



Contents lists available at ScienceDirect

Journal of Hand Surgery Global Online

journal homepage: www.JHSGO.org

Original Research

Aesthetic Reconstruction of Fingers and Thumbs With the Vascularized Half–Big Toenail Flap With Minimum Donor Site Morbidity

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ARTICLE INFO

Article history:

Received for publication February 13, 2020

Accepted in revised form May 23, 2020

Available online June 29, 2020

Key words:

Aesthetic finger reconstruction

Donor site

Minimum invasion

Partial toe transfer

Primary wound closure

Purpose: The vascularized half–big toenail flap is a short-pedicle free vascularized flap approximately 30 mm in size that contains a fibular half-nail with a 5-mm skin edge and the partial distal phalanx bone. The fingertip skin of the amputated finger is reflected to cover the skin deficiency. The sensation and function are maintained at the donor site, and primary wound closure of the donor site is possible. This study aimed to evaluate the clinical outcomes of thumb and finger reconstruction operations performed using this flap.

Methods: We assessed 16 patients (19 digits) with digit amputation who underwent this procedure. We evaluated the following parameters: reconstructed digits, amputation level, survival rate, period until bone union, elongated length, morphologic indices, feeding artery, vein distribution, static 2-point discrimination, and patient occupation. We used the Michigan Hand Outcomes Questionnaire for the evaluation of the function and appearance of the arm.

Results: We reconstructed 3 thumbs and 16 fingers. No patients with zone I or V or palm amputation underwent surgery. Flap survival was obtained in all cases, including one atrophic case. Elongated length was 14.1 mm (range, 0–30 mm). The width and longitudinal/axial convexity of the transferred nail increased and the length decreased, whereas the width of the donor site nail increased at final follow-up. Reasonable sensation of the flap was obtained. The feeding artery was the plantar digital artery in 15 toes, the branch in 1, and the arterial anonymous vessel in 3. We could harvest the vein in the first web in 16 toes. All patients went back to their former jobs.

Conclusions: The aesthetic and functional outcomes of the reconstructed thumbs and fingers significantly improved. Donor site functional morbidity was minimum. Nevertheless, patients' expectations regarding the reconstructed digit seemed to be that of an intact digit.

Type of study/level of evidence: Therapeutic IV.

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Posttraumatic thumb or finger loss results in notable functional and aesthetic impairment. To address these impairments, multiple reconstructive procedures, such as a great toe transfer, second toe transfer, wraparound flap, and their respective modifications, have

been described.^{1–11} However, donor site defects have been underestimated.^{12,13}

The vascularized half–big toenail flap was originally developed by Kuroshima¹⁴ in 1990. The tibial half of the nail (the sensation, function, and morphology of the toe tip) is maintained in the donor site. Furthermore, primary wound closure of the donor site is possible, which suggests a potential solution for donor sacrifice often noted by patients who undergo reconstructive surgery.

The purpose of this article was to review the clinical outcomes of the use of half–big toenail flaps retrospectively in the reconstruction of thumbs and fingers. We hypothesized that the half–big

Declaration of interests: No benefits in any form have been received or will be received by the authors related directly or indirectly to the subject of this article.

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<https://doi.org/10.1016/j.jhsg.2020.05.005>

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toenail flap would provide a good alternative for thumb and finger reconstruction with good functional and aesthetic outcomes.

Materials and Methods

There were 115 cases of single-digit amputation and 30 of multiple-digit amputation (65 digits) in which reconstructive surgery was indicated between 2007 and 2017. Among them, we assessed the cases of 16 patients (14 males and 2 females) with single-digit amputation and 3 with multiple-digit amputation (6 digits) who underwent a vascularized half–big toenail flap for reconstruction. Mean follow-up after surgery was 26.7 months (range, 8–63 months).

We obtained approval for the study from our institutional review board and informed consent from all patients who participated in the study. We retrospectively reviewed the following parameters: reconstructed digits, level of amputation (zone classification of Komatsu and Tamai¹⁵), survival rate, time to bony union as assessed by radiologic obliteration of the fracture line, elongated length, morphological indices, feeding artery, vein distribution, static 2-point discrimination (S2PD), occupation, sports or hobbies, and complications.

Morphological indices were corrected by the coauthors (M.N. and K.N.), who were not involved in the care of patients, using a PC monitor. Indices included width, length, and longitudinal/axial convexity of the transferred nail and the tibial half of the donor nail before surgery and final follow-up (Fig. 1).

We used the Michigan Hand Outcomes Questionnaire to evaluate the function and appearance of the upper limb and the American Academy of Orthopedic Surgeons Lower Limb Questionnaire (LLQ) to evaluate lower limb function before surgery and at final follow-up. The LLQ evaluates stiffness, swelling, and pain during walking, ascending and descending steps, and resting. The full potential score is 8.

We analyzed descriptive statistics using Mann-Whitney U test. $P < .05$ was considered to indicate statistical significance.

Surgical techniques

The flap is a short pedicle–free vascularized flap approximately 30 mm in size containing the fibular half-nail with a 5-mm skin edge as well as the partial distal phalanx bone. The weight-bearing plantar skin and subdermal tissue are preserved.

The half–big toenail flap is fed by a plantar digital artery or a dorsal arterial innominate vessel and harvested with fibular subdermal tissue. A free skin graft is necessary for subdermal tissue.

The fingertip skin of the amputated finger is reflected to cover the skin deficiency. The edge of the reflected flap forms the ulnar side of the lateral nail fold of the half–big toenail flap for cases in which the free flap is transferred to the radial side of the amputated finger. Combination with the reflected flap can reduce the size of the free flap, which enables primary wound suture of the donor site. If the length of the reflected flap is too short and sutured under tension, the half–big toenail flap is shifted toward the reflected flap and the axis of the nail deviates. Coincidence of the median line of the transferred nail and that of the recipient digit creates the reconstructed digit aesthetic.

