Cosmetic and Functional Results of a Newly Reconstructed Thumb by Combining the Phalange of Second Toe and the Great Toenail Flap Transplantation

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Abstract

BACKGROUND Microsurgical toe-to-hand transfer is a gold standard when it comes to repairing a thumb defect. Great toenail flap, thumbnail valva flap, free great toe and second toe transplantation are the common methods in thumb reconstruction. Second toe transplantation achieves good function, but poor aesthetics. Great toe transplantation achieves better aesthetics, but hindered walking, due to the foot’s loss of the great toe and moreover suboptimal thumb function. It is difficult to maintain both functional and aesthetic satisfaction in thumb reconstruction.

METHODS We experimented with three different methods of toe to hand transfer. From October 2009 to July 2019, 30 patients with traumatic thumb defects received one of 3 different kinds of thumb reconstruction in our clinic according to their level of amputation. Divided evenly into three groups of ten, group one received a great toe transplantation, group two received a second toe transplantation, and group three received a combined great toenail flap and second toe phalange transplantation. Each of the patients’ thumbs had different levels of amputation at the metatarsophalangeal joint (MPJ) or distal interphalangeal joint (DIPJ).

RESULTS 1 patient suffered from a partial flap necrosis and received a groin flap to cover the defect. No other thumbs had any complications. The functional and aesthetic results of both the donor and the recipient sites were satisfactory.

CONCLUSIONS Compared to the great toe or second toe transfer, combined free transfer of the great toenail flap and 2nd toe phalange achieved a substantially better functional and aesthetic result in the thumb reconstruction.

Introduction

Thumb amputation immensely handicaps a hand’s function. Plastic surgeons do their best to construct functional, while at the same time, aesthetically pleasing thumbs for their patients. The free toe-to-thumb transfer is a milestone in the clinical application of microsurgery technique [1, 2]. The skin and structure of the toe are very similar to the hand; thus, the functional restoration is an excellent technique that results in minimal morbidity at the donor site[3]. The great toe transfer is recognized as being able to achieve both aesthetic appearance and good function in the reconstructed thumb, while the second toe transfer is thought to result in less donor site morbidity [4]. The current specific considerations regarding the selection of the toe(s) are greatly based on the surgeon’s experience and patient’s need[5].

It is important to harvest the proper free toe flap by taking the particular thumb defect into account. In this study, we present our new technique of using a free flap combined with the great toenail and second toe phalange, in addition to necessary vessels, nerves, and tendons, to reconstruct the thumb. We have achieved both better functional and aesthetic results when compared to solely great toe or second toe transfers.
Materials And Methods

Patient data

30 patients who sustained thumb amputations between October 2009 and July 2019 were reviewed in this study. There were 18 male and 12 female patients that were an average of 31 years old (range: 14–48 years). The reasons for amputation were from accidents with manufacturing tools such as: the machine press (10 patients), power saw (6 patients), iron press (6 patients) and drill (8 patients). 20 patients underwent right thumb amputations and 10 patients had left thumb amputations. 29 patients received thumb reconstructions immediately after their injuries and 1 patient received a delayed reconstruction 16 years after the accident.

Surgical procedure

Debriding of the necrosis tissue was first performed in the operation room and the arteries, veins, nerves, and tendons of the injured thumb were identified and isolated. The surgical plan was made according to the size and shape of the defect. The patient's lifestyle and local condition of the donor site were also considered in the selection of the donor site.

The reconstruction method was chosen based on the thumb amputation level and patient's career background. For the defects that involved the distal interphalangeal joint (no matter transverse, oblique or longitudinal defect), great toe to hand transfers were performed for thumb reconstruction as reported [6–8]. The second toe is smaller and shorter than the normal thumb in appearance, but can achieve better function than the great toe[9, 10]. We used the second toe transfer for patients who suffered metacarpal bone or proximal phalanx defects with higher demands for function and lower demands for appearance. For those who had higher demands for both appearance and function of the reconstructed thumb, the second toe phalange covered with the great toenail flap was used. Once the operation method was determined, Doppler was used to locate the donor and recipient vessels.

