



Combination free foot flaps for digit reconstruction: A retrospective analysis of 37 cases

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KEYWORDS

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Summary Combination foot flaps for digit reconstruction was previously introduced by our group as an alternative method for toe-to-hand transfer. The aim of this study was to analyze our experience with the combination foot flaps and to present the surgical refinements that were introduced. A prospective study was conducted including all combination foot flaps performed at our hospital since September 2009. Surgical refinements that were introduced during this study included island flap for repair of toenail donor site and the use of Z-plasty. The median operation duration was 6.7 hours (range 3.5–13 h). Among 74 flaps, partial necrosis occurred in three flaps (4.1%); two palmar flaps (2.7%) were bulky. Among 37 cases of reconstructed digits, contracture of the first web occurred in one case (1.4%). All the patients were able to walk well and did not complain of any pain or cold intolerance. Wound dehiscence of donor site was observed in three patients (8.1%). Toenail deformity occurred in one case (2.7%). The combination foot flap is a reliable option for digit reconstruction with minimal donor site complications.

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Introduction

Traumatic digit amputations could compromise pinch and grasp functions of the digits¹. Toe-to-hand transfer has become the preferred choice for reconstruction of digit defects presently^{2–5}. However, the disadvantage of this method is that a toe needs to be sacrificed, and transfer of the toe results in excess bulk and contour irregularity of the repaired finger or thumb^{1,6}. To improve the digit pulp and

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restore the digit nail without sacrificing a toe, we divided the toe flap into two parts: a dorsal nail-skin flap harvested from one toe and a flap for coverage of the digit palmar defect harvested from another part of the body^{7,8}. If necessary, a grafted iliac bone is used to replace the original length of the digital skeleton. A toenail flap was used to repair the dorsal defect and a free flap was used to repair the palmar defect⁹. This method allows for the toe-to-hand transfer without sacrificing a toe.

In our previous reports, we presented a review of literature on the use of an ipsilateral second dorsal nail-skin flap in combination with a contralateral medial second toe flap for finger degloving injury and reported on combining two foot flaps with iliac bone graft for the reconstruction of a thumb defect⁷⁻⁹. We performed our first combined flap thumb reconstruction in 2009. Our experience has steadily increased since then, and we have introduced several surgical refinements. The aim of this study was to analyze our experience with combination foot flaps for digit reconstruction and to present the surgical refinements that have been introduced during the past 8 years.

Methods

In this retrospective analysis, the medical records of all patients in our hospital who had skin defects with or without accompanying bone defects and received combination flaps for digit reconstruction between September 2009 and November 2017 were reviewed. The study was approved by the Institutional Review Committee of Ruihua Hospital affiliated to Soochow University and was performed in accordance with the standards of ethics described in the Declaration of Helsinki. Informed consent was verbally obtained from all patients. Patient demographics, mechanism of injury, operation details, length of hospital stay, follow-up length, and complications were recorded. Complications were categorized as recipient site and donor site complications. Recipient site complications included total flap loss, partial flap loss, and wound problems (wound dehiscence and/or skin necrosis). Donor site complications included graft skin necrosis and wound dehiscence. The length of follow-up was defined as the time between the patient's last visit and the date of the operation.

Surgical Technique

According to the surgeons' preference, combined flaps were designed on one pedicle or two pedicles [Fig. 1]. If one pedicle was needed, before surgery, a Doppler probe was used to detect the presence and location of the first dorsal metatarsal artery. The location and depth of the first metatarsal artery was noted.

For injuries that also had bone defects, an iliac crest bone graft was needed. The bone grafts were used to reconstruct the thumbs or fingers such that they were similar in width and length as those of the corresponding digit on the uninjured side, including a wedge shape being wider proximally [Fig. 2B]. The cortical bone of the grafted bone was placed toward the lateral side [Fig. 2D], and the distal side was grooved to fix the transplanted toenail [Fig. 2C].



