.

CONCLUSIONS

A dorsal digital perforator flap combined with a cross-finger flap is an effective and reliable method for the reconstruction of fingertip degloving injuries. This technique, with fewer donor site complications, can provide good sensation and aesthetic appearance for the fingertip.

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