Donor site preparation: Incisions were made according to the design (Fig. 7a,b). Dissection was performed to isolate the first and second branches of the dorsal vein and achieve sufficient pedicle length. We then ligated the other vein branches and made incisions at the web and plantar areas to find the first plantar metatarsal artery, the digital nerve, and its branches. We had to next Confirm the toe web vascular type and isolate the blood vessels and nerves. If the dorsalis pedis artery was chosen for the anastomosis, isolation of the dorsal artery was performed and the deep plantar branches were ligated to achieve the blood supply model as the dorsal artery-the first dorsal artery-toe artery. Sometimes, the first dorsal metatarsal artery has variation. The dorsalis pedis artery-plantar artery-toe arterial blood supply mode should be maintained for type III dorsal metatarsal arteries. If the first plantar artery were chosen to perform the anastomosis, it would not have been necessary to consider the toe web vascular type or isolated the first dorsal metatarsal artery. The neurovascular bundle was then exposed and dissected together with the free flap. Ligation of the hallux cross artery was carefully performed and the second
phalanx was cut according to the defect of recipient site. This was followed by the isolation of the hallux and 2 phalange flap.

(1) **Bone reconstruction**: We used wires and Kirschner to fix the bones for earlier functional rehabilitation.

(2) **Tendon reconstruction**: After the second toe phalange with vessels, nerves, and tendons were fixed to the phalangeal bone of the thumb with Kirschner wire, the extensor tendon and the flexor tendons were repaired and put in their rest positions. If the original amputation included the proximal site of the metacarpophalangeal joint, the pollicis brevis tendon also needed to be repaired. To do accomplish this, two functions needed to be restored. The digital flexion function was restored by replacing the hallucis longus flexor and extensor tendons with the 2nd inherent extensor and the 4th superficial flexor tendons. The function of opposition was achieved by using a dynamic tendon as a substitute in a similar way.

(3) **Nerve reconstruction**: Nerves needed to be sutured under tension free circumstances. The proximal nerve avulsion defect was reconstructed by suturing the 2nd digital nerve (ulnar side) with the donor nerve.

(4) **Vascular reconstruction**: Anastomosis was done to complete the vascular reconstruction. Patients received end to end anastomosis through subcutaneous tunnels between the first dorsal metatarsal artery and the radial artery at the snuffbox, in addition to between the saphenous vein and the deep branch of cephalic vein. If the diameter of first dorsal metatarsal artery was too small or absent, anastomosis of the first plantar metatarsal artery and the finger inherent artery was done instead.

(5) **Donor site closure**: The second phalanx flap was then transplanted to the tibial side of the hallux and the exposed bone was covered with the hallux nail and skin flap. (It was important to keep the pedicle in tension free circumstances). The hallux flap was sutured to the skin on the second phalanx flap (Fig. 4a). For the distal thumb joint reconstruction, a full thickness skin graft on the great toe and direct closure of the 2nd toe were performed; the second toenail flap was used to cover the great toe defect in other patients.

The defect of the great toe was able to be easily covered by the second toe skin flap and thus the wound required no necessary skin grafts. The Figs. 1–5 show the surgical procedures and techniques.

Antibiotics, spasmolysis, and anticoagulation treatment were prescribed post operation. Normal daily activity of the foot started at 2 weeks post operation and rehabilitation of the reconstructed thumb started at 4 weeks post operation.

The Kirschner wire was removed at 6 weeks post operation after X-ray confirmation of bone healing. Distal interphalangeal joint fusion of the 2nd toe was achieved as planned. Bone fusion of the 2nd toe shortened the length of the reconstructed thumb to a final, close-to-normal size.

Rehabilitation: (1) X-rays were taken six weeks post operation to confirm the bone fusion and that the external fixation was removed. Passive and active functional exercises were also started at this time with
a hand brace to avoid detrimental flexor and extensor tendon adhesions. (2) Electromagnetic waves were used at the reconstructed thumb pulp to stimulate nerve regeneration. (3) Iron therapy balls and 15 kg rubber bands were used to practice the thumb grip strength, pinch strength, and other muscle functions.