Figure 1 A) Design of the great toenail flap and the dorsalis pedis flap based on one pedicle. B) Design of the great toenail flap and the second toe medial flap based on one pedicle. C) Design of the second toenail flap and the great toe lateral flap based on one pedicle. D) Design of the great toenail flap and the dorsalis pedis flap based on two pedicles. E) Design of the great toenail flap and the second toe medial flap based on two pedicles. An island toe medial flap was designed for the repair of the great toe donor site. F) Design of the second toenail flap and the second toe medial flap based on two pedicles.

A great toenail flap was used to repair the dorsal defect of the thumb, and a second toenail flap was used to repair the dorsal defect of the thumb or finger. All the toenail flaps were designed to be 0.3 cm longer than the defect size. A medial second or great toe flap, dorsalis pedis flap, or a flap based on the descending branch of the ulnar artery was designed to use for the repair of palmar skin defects of the thumb or finger. The selection of flap was based on the area of the palmar defect. The length and width of the flaps were designed to be 0.5 cm longer than the palmar defect size. Proximally, all the flaps were designed in a teardrop shape. The techniques used for flap harvest have been described in our previous articles [7-9].

Postoperative Treatment

All patients remained on bed rest for 7-10 days following the operation. The repaired hand was positioned such that the hand was at the heart level, and a plaster splint was applied to reduce the movement of the repaired hand. Dipyridamole, anisodamine, and papaverine were routinely used during treatment. Antibiotics were administered routinely for 1 week after surgery. A compression bandage was left on the donor feet, and the feet were kept elevated for 7 to 10 days. When the wound healed, approximately 2 weeks after surgery, progressive rehabilitation of the hand was initiated.

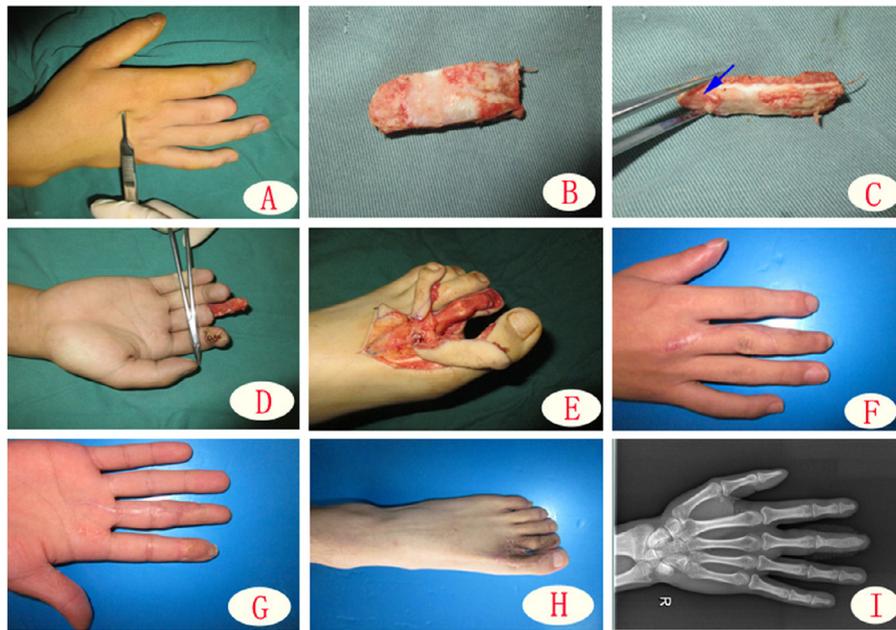


Figure 2 A) Preoperative defect proximal to proximal interphalangeal joint in the right middle finger after amputation. B) The bone graft was similar in width and length as those of the corresponding digit on the uninjured side. C) The distal side was grooved for the transplanted toenail to be fixed on (Blue arrow). D) The cortical bone of the grafted bone was placed toward the lateral side. E) The defect was covered and reconstructed with the combined great toenail flap and second toe medial flap based on one pedicle. F, G) 15 months after surgery satisfactory esthetic results. H) Donor sites were also acceptable. I) X-ray 15 months after the operation.