An autogenous iliac crest corticocancellous bone graft is used for cases in which elongation exceeds 2 cm. We perform a skin plasty for the subdermal tissue of the free flap and the crease of the reflected flap after surgery, as needed.

From an aesthetic point of view, the half–big toenail flap is transferred to the radial side of the amputated finger, because the

radial side of the finger is more visible than the ulnar side (Fig. 2).¹⁴

Results

We reconstructed 3 thumbs and 16 fingers. No patients with zone I or V or palm amputation underwent surgery. With the exception of one case, patients with multiple-finger amputation preferred to undergo reconstruction of all amputated fingers (Table 1). Flap survival was obtained in all cases, including one atrophic case. Bone union was achieved at 11.2 weeks (range, 8–16 weeks). Mean elongated length was 14.1 mm (range, 0–30 mm), including 3 cases in which an iliac bone graft was used. Regarding the morphological indices, we excluded one atrophic case.

Mean width of the transferred nail was 8.0 ± 1.2 mm before surgery and 9.2 ± 1.3 mm at final follow-up; mean length was 14.2 ± 2.0 and 11.7 ± 2.0 mm, respectively; mean transverse convexity was 32.9 ± 6.2 and 61.1 ± 26.2 mm, respectively; and mean longitudinal convexity was 12.1 ± 12.4 and 23.1 ± 14.5 mm, respectively. Regarding the residual donor site nail, mean width was 8.0 ± 1.2 mm before surgery and 11.6 ± 1.6 mm at final follow-up; mean length was 14.2 ± 2.0 and 13.5 ± 1.9 mm, respectively; mean transverse convexity was 37.8 ± 9.6 and 54.1 ± 15.5 mm, respectively; and mean longitudinal convexity was 12.1 ± 12.4 and 12.5 ± 11.5 mm, respectively (Fig. 3). Table 1 and Figure 4 show the feeding arteries. We could harvest the vein in the first web in most cases (Table 1, Fig. 4). Mean S2PD was 10.5 mm (range, 5–16 mm) in the zone II group and 15.1 mm (range, 5–20 mm) in the zone III group, whereas there was no recovery in zone IV of the free flap. In contrast, in the reflected local flap, mean S2PD was 8.6 mm (range, 5–15 mm) in the zone II group and 11.0 mm (range, 5–20 mm) in the zone III group, with no recovery in zone IV. The S2PD of the free flaps and reflected local flap between zones II and III did not differ significantly ($P = 0.63$ and $P = 0.21$, respectively); furthermore, the S2PD of the free flaps and reflected local flap also did not differ significantly ($P = 0.15$).

Table 2 lists the Michigan Hand Outcomes Questionnaire scores. The aesthetics score before surgery was markedly lower than the other functional scores. The score improved significantly, especially in the group with thumb or multiple-finger amputation ($P < 0.01$). However, mean score at the final follow up was at most two-thirds of the full potential score. Among the cases with single-finger amputation, function was not considerably impaired before surgery and at final follow-up. In contrast, function improved remarkably among cases of thumb or multiple-digit amputation. The LLQ scores indicated no functional disturbance regarding the feet except for mild stiffness in 6 toes. All patients went back to their former jobs and were able to participate in sports and hobbies (Table 1).

Complications included fractures of the distal phalanx of big toes during surgery in 2 patients. We fixed them with a Kirchner wire, and the bone healed. Defects of the distal phalanx showed osteogenesis after surgery; no fracture of the donor site was noted after surgery.

Pressure sores at the donor skin delayed wound healing in 3 patients. Occlusive dressing healed the wound in 2 to 8 weeks. Partial necrosis of the skin graft was noted in 5 patients, and infection of the residual nail of an amputated stump was noted in one. The infection was healed by removing the residual nail.

Postoperative transient circulatory insufficiency of a free flap was observed in 2 patients, whereas atrophy of a free flap was observed in one patient in whom the plantar digital artery was used as a feeding vessel. In these 2 patients, we planned a second-look surgery in the operating room. However, the circulation



Figure 1. Morphological indices. **A** Horizontal and vertical lines show width and length, respectively. **B** Angle of longitudinal convexity. **C** Angle of transverse convexity.

