One-stage cosmetic finger reconstruction using a second toe island flap containing terminal branches of the toe artery

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ABSTRACT

Introduction: A finger reconstructed by toe transfer may have morphological defects. We report the results of second toe transfer for 1-stage finger reconstruction with an island flap based on terminal branches of the toe artery.

Hypothesis: The technique can improve the morphological outcomes of reconstructed fingers.

Materials and method: Between January 2008 and June 2011, toe-to-finger transfer was performed for 36 fingers in 31 patients. An island flap containing terminal branches of the toe artery was embedded in the neck of the second toe to eliminate the morphological defect caused by stenosis in that area.

Results: All reconstructed fingers and all flaps survived. No donor site complications occurred. The mean follow-up was 8 months (range, 5 to 25 months). The morphology of the reconstructed finger was close to that of a normal finger, and a natural transition could be observed in the flap, the finger neck, and the junction between the toe and the finger. Sensory recovery of the flap ranged from 51% to 53%. The mean pinch strength of the reconstructed fingers was 48% to 60% of that of the contralateral side. The mean DASH scores were 52.9, 48.9, and 46.0 for patients that had the index, third, and fourth fingers reconstructed, respectively, and the lowest mean aesthetic score was 70.

Discussion: The method provides good aesthetic and functional outcomes, and overcomes aesthetic deficiencies associated with other methods of toe transfer for finger reconstruction.

Level of evidence: Level IV.

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1. Introduction

Loss of hand function and deformities due to the finger defects as a result of trauma may seriously affect quality of life and mental health. Commonly used methods for finger reconstruction include deepening the first web space, tubular flap transfer together with bone grafting, elevating and lengthening of the stump, and finger rotation [1]. Each method has its own advantages and disadvantages, and patients are rarely satisfied with the results of these techniques. Since the first toe-to-thumb transfer in 1966, free toe transfer using vascular anastomosis has become a routine method for the repair and reconstruction of thumb and finger defects [1–4]. New methods and surgical techniques have allowed various forms of toe tissues to be used for the repair and reconstruction of varying degrees of thumb and finger defects with very high success rates [5–12]. Despite these advances, however, there are still many deficiencies in the reconstructed finger compared to the original finger.

Morphologic defects mainly include mild clubbing in the distal phalanx, finger pulp enlargement, and neck stenosis. The main reason for these defects is that the toes are thin and short while the fingers are thick and long, and toe pulp is in a pedestal shape while the fingertips have a natural conical shape. There is abundant fat in the subcutaneous tissue of the plantar side of the metatarso-phalangeal joint, and the dorsoplantar diameter at this site is significantly greater than that of the toe body while the sagittal diameter of the metacarpophalangeal joint and that of the finger body are similar. Mild clubbing in the distal phalanx can be resolved by fixing the distal interphalangeal joint in a hyperextended position during surgery. However, the other 2 deformities are difficult to manage and the outcomes are poor [13–17].

In March 2008, we designed a triangular flap in the neck and pulp of the second toe and transferred it to the finger for the reconstruction of finger morphology. We used the flap for the repair of 6 fingers, and it not only resolved the enlargement in the finger pulp, but also improved the stenosis in the neck [18]. Other surgeons also reported satisfactory outcomes with the technique [19]. However,
we found that this procedure had 2 shortcomings. The first is that improvement of the neck stenosis is limited due to the influence of the rotation angle of the local triangular flap. The second is that the "cat ear" deformity produced by the transfer of the triangular flap affects the short-term morphology. To resolve these shortcomings, we designed an island flap containing terminal branches of the toe artery. The benefits of the procedure are:

- it is simple to perform;
- a second procedure is not needed;
- the morphological transition after repair is natural;
- the rotation angle is not limited;
- the method not only eliminates the enlargement in the finger pulp and the neck stenosis of the reconstructed finger, but also reduces the enlargement in the anastomotic junction between the finger and the toe.

The purpose of this study is to present the results of 36 finger reconstructions using an island flap based on terminal branches of the toe artery. Our hypothesis was that the technique can improve the morphological outcomes of reconstructed fingers, particularly neck stenosis due to the influence of the rotation angle of the local triangular flap and the "cat ear" deformity produced by transfer of the triangular flap.