Evaluation of Outcomes

To eliminate biases during analyses, evaluation was done by a senior hand surgeon who did not attend the surgical cases. During follow-up, static two-point discrimination (2PD) was used to measure sensation in the flaps. Subjective criteria using patient-centered questionnaires, Michigan Hand outcome Questionnaire (MHQ)¹⁰ and Maryland foot rating score,¹¹ were used to evaluate overall outcomes of the repaired hand and the donor sites after the operation.

Results

Patient Demographics

Between September 2009 and November 2017, a total of 37 combined flap digit reconstructions were performed on 37 patients with a median follow-up of 27.4 months (range 11-78 months). Patient demographics are presented in Table 1. There were 11 women and 26 men. Mean patient age was 27.1 ± 10.7 years at the time of surgery. The injured hands included 18 right hands and 19 left hands. Of the 37 combined flap digit reconstructions, thumbs were reconstructed in 23 patients, index fingers in 8 patients, middle fingers in 3 patients, ring fingers in 2 patients, and small finger in 1 patient.

Surgical Procedure Details

Twelve surgery cases were performed in the first stage and the remaining 25 in the second stage. The median operation times were 6.7 (range 3.5-13) hours (Table 2). Iliac crest bone grafts were used in 19 cases. Twenty-six great toenail flaps and 11 second toenail flaps were harvested for restoration of dorsal defects. Twenty-four medial second toe flaps, 3 medial great toe flaps, and 10 dorsalis pedis flaps were harvested for restoration of palmar defects. Twenty-one combination flaps were based on one pedicle, whereas the others were based on two pedicles. There were 74 free flaps in total. Thirty-four donor sites of toenail flaps and all the donor sites of palmar flap were repaired using skin grafts from thighs in 5 cases, crus in 11 cases, and abdomen in 18 cases. Three donor sites of toenail flaps were repaired using island toe flaps.

Results for Recipient sites

The shape and size of the reconstructed thumbs or fingers were comparable to those of the corresponding thumb and fingers on the uninjured side, except for two, which required debulking. The MHQ score of the repaired hand was 80.3 ± 5.2 points (Table 2). The sensation of the reconstructed digital pulp was 10.0 ± 3.1 points. One female patient did not go back to work and looked after the family at home. Two patients changed the kind of the job. All other patients went back to do the original work. Among 74 flaps,

Table 1

Case	Occupation	Age/sex	Injured finger/level	Emergency operation	Bone graft	Toenail flap	Pulp flap	Number of pedicles	Restoration of donor site
1	Machine operator	36/M	Right index finger/proximal phalangeal	N	N	Right great toe	Right second toe medial flap	One	Skin graft from right leg
2	Machine operator	18/M	Right thumb/proximal phalangeal	N	Y	Right great toe	Right dorsalis pedis flap	One	Skin graft from the right leg
3	Student	15/M	Left thumb/proximal phalangeal	N	Y	Left great toe	Left second toe medial flap	One	Skin graft from the left leg
4	Machine operator	25/M	Right thumb/proximal phalangeal	N	Y	Left great toe	Left dorsalis pedis flap	One	Skin graft from the abdomen
5	Machine operator	24/F	Right thumb/distal phalangeal	N	Y	Right great toe	Right second toe medial flap	One	Skin graft from the abdomen
6	Machine operator	21/F	Right index finger/distal phalangeal	Y	N	Right second toe	Left second toe medial flap	Two	Island pedicle flap of the great toe, skin graft from the left leg
7	Machine operator	27/M	Right index finger/distal phalangeal	Y	N	Right second toe	Left second toe medial flap	Two	Skin graft from the right leg
8	Machine operator	48/F	Left index finger/distal phalangeal	Y	N	Right second toe	Right great toe lateral flap	One	Skin graft from the right leg
9	Machine operator	19/M	Left small finger/distal phalangeal	Y	N	Right second toe	Left second toe medial flap	Two	Skin graft from the left leg
10	Machine operator	19/M	Right thumb/proximal phalangeal	Y	N	Left great toe	Right second toe medial flap	Two	Skin graft from the abdomen
11	Machine operator	45/F	Left thumb/distal phalangeal	Y	N	Left great toe	Right second toe medial flap	Two	Island pedicle flap of the second toe, skin graft from the left leg
12	Machine operator	19/M	Left index finger/distal phalangeal	Y	N	Left second toe	Right second toe medial flap	Two	Skin graft from the right leg
13	Machine operator	42/M	Left thumb/distal phalangeal	Y	N	Right great toe	Right second toe medial flap	One	Skin graft from the right leg
14	Intern	19/F	Left index finger/middle phalangeal	Y	N	Right second toe	Left second toe medial flap	Two	Skin graft from the left leg
15	Machine operator	17/M	Right middle finger/distal phalangeal	Y	N	Left second toe	Right second toe medial flap	Two	Skin graft from the right leg
16	Machine operator	31/M	Left thumb/distal phalangeal	N	Y	Left great toe	Right second toe medial flap	Two	Skin graft from the abdomen
17	Machine operator	18/F	Left middle finger/distal phalangeal	Y	N	Right second toe	Left second toe medial flap	Two	Skin graft from the right leg
18	Machine operator	23/F	Right ring finger/distal phalangeal	N	Y	Left second toe	Right second toe medial flap	Two	Skin graft from the abdomen
19	Machine operator	36/M	Left thumb/distal phalangeal	N	N	Left great toe	Left second toe medial flap	One	Skin graft from the abdomen
20	Machine operator	36/M	Left index finger/distal phalangeal	N	N	Left great toe	Left second toe medial flap	One	Skin graft from the left leg