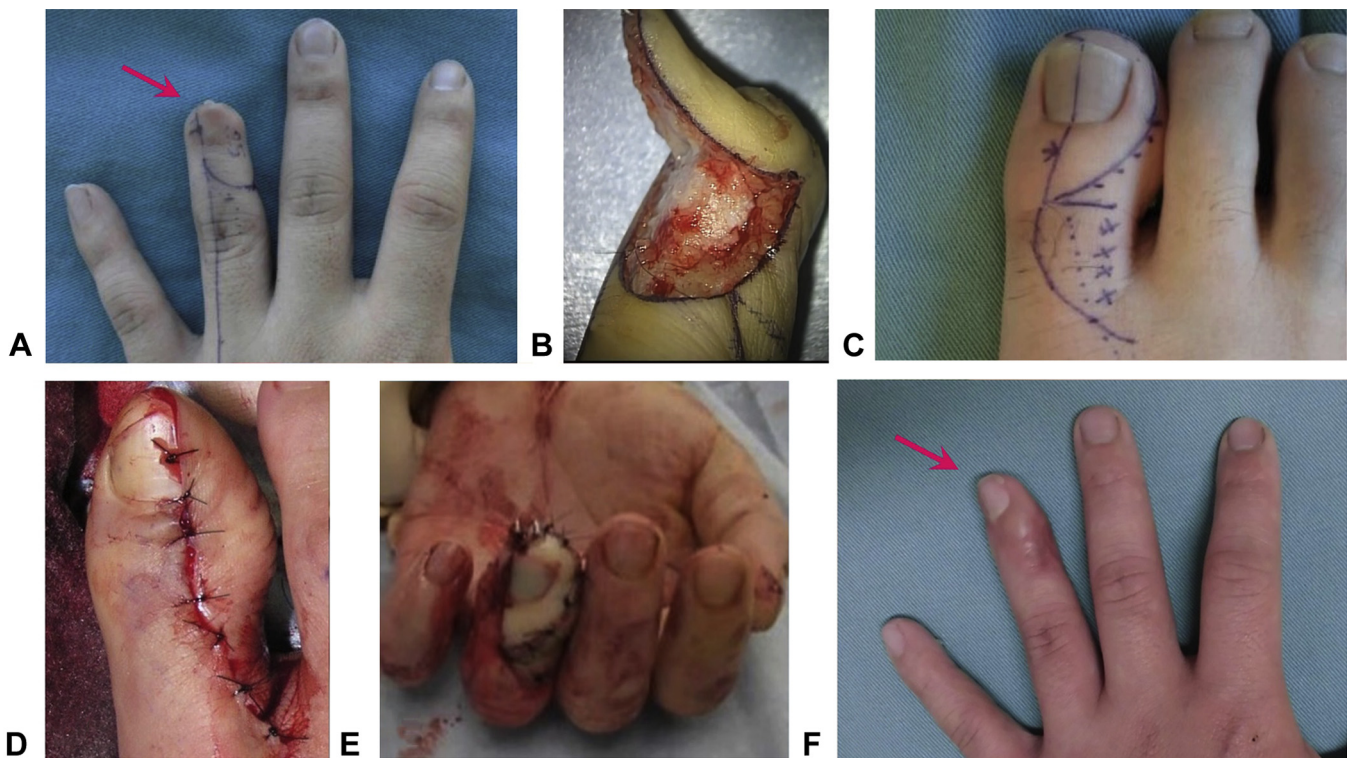


Figure 2. **A, B** The fingertip skin of the amputated finger is reflected to cover the skin deficiency. **C** The design of the half–big toenail flap. **D** Primary suture of the donor site is possible. **E** Appearance after transfer. The edge of the reflected flap formed the ulnar side of the lateral nail fold of the half–big toenail flap. **F** Appearance at final follow-up.

recovered soon after we administered an axial block in both patients. In the atrophic case, we failed to harvest a sufficient volume of subdermal tissue between the digital plantar artery and the flap. Circulation of the atrophic flap was insufficient and eventually became atrophic.

Case Reports

Case 1

Patient 1 was a 33-year-old woman who was seen at follow-up 34 months after surgery. The patient's right thumb had been amputated by a human bite at a psychiatric facility. We performed amputation stump plasty. She did not choose a wraparound flap because of donor site impairment, despite preferable

morphological resemblance with this option. We reconstructed the right thumb with zone II amputation using the half–big toenail flap 9 months after the injury. Although the transferred nail was small for the thumb, the patient was satisfied with the appearance of thumb and the donor site (Fig. 5). She returned to her job and visited our office while wearing sandals the summer after the surgery.

Case 2

Patient 2 was a 45-year-old woman who was seen at follow-up 17 months after surgery. The patient's right index finger had been amputated by a meat slicer, and we performed amputation stump plasty. We reconstructed the right index finger with zone II amputation 4 months after the injury. The nail became shorter and

Table 1
Summary of 16 Patients With Thumb and Finger Reconstruction

Patient	Sex	Age, y	Digit	Zone	Result	Elongation, mm	S2PD (Reflected Flap), mm	S2PD (Free Flap), mm	Feeding Artery	Vein	Job	Sports/Hobby	LLQ
1	F	33	Thumb	II	Survived	10	11	10	DPA	First web	Care staff		7
2	F	45	Index	II	Survived	15	5	5	DPA	First web	Food processor		8
3	M	29	Index	II	Survived	15	10	11	DPA	First web	Mechanics		7
4	M	32	Index	II	Survived	5	5	10	DPA	Tibial side	Mechanics	Surfing	8
5	M	55	Middle	II	Survived	15	15	16	DPA	First web	Mechanics		8
6	M	29	Ring	II	Survived	0	5	5	DPA	First web	Mechanics		7
7	M	36	Ring	II	Survived	15	6	15	AIV	First web	Mechanics		7
8	M	30	Ring	II	Survived	15	10	12	DPA	First web	Mechanics	Tennis	7
9	M	20	Ring	II	Survived	15	11	15	DPA	First web	Construction worker		7
10	M	20	Index	II	Survived	5	5	5	DPA	First web	Mechanics		8
			Middle	II	Survived	10	5	5	AIV	First web			7
11	M	46	Ring	II	Survived	15	11	16	DPA	First web			7
			Index	III	Survived	10	5	16	DPA	Tibial side	Mechanics		7
12	M	27	Thumb	III	Survived	30	20	20	DPA	First web	Mechanics	Video game	8
13	M	66	Thumb	III	Survived	25	5	5	AIV	First web	Mechanics		7
14	M	36	Middle	III	Survived	25	16	20	DPA branch of digital plantar artery	First web	Mechanics		7
15	M	41	Middle	III	Atrophic	15	10	20	DPA	First web	Mechanics		7
16	M	41	Ring	III	Survived	5	16	20	DPA	First web	Mechanics		7
			Middle	IV	Survived	23	–	–	DPA	First web			8

AIV, Arterial innominate vessel; DPA, digital plantar artery.