Rehabilitation Schedule: (1) Postoperative tendon adhesion is the main factor that negatively affects the reconstructed thumb function, but early functional rehabilitation minimizes this problem. The preparation stage starts 4–6 weeks post operation. In addition to passive movements for 5–10 minutes, 2 times a day, active movements were practiced with the guidance of a physician. (2) Continuous passive joint motion exercises were started 6 weeks post-operation and were done for four weeks. Initial activity was measured with a BTE Primus hand function rehabilitation assessment instrument. 5-10b traction strength was increased daily when there was no significant pain during the 30 minute exercise. Tendon release was performed if tendon adhesion occurred. (3) At 8–12 weeks post operation, the muscle strength training stage was begun. Isokinetic training was performed at 60 b/s, 90 b/s, and 120 b/s, 30 times a day. (4) 10–14 weeks post operation was the hand coordination training stage. According to the work characteristics of the patients, individually simulated vocational training was performed 30–60 min/day. Reassessment of the hand function was performed 6 months post operation. By individually simulating the patients with vocational training, we were able to prepare the patient to work once again.

Results

29 reconstructed thumbs recovered smoothly with no complications. Although 1 case suffered partial flap necrosis, we used the abdominal flap as a lifeboat and the patient recovered successfully. No patients had complications at the donor site. The average length of the hospital stay in groups I, II, and III was 18.5 days (range: 15–31 days), 17.2 days (range: 14–23 days) and 17 days (range: 14–21 days) respectively. The mean follow-up time was 12 months (range: 8–20 months) in group I, 12 months (range: 7–18 months) in group II, and 12 months (range: 5–19 months) in group III.

In this case series, 30 patients were separated into 3 groups according to the type of toe-to-thumb operation they received. Group I had 10 cases of great toe transplantations, group II had 10 cases of second toe transplantations, and group III had 10 cases of combined great toenail flap second toe phalanges. Total active motion(TAM) of the transplanted thumbs in Group I, II, and III was 68 ± 7.8, 83 ± 5.1, and 83 ± 5.5 respectively, which was compared with the contralateral healthy thumbs of the patients. Sensation recovery was measured with the static 2-point discrimination test (S-2PD). Results of group I, II, and III were 7.6 ± 1.4 mm, 8.1 ± 1.2 mm, and 7.5 ± 1.3 mm respectively. No patients suffered any painful paraesthesias. The Michigan Hand Questionnaire (MHQ) was used to measure the reconstructed thumb function 10 months after the operation. The subjective self-assessment function and cosmetic scores of the newly replanted thumb are described in Table 1.
Table 1 Postoperative results of the new thumbs and complications

| Group | Case | Follow-up (mean) (months) (mm) | TAM (%) | S-2PD (mm) | Satisfaction score (MHQ) Function | Aesthetic | Donor site complications |
|-------|------|-------------------------------|---------|------------|----------------------------------|-----------|-------------------------|
| I     | 10   | (8–20) 12                     | 68 ± 7.8| 7.6 ± 1.4  | 70.0 ± 4.5                       | 73.0 ± 3.6| Partial flap necrosis (<10 %) in one case |
| II    | 10   | (7–18) 12                     | 83 ± 5.1| 8.1 ± 1.2  | 89.0 ± 4.3                       | 68.0 ± 3.8| None                     |
| III   | 10   | (5–19) 12                     | 83 ± 5.5| 7.5 ± 1.3  | 90.0 ± 5.0                       | 87.0 ± 4.8| None                     |

TAM=total active motion (Motion recovery evaluated by total active motion compared with the contralateral thumb); S-2PD=static 2-point discrimination; MHQ Michigan Hand Questionnaire

The mean follow-up time was 12 months (range: 8–20 months, SD=3.47) in group I, 12 months (range: 7–18 months, SD=2.81) in group II, and 12 months (range: 5–19 months, SD=3.13) in group III.

Group I, thumb reconstruction by great toe transplantation;

Group II, thumb reconstruction by second toe transplantation;

Group III, thumb reconstruction by the great toe flap and the phalanges of the second toe.