(continued on next page)

Table 1 (continued)

Case	Occupation	Age/sex	Injured finger/level	Emergency operation	Bone graft	Toenail flap	Pulp flap	Number of pedicles	Restoration of donor site
21	Machine operator	43/M	Left thumb/proximal phalangeal	N	Y	Left great toe	Right dorsalis pedis flap	Two	Skin graft from the abdomen
22	Machine operator	44/F	Right thumb/distal phalangeal	N	Y	Right great toe	Right dorsalis pedis flap	One	Skin graft from the abdomen
23	Machine operator	28/M	Right thumb/proximal phalangeal	N	Y	Right great toe	Left dorsalis pedis flap	Two	Skin graft from the abdomen
24	Machine operator	44/M	Right thumb/proximal phalangeal	N	Y	Right great toe	Left dorsalis pedis flap	Two	Skin graft from the abdomen
25	Machine operator	49/F	Right thumb/proximal phalangeal	N	Y	Right great toe	Right dorsalis pedis flap	One	Skin graft from the abdomen
26	Intern	16/M	Right thumb/proximal phalangeal	N	Y	Left great toe	Left dorsalis pedis flap	One	Skin graft from the abdomen
27	Machine operator	34/M	Left thumb/distal phalangeal	N	Y	Right great toe	Right second toe medial flap	One	Skin graft from the abdomen
28	Machine operator	18/F	Right thumb/proximal phalangeal	N	Y	Right great toe	Right dorsalis pedis flap	One	Skin graft from the abdomen
29	Student	12/M	Left thumb/distal phalangeal	N	Y	Left great toe	Left second toe medial flap	One	Skin graft from the abdomen
30	Machine operator	20/M	Left thumb/proximal phalangeal	N	Y	Left great toe	Left dorsalis pedis flap	One	Skin graft from the left leg
31	Machine operator	22/F	Left thumb/distal phalangeal	N	Y	Left great toe	Left second toe medial flap	One	Skin graft from the abdomen
32	Student	17/M	Right middle finger/middle phalangeal	N	Y	Left second toe	Left great toe lateral flap	One	Skin graft from the abdomen
33	Machine operator	18/M	Left index finger/distal phalangeal	N	N	Right great toe	Left second toe medial flap	Two	Skin graft from the left leg
34	Machine operator	24/M	Right thumb/distal phalangeal	N	N	Right great toe	Right second toe medial flap	One	Skin graft from the right leg
35	Machine operator	33/M	Left thumb/distal phalangeal	N	Y	Right great toe	Right second toe medial flap	One	Skin graft from the abdomen
36	Machine operator	20/M	Left thumb/distal phalangeal	Y	N	Left great toe	Right second toe medial flap	Two	Island pedicle flap of the second toe, skin graft from the left leg
37	Machine operator	24/M	Right ring finger/distal phalangeal	N	N	Right second toe	Right great toe lateral flap	One	Skin graft from the right leg
Average		27.1							
STDEV		10.7							

M: Men; F: Female; Y: Yes; N: No.