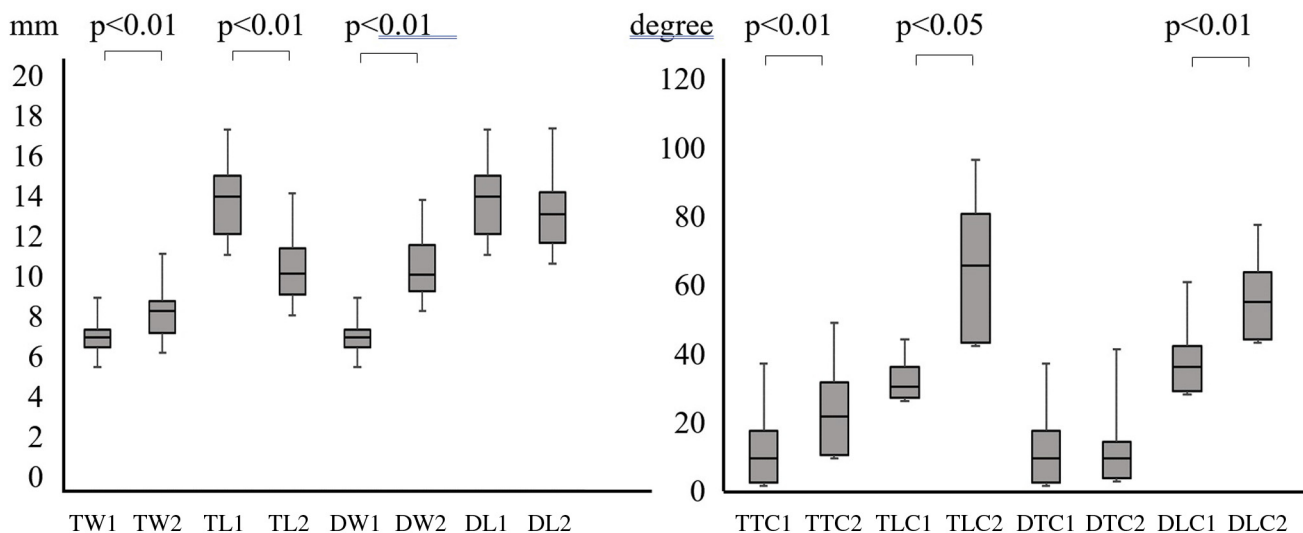


Figure 3. Morphological change of transferred/donor nails. DL1, length of donor nail before surgery; DL2, length of donor nail after surgery; DLC1, longitudinal convexity of donor nail before surgery; DLC2, transverse convexity of donor nail after surgery; DTC1, transverse convexity of donor nail before surgery; DTC2, transverse convexity of donor nail after surgery; DW1, width of donor nail before surgery; DW2, width of donor nail after surgery; TL1, length of transferred nail before surgery; TL2, length of transferred nail after surgery; TLC2, transverse convexity of transferred nail after surgery; TW1, width of transferred nail before surgery; TW2, width of transferred nail after surgery; TTC1, transverse convexity of transferred nail before surgery; TTC2, transverse convexity of transferred nail after surgery. The width and longitudinal/transverse convexity of the transferred nail was significantly increased whereas the length was significantly decreased. The width and transverse convexity of the donor nail were significantly increased.

wider. Axial convexity of the transferred nail subsequently increased (Fig. 6). She returned her job and was satisfied with the appearance.

Case 3

Patient 11 was a 46-year-old man who was seen at follow-up 29 months after surgery. The patient’s index, middle, and ring fingers had been amputated by a metal-cutting machine. We performed amputation stump plasty of the index finger, because this finger had been crushed. Replanting the amputated middle finger to middle finger and ring finger to ring finger would require 2 vein

grafts, so ectopic replantation of the less-damaged combination of the distal ring finger and proximal middle finger was performed, which allowed us to reduce the number of vein grafts required. Although the ring finger survived, it became atrophic. We reconstructed the index finger and atrophic ring finger at 5 and 8 months after the injury, respectively (Fig. 7). The patient returned to his former job and his feet were not impaired.

Case 4

Patient 13 was a 66-year-old man who was seen at follow-up 18 months after surgery. The patient was a mechanic whose thumb