2. Methods

2.1. Patients

A total of 31 patients, 22 males and 9 females, with a mean age of 28 years (range, 18–40 years) were included in the current study, and 36 fingers were reconstructed. The injuries were due to a stamping machine in 15 cases, machine crush injuries in 9 cases, and twist injuries in 9 cases. Defects were located in the second, third, fourth, and fifth fingers in 6 cases, in the second, third, and fourth fingers in 5 cases, in the third, fourth, and fifth fingers in 3 cases, in the second and third fingers in 5 cases, in the third and fourth fingers in 4 cases, in the second finger in 4 cases, in the third finger in 3 cases, and in the fourth finger in 1 case. Two fingers were reconstructed in 5 cases, and 1 finger was reconstructed in the other 26 cases. The second finger was reconstructed in 17 cases, the third finger in 15 cases, and the fourth finger in 4 cases.

One-stage emergency reconstruction was performed for 26 cases, while elective surgery was performed for 5 cases. The areas of the transferred flap containing terminal branches of the toe artery ranged from 0.8 cm × 0.5 cm to 1.5 × 1.0 cm. Among them, 1 case with defects in the second to fifth fingers had associated skin defects in the palm and dorsum of the hand. A free inguinal flap with a pedicle containing the superficial epigastric artery was used during finger reconstruction to repair the wound.

Indications for the procedure were 16 to 45 years of age, III–V– defects in the second to fourth fingers [20], no life-threatening complications, no vasogenic disease, and the ability to tolerate microscopic surgery.

2.2. Surgical procedure

Complete debridement was carried out for the recipient site, and anatomical marking of the vessels and nerves of the donor site was performed.

The second toe was harvested routinely. An island flap 1.0–1.5 cm in length and 0.5–0.8 cm in width at the base was designed along the terminal branch of the toe artery in the protuberance (usually the tibial side of the second toe). The flap pedicle was located at either the ulnar side or radial side of the "neck" stenosis (ventral surface of the new DIP joint). The proximal part of the flap was taken as the pedicle. The point of rotation should not exceed one half of the plane of the middle phalanx. A transverse incision was made from the flap pedicle to the narrowest site of the "neck". The incision should not exceed the surface projection of the contralateral artery and nerves to form an island flap located lateral to the "new finger" pulp. The pedicled island flap will be embeded to the neck stenosis to reduce the bulkier "new finger" pulp and simultaneously improve the neck stenosis. These defects were resolved through a single operation and the morphology of the reconstructed finger was remodeled. An illustration of flap design is presented in Fig. 1.

The flap was harvested by incising the skin along the designed line. The subcutaneous tissue was sharply dissected to expose the toe artery and nerve bundle, and the nerve was carefully isolated. The flap skin was incised, and the flap was carefully harvested at the deep layer of the deep fascia. The toe artery and its terminal branch were carefully protected. Then the skin was incised along the transverse incision under the "new finger" pulp while carefully protecting the toe artery and nerve. The subcutaneous fibrous septum was carefully cut off, and a spindle-shaped wound was formed at the site of the incision. The flap containing terminal branches of the toe artery was then dissected backward to the pedicle, rotated inferiorly and covered the spindle-shaped wound, which was then closed with 5-0 silk suture.

The second toe was transferred to the affected area, then a single Kirschner wire was used to fix the bones. Tendon was then sutured, vessels anastomosed, and nerves reconnected. Subcutaneous tissue was then repaired after revascularization, and skin tension was adjusted before finally closing the skin.

Local remodeling was carried out under the assistance of electric tourniquet 20 min after the blood flow was confirmed. The
wound formed in the lateral side of the finger pulp was advanced and directly sutured. The tourniquet was released and circulation of the reconstructed finger and flap were observed. The operation was completed if there were no problems with blood circulation.

2.3. Postoperative treatment

All patients received routine anticoagulants, antispasmodics, and anti-inflammatory medications, and all patients remained at absolute bed rest for 7–10 days. The blood circulation of the transferred flap was closely monitored for evidence of compromised circulation by observation of skin temperature, skin color, skin tension, and capillary reaction.