Table 2

Case	Operative time (hours)	Hospital stay (days)	Follow-up time (months)	Recreation	Results of recipient site			Results of donor site	
					2PD (mm)	MHQ	Complications	Maryland	Complications
1	8.25	9	15	Y	12	82		89	Wound dehiscence
2	7	20	20	Y	9	86.2		98	
3	6.5	12	15	Y	13	81.4		96	
4	7	14	13	Y	14	73.2		96	
5	7.5	15	18	Y	9	85.3		97	
6	10.5	13	24	Y	9	82	Flap bulky	88	
7	7	15	30	Y	8	87.5		92	
8	6	15	40	Y	6	80.6		94	
9	4.5	14	36	Y	8	82		97	
10	10.5	31	35	Y	11	81		93	Wound dehiscence
11	5	17	32	Y	6	83.4		94	
12	4.25	11	47	Y	5	79.6		91	
13	5	21	39	Y	10	85.3		90	
14	7	43	55	Y	8	82.6	Partial necrosis of flap	87	
				Job change					
15	10	14	51	Y	8	78	Nail deformity	97	
16	7	19	22	Y	10	81		92	
17	4.75	11	46	Y	7	83.1	Nail deformity	89	
18	4	14	16	Y	12	76		92	
19	4	15	18	Y	12	81.1		94	
20	3.5	13	20	Y	9	84		90	
21	9.5	20	17	Y	14	72		94	Scar formation
22	6	15	23	Y	10	80		90	Scar formation
23	6	37	21	Y	10	68		92	Wound dehiscence
24	10	16	15	Y	14	71	Contracture of the first web	91	
25	8	16	15	N	14	74		89	
26	8.5	17	13	Y	15	69	Partial necrosis of flap	82	
				Job change					
27	5	15	21	Y	11	80.6		96	
28	3.75	32	12	Y	14	76.2	Partial necrosis of flap	92	Cold intolerance
29	4	20	38	Y	5	86.4		96	
30	7.25	27	20	Y	12	76		92	Scar formation
31	4.75	14	78	Y	3	91.3		98	
32	13	15	11	Y	15	77.4		89	
33	3.5	14	16	Y	11	81		94	
34	7	15	53	Y	6	86.3	Flap bulky	92	
35	5	13	23	Y	9	83.9		92	
36	11	15	31	Y	8	81.1		98	
37	5	16	16	Y	13	80.7		90	
Average	6.7	17.6	27.4		10	80.3		92.5	
STDEV	2.4	7.3	15.3		3.1	5.2		3.5	

2PD: Two-point discrimination; MHQ: Michigan Hand outcome Questionnaire; Y: Yes; N: No.

partial necrosis occurred in three flaps (4.1%); two cases were treated only with dressing changes and one with an abdomen pedicle flap; two palmar flaps (2.7%) were bulky and needed subsequent revision operations. Among 37 cases of reconstructed digits, contracture of the first web occurred in one case (2.7%), which was treated by Z-plasty. X-ray results of the grafted bone in 8 cases showed satisfactory results. Unfortunately, X-ray results of other cases were not followed up.

Results for Donor sites

Wound dehiscence of the donor site was observed in three patients (8.1%). Three cases healed with dressing changes alone, while in one case the use of skin graft was required. Toenail deformity occurred in one case (2.7%), which was repaired through a subsequent operation (Table 2).