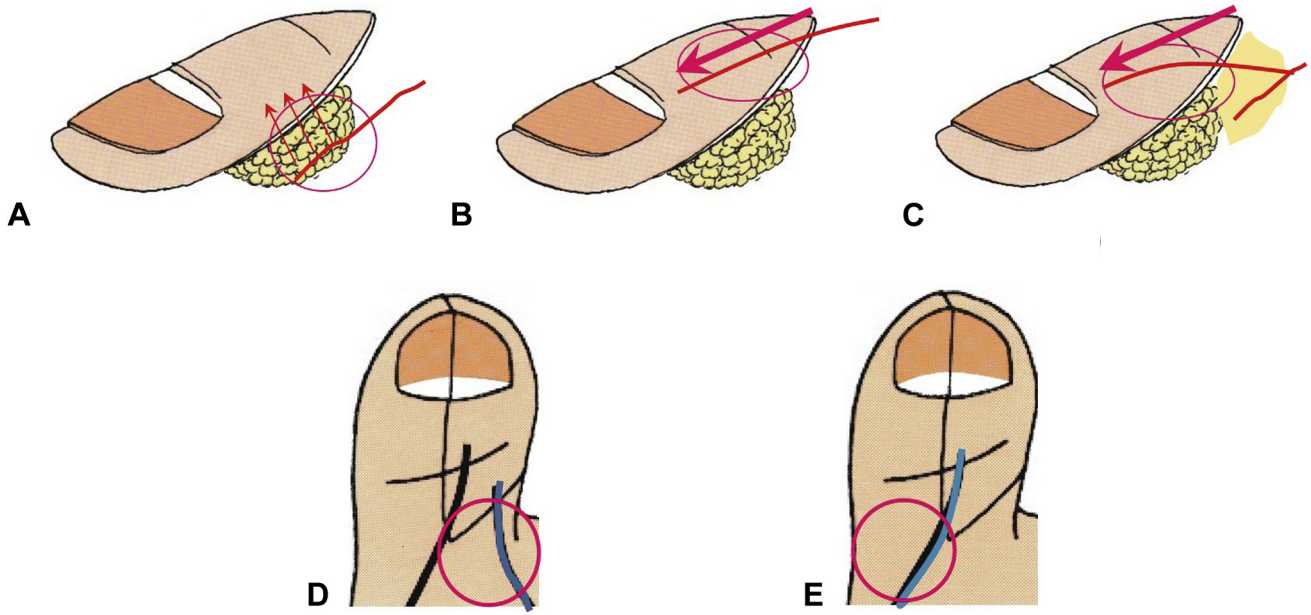


Figure 4. **A** A plantar digital artery was used as a feeding artery in 15 cases. **B** An innominate arterial vessel was used in 3 cases. **C** The branch of the plantar digital artery was used in one case. Types B and C had axial circulation. The proximal fat tissue may contain a branch of the plantar digital artery. **D** Veins were secured in the first web in 17 cases. **E** Veins were secured in the tibial side of the great toe in 2 cases.

Table 2
Scores of Michigan Hand Outcomes Questionnaire*

	Overall Function		Activities of Daily Living		Work Performance		Aesthetics		Satisfaction	
	Before	After	Before	After	Before	After	Before	After	Before	After
Total (n = 16)	64.6 ± 21.0	76.5 ± 14.5	55.8 ± 36.8	88.5 ± 12.1	61.2 ± 38.3	88.8 ± 12.8	27.9 ± 21.3	66.3 ± 9.3	66.0 ± 19.0	77.6 ± 19.0
Multiple or thumb (n = 7)	56.4 ± 21.7	74.3 ± 17.4	31.4 ± 28.7	81.4 ± 12.1	36.4 ± 37.8	82.9 ± 15.0	16.1 ± 18.4	59.8 ± 10.8	51.8 ± 13.2	74.4 ± 11.6
Single (n = 9)	74.2 ± 15.6	79.2 ± 10.2	84.2 ± 25.2	96.7 ± 5.2	90.0 ± 15.2	95.8 ± 3.8	42.8 ± 23.3	74.0 ± 15.5	76.4 ± 14.6	81.3 ± 10.5

* Satisfaction indicates satisfaction with hand function before surgery and at the final follow-up. Multiple or thumb indicates multiple-finger or single-finger amputation. Aesthetics improved significantly. Function improved remarkably among cases of thumb or multiple-digit amputation.

had been amputated by a metal-cutting machine. We replanted the thumb, which became necrotic, and then performed amputation stump plasty. He selected the half–big toenail flap for reconstruction because of minimal invasion of the big toe.

We reconstructed the thumb with zone III amputation with 2.5 cm elongation using an iliac crest bone graft 11 months after amputation stump plasty. The grip power was 32 kg (right)/29 kg (left) and pinch power was 6 kg (right)/6.5 kg (left). There was little morbidity at the donor site according to the LLQ. He went back to his former job as a mechanic (Fig. 8).

Discussion

People, especially women, are hesitant to lose toes for reconstructive surgical procedures such as toe transfer or wraparound flap, particularly in countries where people dislike body defects or regularly wear open-toed shoes in daily life.^{16–22} Wang and Sun²³ claimed that donor sites of wraparound flap were as unattractive as bound feet.

In the current study population, no patients with zone I amputation wished to undergo reconstructive surgery. These choices indicated that having at least a partial nail in the digits of the hands or toes is essential for a digit from an aesthetic viewpoint.^{11,22,24,25} Furthermore, patients with palm amputation did not choose to undergo reconstructive surgery. Among cases in which no aesthetic improvement was expected, no patients wished to undergo further invasive procedures on their feet. The patients expected aesthetic rather than functional improvement.

Historically, a broad nail, an interphalangeal (IP) joint, and the digital nerve suture of the donor to that of the recipient have been believed to be necessary for reconstructing the thumb, and the sacrifice of more than one toe has been accepted to reconstruct a thumb.^{4,7–10} In contrast, Sabapathy et al¹⁸ reported that toe transfer to the thumb slightly improved strength with no difference recognized in the dexterity or function compared with osteoplastic reconstruction. None of the patients in the current study who underwent thumb reconstruction chose a wraparound flap, which is morphologically more desirable. They