Sutures were removed on the 12th postoperative day, and a pressure sleeve was placed on the finger if excessive swelling was noted. The pressure sleeve was constructed based on the morphology of the finger such that the pressure of the sleeve exerted on the finger was approximately 25 mmHg, and the dimensions were based on the principle of Laplace [21]. The patient wore the finger sleeve continuously for 3 months. The pressure and tightness of the sleeve were monitored once a week. If the pressure decreased or the pressure sleeve became loose, then the pressure and tightness of the sleeve were adjusted.

Functional exercise was started 12 days after surgery, and rehabilitation was carried out in stages. The early phase of rehabilitation lasted from 1–2 weeks and consisted of external plaster cast fixation, elevation of the treated limb, local massage, and infrared therapy to improve flap circulation and reduce swelling. The middle phase of rehabilitation consisted of passive joint movement and heat therapy. The late phase of rehabilitation consisted of sensory training and active joint movement with predetermined goals of sensory and functional recovery, and lasted for 2–6 months.

Outcome measures included sensory function, pinch strength, range of motion, and function and aesthetic satisfaction scores. Sensory function was determined by measuring 2-point discrimination using a 2-point discriminator (Lasting Medical Devices Co., Ltd., Shanghai, China). Pinch strength of the affected hand was measured using a dynamometer (Hand evaluation kit plus, Klarity Medical & Equipment Co., Ltd., Guangzhou, China) and the results were presented as the percentage strength of the normal contralateral hand. Range of motion (ROM) was defined as the angle from maximum flexion to maximum extension of the reconstructed finger. The degree of maximum flexion and extension were measured independently, and their sum was considered the range of motion. An orthopedic tool measurement apparatus was used to perform the measurements (Hand evaluation kit plus, Klarity Medical & Equipment Co., Ltd., Guangzhou, China). Functional satisfaction was defined according to the following criteria: capable of performing original task with reconstructed finger (90–100); able to use reconstructed finger (70–90); somewhat difficult to use reconstructed finger (40–70); unable to use reconstructed finger (0–30). In addition, disabilities of the arm, shoulder and hand (DASH) scores [22] were also determined. Aesthetic satisfaction was defined according to the following criteria: pleasing appearance (80–100); acceptable appearance (50–80); poor appearance/patient unable to accept appearance (0–50).

After discharged, patients were followed-up every 3 months to observe the improvement in the morphology after local flap transfer, remodeling, and sensory recovery in the finger pulp.

3. Results

All reconstructed fingers survived. All flaps embedded to manage the stenosis in the narrow neck of the toe survived, primary healing of the incision was achieved, and the wound in the donor site healed satisfactorily. Pressure treatment was applied for 9 fingers that were found to be swollen 12 days after surgery. No donor site complications occurred. Bony union occurred in all phalanges, and the internal fixation device was removed 4–12 weeks after surgery (mean, 8 weeks). The mean follow-up duration was 8 months (range, 5 to 25 months). The morphology of the reconstructed finger was close to that of a normal finger, and a natural transition could be observed in the finger pulp, the finger neck, and the junction between the toe and the finger.

Functional and aesthetic outcomes are presented in Table 1. Sensory recovery of the finger pulp ranged from S1 to S3+. The mean pinch strength of the reconstructed fingers was 48% to 60% of that of the contralateral side. ROM of the reconstructed fingers varied with the joint reconstructed, with the greatest ROM seen in the metacarpophalangeal joint and the least seen in the distal interphalangeal joint. The lowest mean functional score was 76 and the lowest mean aesthetic score was 70. The mean DASH scores were 52.9, 48.9, and 46.0 for patients that had the index, third, and fourth fingers reconstructed, respectively.

At the last follow-up, comparison between the reconstructed finger and the corresponding finger of the unaffected side showed that the mean circumference of the reconstructed finger was 5.1 ± 0.3 cm and the circumference of the corresponding finger on the unaffected side was 5.2 ± 0.4 cm. The circumference of the narrowest part in the neck of the reconstructed finger was 4.9 ± 0.2 cm, and the circumference of the distal joint in the corresponding finger of the healthy side was 5.3 ± 0.3 cm. Representative cases are presented in Figs. 2–4.