Discussion

Indication of the combined flaps

The aim of this study was to analyze our experience with the use of combined flaps for digit reconstruction and to present the surgical refinements that have been introduced, as we originally used this technique. The most common indication for the use of combination flaps for digit reconstruction is the need to repair the thumb or fingers while preserving the digit length with adequate function. Combination flaps were used for the repair of thumb and finger defects. In the case of thumb defects following the use of combination flaps, the loose capsular ligaments of the thumb carpometacarpal joint with its shallow saddle articulation were intact. The grasp and opposition function of the thumb were maintained without having to reconstruct the flexor and extensor tendons. In the case of fingers that had distal and phalanges defects after the use of combination flap, the central slip tendon and flexor superficialis tendon of the finger were intact, and the flexor and extensor function of the finger were maintained without further functional reconstruction (Supplementary Movie). Therefore, the use of combination flaps for reconstruction helped restore the digit appearance with nail and achieve satisfactory functional results.

Selection of flaps based on one pedicle or two pedicles

The choice of combination flaps with one or two pedicles was based on following principles listed below: for the distal phalanges defects of the thumb and finger and middle phalanges defects of fingers, if the first dorsal metatarsal artery of the donor site is present (Gilbert types I or II), a combination flap based on either one pedicle or two pedicles is selected depending on the surgeon's preference. According to current analysis, no evident differences in surgical time were observed when either kind of combination flaps was used. For proximal thumb defects, wherein the first dorsal metatarsal artery is not present, Gilbert type III, the com-

bined flaps based on two pedicles is selected so that there is sufficient flap surface to repair the wound.

If there is only one vessel that is able to be used in the recipient site, the combined flap based on one pedicle is selected. The combined flap based on two flaps should be connected in series, thus resulting in one pedicle, before use. When the wound area is larger, a combined flap made up of two flaps is used because the harvest of two large flaps based on one pedicle could damage the donor site.

Key points for technique revision

Nail deformity occurred in two cases in approximately 5 years after the operation. Some key points for minimizing the problem are as follows: 1) the width of the iliac bone should be made big enough to support the nail; 2) the distal bone should be grooved suitable for the transplanted toenail to be fixed on. Hematoma formation under the nail should be avoided. These steps will enable better and firmer attachment of the nail to the bone. 3) When harvesting the toenail flap, care should be taken not to damage the nail bed and to ensure that the nail is innervated by the digital nerve.

The follow-up data showed that the sensation in the digit pulp was desirable. The thumb pulp sensation in the first patient who underwent the operation was similar to that of the contralateral thumb and the 2 PD was 3 mm at 70 months after the operation. The first patient who showed desirable sensory outcomes suffered from a distal phalanx defect of the right thumb, while similar favorable outcomes in terms of sensation were not found in the cases wherein proximal phalanx defects were observed. We believe that there may be two reasons for this: first, it is possible that the high quality of nerve coaptation resulted in adequate sensory recovery; second, it is quite likely that a high number of nerves at the recipient sites not only coaptated the nerves but also grew into the pulp. Further studies are currently in progress to help us further understand the mechanism behind the recovery of pulp sensation. No resorption of the grafted bone was seen in eight cases. This may be due to the double sets of the blood system in our design.

Contracture of the first web occurred in one case with proximal phalanx defects. To solve the problem, Z-plasty was used to suture the skin edges. Passive functional exercise was begun once the blood supply of the flaps was restored. All the patients could walk well and did not complain of any pain or cold intolerance. The results obtained were similar to those previously reported¹². Wound dehiscence occurred in one case at a rate of 5%. The most significant of these refinements included the use of island flaps for the repair of the toenail flap donor site and flaps based on the descending branch of the ulnar artery for palmar defects. These modifications helped in significantly improving the healing of toenail flap donor sites without damage to the dorsalis pedis artery. They also facilitated better cold tolerance at the foot donor site. In one case, we observed bone nonunion; this may have happened because the proximal bone was not cut long enough to expose the fresh bone in the patient who had a hot crush injury. This may have resulted in incomplete removal of the necrotic bone, which may have ultimately contributed to the nonunion.

Conclusion

The combination foot flap is a favorable option for digit reconstruction with minimal donor site complications. The appearance and function of the repaired thumbs and fingers are satisfactory. The surgical refinements resulted in a significant reduction in donor site complications.

Conflict of Interest

All named authors hereby declare that they have no conflicts of interest to disclose.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:[10.1016/j.bjps.2018.12.021](https://doi.org/10.1016/j.bjps.2018.12.021).

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