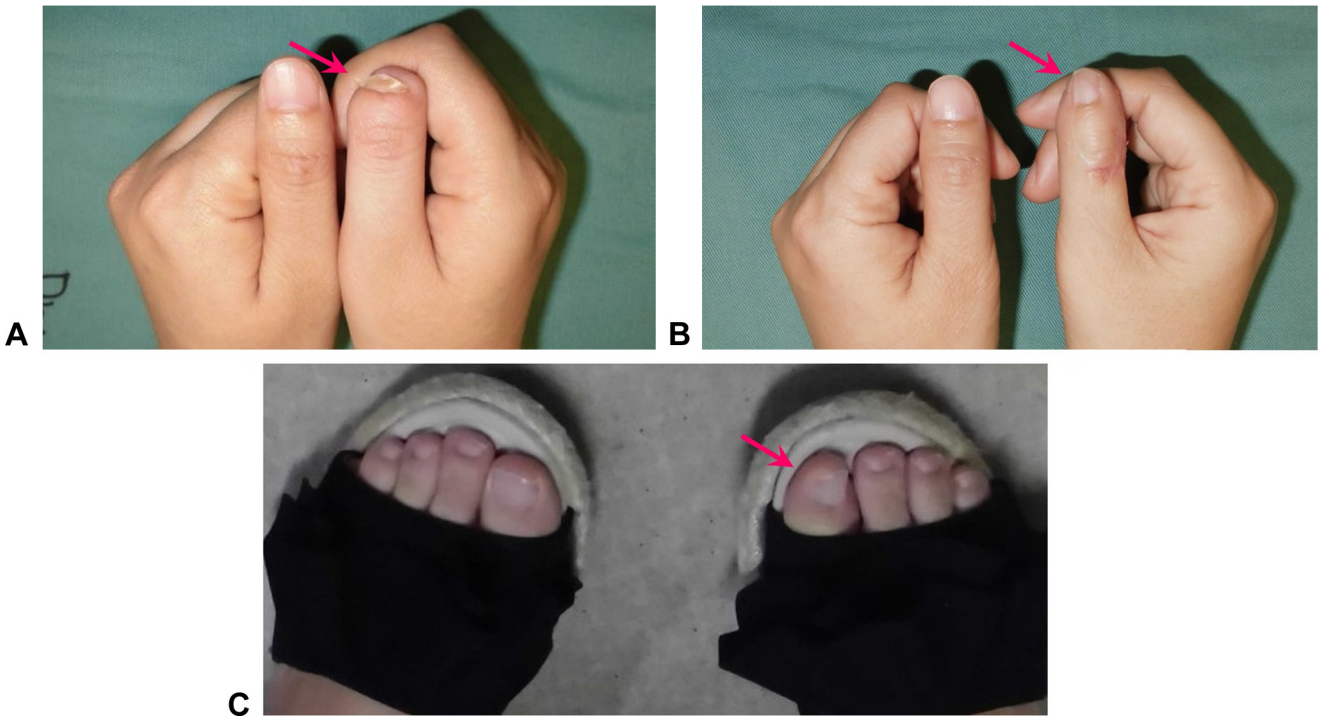


Figure 5. Patient 1: A Right thumb with zone II amputation. B View of reconstruction. C This patient visited our office while wearing sandals the summer after the surgery.

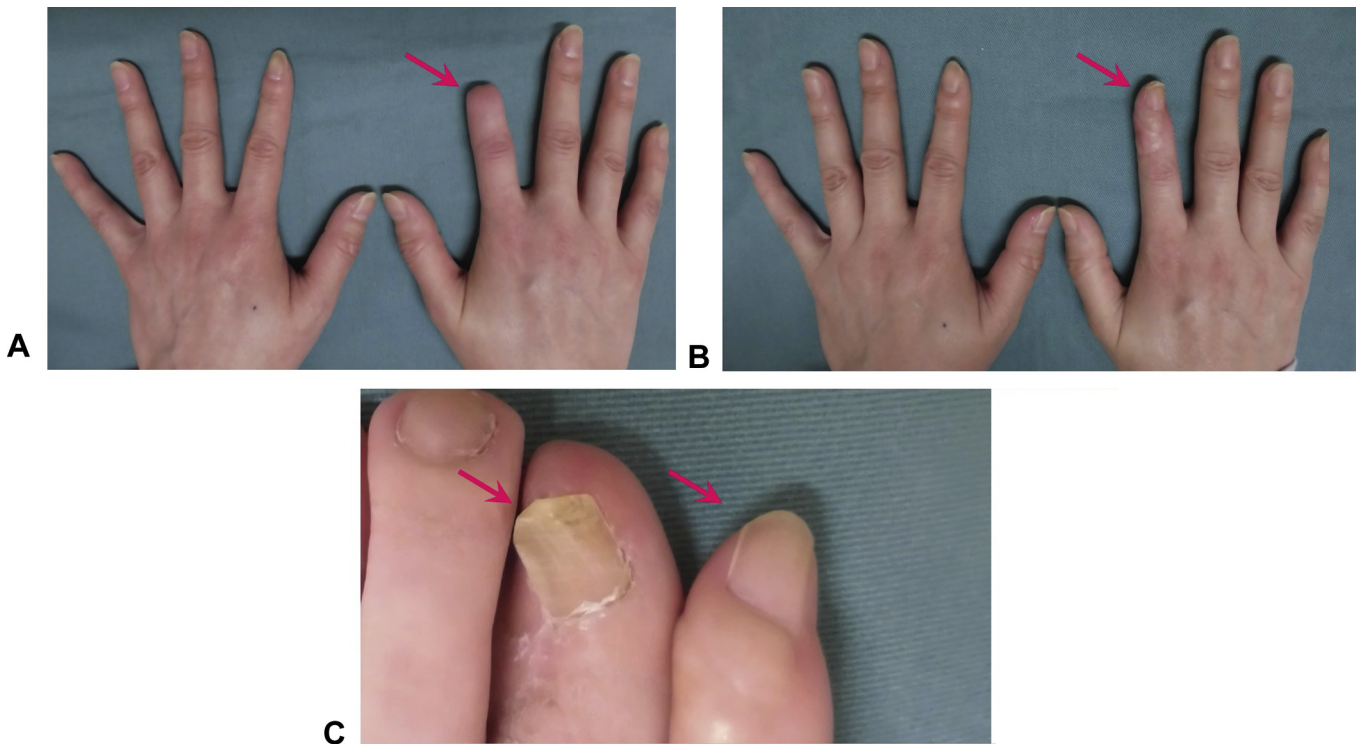


Figure 6. Patient 2: A Right index finger with zone II amputation. B The reconstructed nail has a natural appearance. C The configurations of the transferred and donor nail became different at final follow-up.

claimed that a wraparound flap basically transfers the digital defect from the hand to the toe.

Although nail-to-nail pinch was impossible because the length of the reconstructed thumb was as long as the IP joint, grasp and tip pinch were possible.²⁰

Reconstructing the thumb using a half–big toenail flap should be considered an option for thumb reconstruction, depending on the patient’s cultural background or the activities of daily life.