Example case: a 26-year-old female suffered right thumb amputation at the IP joint 16 years ago (Fig. 6a, b). In order to restore the function and appearance of the affected thumb, toe-to-thumb transplantation was performed. Right hand X-rays showed the defect level to be distal to the metacarpophalangeal joint (Fig. 6c). After a detailed preoperative design (Fig. 7a, b), we harvested the combined flap from the great toenail and metacarpophalangeal joint from the second toe (Fig. 8). The length of the vascular pedicle was 11 cm. The donor site was primarily closed by means of covering the great toe phalangeal with the second toenail flap (Fig. 9). No vein graft or skin graft was performed and a functional thumb with good appearance was achieved (Fig. 10a, b). Good functional and cosmetic result can be achieved by operative treatment (Fig. 11a, b)

### Discussion

The thumb is the most vital part of hand function. The ideal thumb reconstruction from a microsurgical toe transfer should meet the requirements of both form and function with minor donor site morbidity[11–13]. Currently, there are four main types of free toe transfers (total great toe, second toe, great toe wrap-around, and trimmed great toe)[8, 12, 14–17]. Using the great toe to hand transfer, the reconstructed thumb gains good nerve recovery and skin texture, but the cosmetic result of the recipient site and the
function of donor site are not satisfactory. The second toe to hand transfer results in good hand function with less donor site morbidity, but it also leads to poor hand aesthetics[8, 18].

This study aimed to find a combined technique to achieve better results than the other four primary reconstruction methods. In this study, the great toenail flap and second toe phalangeal were chosen as donors to meet the demands. The combination of the two techniques achieved both good appearance and function. Indications of this combined technique include: (1) congenital or acquired thumb absence at any level with non-injured great and second toes; (2) the patient’s preference and agreement for the toe to hand operation method; (3) no present medical history with diabetes, high blood pressure, or cardiovascular or psychological disease; (4) proper local tissue conditions for thumb reconstruction in both the donor site and recipient site.

The main advantages of this combined method are as follows: (1) It combines the advantages of both the great toe and the second toe transfer to achieve an optimal functional and cosmetic result; (2) There is very little handicap to the weight bearing of the donor foot due to the preservation of the great toe phalange; (3) It results in better appearance of the donor site than a full thickness skin graft; (4) It is easy to locate the pedicle flap.

Still, the technique also has some disadvantages: (1) There is total loss of the second toe at the donor site; (2) There is increased difficulty of harvesting the combined flap instead of just the normal toe flap; (3) The operation is time consuming. The contraindications of this combined flap include: (1) Poor general condition; (2) Donor or recipient site infection; (3) Previous injury of the great or 2nd toe; (4) Social or psychological resistance to toe-to-hand transfer.

There are many factors that should be considered before an appropriate surgical plan is made, such as patient’s age, gender, profession, level of amputation, and hand dominance[19, 20]. In this case series, all the patients that received combined free transfer of the great toenail flap and 2nd toe phalange achieved not only good function and appearance at their donor sites, but also acceptable functional and cosmetic results of the newly reconstructed thumb. The composite transplantation is a great alternative choice for thumb reconstruction.

In this report, 30 cases with thumb amputations were successfully reconstructed with three different methods. Although the technique has some potential risks, our results indicate that the combined free transfer of great toenail flap and 2nd toe phalange achieves both functional and aesthetic satisfaction in thumb reconstruction.

Declarations

Conflict of interest

The authors have no financial conflicts of interest.
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Authors’ contributions

YFY designed the study, drafted the initial manuscript and revised the manuscript.

XT, YZL, BB, YY, TB and JNW collected data, carried out the initial analyses, manuscript preparation. All authors read and approved the final manuscript.

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Availability of data and materials

Not applicable.

Ethics approval and consent to participate

The study had been approved by the ethical committee of the participating hospitals. All subjects signed informed consent by each patient. All clinical investigations had been conducted according to the principles expressed in the Declaration of Helsinki.

Consent for publication

Consent for publication was obtained from every individual whose data are included in this manuscript.

Competing interests

The authors declare that they have no competing interests.