The configuration of the nail of the half–big toenail flap is narrower and longer than the nails of a hand at the time of

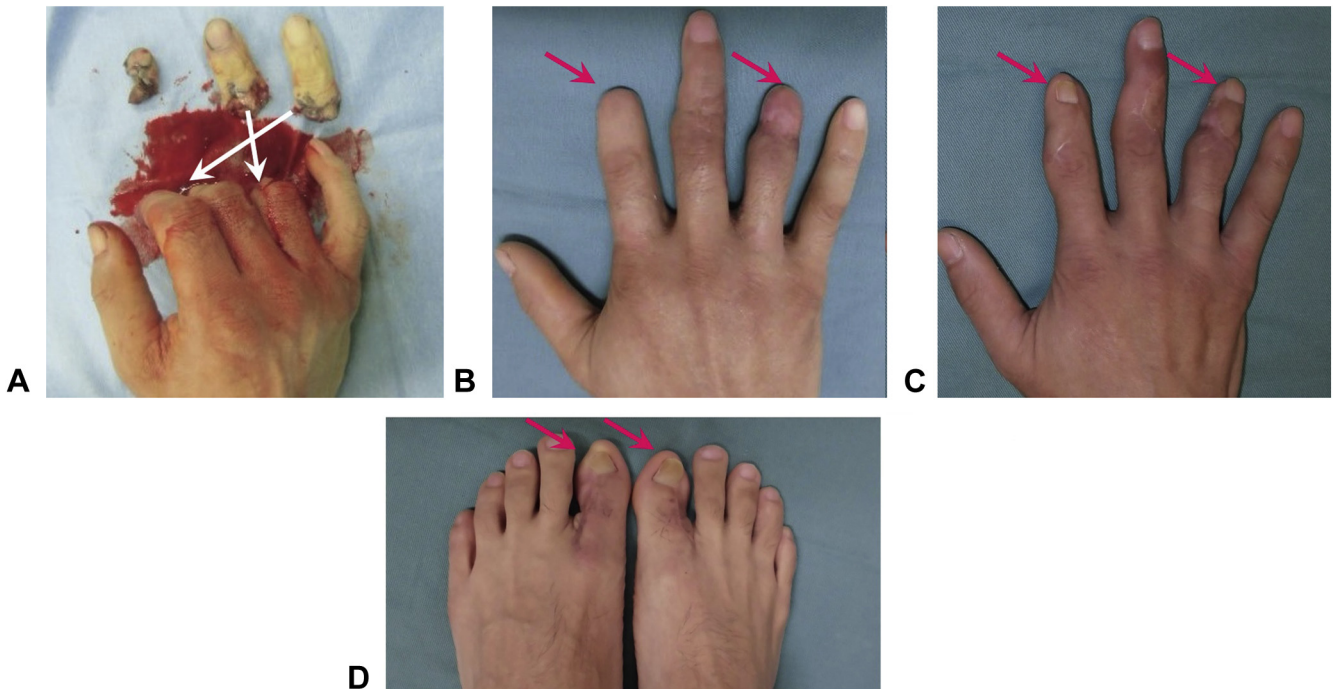


Figure 7. Patient 3: **A** We performed ectopic replantation. **B** The middle finger survived without a vein graft. The ring finger became atrophic. **C** We reconstructed the index and ring fingers. **D** View of the donor sites.