References

1. Mavrogenis, A.F., et al., The history of microsurgery. Eur J Orthop Surg Traumatol, 2019. 29(2): p. 247-254.

2. Roger de Oña, I., A. Garcia Villanueva, and A. Studer de Oya, An Alternative Thumb Reconstruction by Double Microsurgical Transfer From the Great and Second Toe for a Carpometacarpal Amputation. J
3. Stang, F., et al., [Abductor digiti minimi muscle flap for defect coverage of the hand]. Oper Orthop Traumatol, 2013. 25(4): p. 372-80.

4. Sabapathy, S.R., H. Venkatramani, and P. Bhardwaj, Reconstruction of the thumb amputation at the carpometacarpal joint level by groin flap and second toe transfer. Injury, 2013. 44(3): p. 370-5.

5. Wang, J. and J.C. Gillette, Carrying asymmetric loads while walking on an uneven surface. Gait Posture, 2018. 65: p. 39-44.

6. Zhu, H., B. Bao, and X. Zheng, A Comparison of Functional Outcomes and Therapeutic Costs: Single-Digit Replantation versus Revision Amputation. Plast Reconstr Surg, 2018. 141(2): p. 244e-249e.

7. Del Piñal, F., Extreme Thumb Losses: Reconstructive Strategies. Plast Reconstr Surg, 2019. 144(3): p. 665-677.

8. Tsai, T.Y., et al., Patient-Reported Outcome Measures for Toe-to-Hand Transfer: A Prospective Longitudinal Study. Plast Reconstr Surg, 2019. 143(4): p. 1122-1132.

9. Ju, J., J. Li, and R. Hou, Microsurgery in 46 cases with total hand degloving injury. Asian J Surg, 2015. 38(4): p. 205-9.

10. Liu, C., et al., Experimental study of tendon sheath repair via decellularized amnion to prevent tendon adhesion. PLoS One, 2018. 13(10): p. e0205811.

11. Ladd, A.L., The Teleology of the Thumb: On Purpose and Design. J Hand Surg Am, 2018. 43(3): p. 248-259.

12. Liu, C., et al., Repair of thumb defect by using the toenail flap: biomechanical analysis of donor foot-a retrospective cohort study. J Orthop Surg Res, 2019. 14(1): p. 287.

13. Wall, L.B. and C.A. Goldfarb, Tendon Transfers for the Hypoplastic Thumb. Hand Clin, 2016. 32(3): p. 417-21.

14. Lin, C.H., Toe-to-thumb reconstruction. Injury, 2013. 44(3): p. 361-5.

15. Lin, P.Y., et al., A systematic review of outcomes of toe-to-thumb transfers for isolated traumatic thumb amputation. Hand (N Y), 2011. 6(3): p. 235-43.

16. Ju, J., L. Li, and R. Hou, Transplantation of a Free Vascularized Joint Flap from the Second Toe for the Acute Reconstruction of Defects in the Thumb and other Fingers. Indian J Orthop, 2019. 53(2): p. 357-365.

17. Yuan, F., et al., Evidence-Based Practice in the Surgical Treatment of Thumb Carpometacarpal Joint Arthritis. J Hand Surg Am, 2017. 42(2): p. 104-112.e1.

18. Li, B., et al., EFFECT OF SECOND TOE-TO-HAND TRANSFER ON THE PLANTAR PRESSURE DISTRIBUTION OF THE DONOR FOOT. Acta Ortop Bras, 2016. 24(1): p. 39-42.

19. Elbeshbeshy, B. and N. Paksima, Post-traumatic thumb reconstruction. Bull Hosp Jt Dis, 2001. 60(3-4): p. 130-3.

20. Shehata Ibrahim Ahmed, M., E. Salah Ibrahim, and H. Ibrahim Eltayeb, Evaluation of versatility of use of island first dorsal metacarpal artery flap in reconstruction of dorsal hand defects. Asian J Surg,
Figures

Figure 1

The harvested great toenail flap and second toe phalangeal
Figure 2

The donor site after the flap was harvested
Figure 3

The inset great toenail flap and second toe phalangeal
Figure 4

The sutured nerve and tendon of the metacarpal thumb
Figure 5

The covering of the defect of the great toe by using the second toe skin flap.
Figure 6

The donor site closed by the second toenail flap

Figure 7

a, b. 6 months of follow-up after operation.