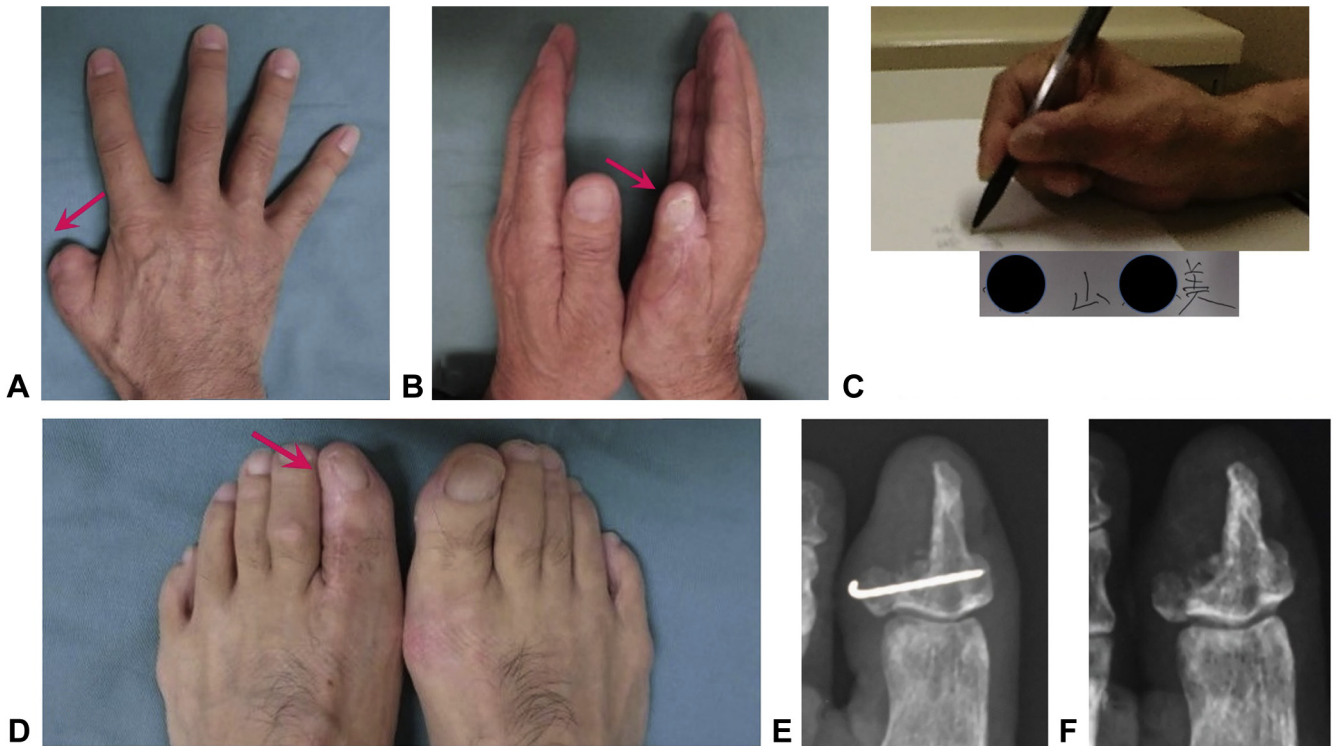


Figure 8. Patient 4: **A** Right thumb with zone III amputation. **B** Reconstruction with 2.5 cm elongation. **C** No difficulty in writing. **D** The donor site has comparatively a small deformity. **E** We fixed the fracture of the distal phalanx with a Kirchner wire during surgery. **F** The bone healed.

harvesting. Kuroshima²⁶ reported that the transferred nail became wider and shorter, the transverse convexity increased, and the donor nail became wider. In addition to these changes, this study showed that the longitudinal convexity of the transferred nail and

the axial convexity of the donor site nail increased. The mechanism is not clearly understood; however, the configuration of the nail plate is crucially determined by the shape of the distal phalanx.²⁷ Moreover, the shape of the digit and mechanical stress may affect

the configuration,²⁸ because the residual donor site nail is strongly affected by the mechanical stress of the body weight and the transferred nail and donor site nail, which were almost symmetric at surgery, became apparently asymmetric at the final follow-up examination (Fig. 6).

Nail-fold plasty has been reported to be necessary in cases involving partial toe transfer to fingers, because the tibial side of the transferred nail lacks a nail fold.⁶ However, for these reasons, morphological adjustment of the transferred nail, such as shortening the transferred nail or nail-fold plasty during surgery, was unnecessary, because the donor site nail ultimately comes to resemble the fingernail.¹⁴

Circulation of the flap using a plantar digital artery as a feeding artery is maintained by random circulation of the subdermal tissue between the flap and the plantar digital artery. In contrast, a half–big toenail flap using an arterial innominate vessel has axial circulation in the flap.¹⁴ The arterial innominate vessel was no more than 0.3 to 0.4 mm in diameter, and we were able to identify it in a few cases. We identified a branch of the plantar digital artery that also had axial circulation. In the case of partial toe transfer using a plantar digital artery as a feeding artery, securing the proximal fat tissue to the flap may make circulation more reliable (Fig. 3).

We conducted Doppler ultrasound to identify the dorsal artery. However, preoperative evaluation of the artery using Doppler ultrasound was inaccurate because it may simultaneously detect the sound of the plantar digital artery. We did not conduct evaluations using magnetic resonance angiography or contrast-enhanced angiography, because the plantar digital artery is always easy to secure if we cannot identify the dorsal artery.

In partial toe-transfer flaps with a short vascular pedicle, securing a vein is more important. Observation of the vein distribution of the dorsal foot with near-infrared light indicated that securing the veins in the first web space would be highly possible. In approximately 10% of cases, additional tibial exposure is required to secure a vein.^{29,30}

Sensation of the replanted finger has been reported to improve without coaptation of the digital nerve up to zone III.³¹ Our cases of zone III reconstruction showed less sensory recovery than zone II reconstruction, albeit without a significant difference, and no recovery in zone IV. The patients had no problems regarding their tasks. However, transplanting the free flap with a digital nerve might have been a better option when reconstructing zone III or IV amputated digits.

The osteotomy line of the distal phalanx of the big toes was too close to the IP joint in some cases. To manage fractures during surgery, we established a rule to confirm the location of the joint using a 23-gauge needle before osteotomy. Delayed wound healing of the donor site occurred in several cases. The skin of the donor site became thin in places after flap harvesting. Excessive compression by dressings or walking after discharge were considered to be reasons for delayed healing.

Necrosis of the full-thickness skin grafts was probably due to compression insufficiency, because the subdermal tissue under the skin graft had arterioles from the digital plantar artery to the flap, and the applied compression may not have been adequate in cases of circulatory impairment.

Postoperative circulatory insufficiency of a free flap was observed in 2 cases in which the plantar digital artery was used as a feeding vessel; the circulation recovered soon after we administered an axial block in both cases. We assumed that the transient circulatory insufficiency was due to vasoconstriction of arterioles between the digital plantar artery and the flap. Regarding the atrophic case of a free flap, in which the plantar digital artery was

also used, the subdermal tissue employed might not have contained sufficient arterioles to the flap.

This study had some limitations, including its retrospective design and the relatively small study population. Furthermore, the follow-up of 2 patients was less than 1 year. The disadvantage of this operation was that the half–big toenail flap could not be applied to more than 2 fingers. It was difficult to achieve primary elongation of more than 3 cm in one stage owing to the circulation of the reflected local flap and the short pedicle of the free flap.³² The maturation of an amputated finger stump was mandatory, because this technique involved the combination of the free flap and the local flap of an amputated stump.

Performing the sensory examination using S2PD might have indicated a weaker recovery than reality, because the distal skin edge of both the free and reflected flaps had a weaker sensation than the more proximal area, and patients often did not feel the distal S2PD pins. Semmes-Weinstein monofilaments test to the middle of the flaps might have been more accurate.

However, despite the limitations of study and the disadvantages of the surgery, the half–big toenail flap resulted in an improved aesthetic appearance and function of hands and minimal donor site morbidity compared with other reconstructive procedures. Nevertheless, the final average aesthetics score was far below the full potential score, indicating continued dissatisfaction with appearance. We considered patients' expectations regarding the aesthetic of the reconstructed digit to be an appearance that resembled an intact digit. We must therefore strive harder to improve patients' aesthetic satisfaction.

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