4. Discussion

In 2008, we designed a triangular flap in the neck and pulp of the second toe and transferred it to the finger for the reconstruction of finger morphology and achieved satisfactory outcomes. However, we found in the clinical application that this procedure had 2 shortcomings: improvement of the neck stenosis was limited due to the influence of the rotation angle of the local triangular flap and the “cat ear” deformity produced by the transfer of the triangular flap adversely affected the short-term morphology. To improve these shortcomings, we designed an island flap containing terminal branches of the toe artery and as reported in this study, have achieved good functional and aesthetic outcomes.

Free toe transfer has become a preferred method of thumb and finger reconstruction and generally yields good functional results [1,10,23,24]. While initially secondary transfer was commonly performed, study has shown that primary transfer results in

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Postoperative outcomes.</th>
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<tbody>
<tr>
<td>Finger</td>
<td>Index</td>
</tr>
<tr>
<td>Patients (n)</td>
<td>17</td>
</tr>
<tr>
<td>3-2PD (mm)</td>
<td>12 (7 to 15)</td>
</tr>
<tr>
<td>Pinch strength (% of contralateral hand)</td>
<td>60 (40–80)</td>
</tr>
<tr>
<td>Range of motion (°)</td>
<td></td>
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<tr>
<td>MCP joint</td>
<td>82 (70–90)</td>
</tr>
<tr>
<td>PIP joint</td>
<td>48 (40–70)</td>
</tr>
<tr>
<td>DIP joint</td>
<td>25 (15–36)</td>
</tr>
<tr>
<td>Total angular motion</td>
<td>150 (120–85)</td>
</tr>
<tr>
<td>Satisfaction score</td>
<td></td>
</tr>
<tr>
<td>Function</td>
<td>84 (70–95)</td>
</tr>
<tr>
<td>Aesthetic</td>
<td>70 (50–96)</td>
</tr>
<tr>
<td>DASH score</td>
<td>52.9 (46.0–89.0)</td>
</tr>
</tbody>
</table>

DASH: disabilities of the arm, shoulder and hand. Data are presented as mean (range). 3-2PD: static two-point discrimination; MCP: metacarpophalangeal; PIP: proximal interphalangeal; DIP: distal interphalangeal.
comparable outcomes and reduces the need for a second surgery [25]. Despite the advantages of free toe transfer, the reconstructed finger is deficient in functional and aesthetic measures [23]. Enlargement in the anastomotic junction between the finger and the toe is primary reason for the poor morphology of the reconstructed finger. A commonly used method for correcting this is to remove the fat under the V-shaped flap at the dorsal side of the second toe and carry out V-shaped excision on the skin containing the V-shaped flap in the remnant finger. Repeated trimming and remodeling are required which significantly extends the operative time, and the postoperative morphology is not ideal.

Intraoperative remodeling during 1-stage reconstruction and intraoperative remodeling during the second surgery of 2-stage reconstruction are common methods for improving the function and aesthetics of the reconstructed finger. There are many methods for remodeling in 1-stage reconstruction surgery. Woo et al. [14] improved the circumference of the narrow portion of the second toe by serrated skin suture at the anastomosis site, significantly improving the morphology of the reconstructed finger. However, this method can only be applied for reconstruction of the distal phalanx. Wang et al. [15] performed 1-stage transfer of the adjacent toe side flap to the neck of the finger pulp and obtained good outcomes. However, the procedure is complicated with increased surgical risk. Kang et al. [16] designed a small spindle-shaped flap in the plantar side of the distal phalanx of the second toe and rotated it 180° to fill the stenotic site in the finger pulp and achieved a good outcome; however, it is difficult to rotate the flap 180° which can affect the outcome. Tang et al. [17] removed the subcutaneous...
Fig. 3. A and B. Preoperative defect distal to the middle part of the proximal phalanx in the left second finger. C. Design of second toe reconstruction. D. Completed finger reconstruction. E. Simultaneous intraoperative design of the flap containing terminal branches of the toe artery. F. Reconstructed finger and flap 12 days after surgery. G and H. Application of the pressure sleeve from 12 days after surgery. I. Two months after pressure treatment. J–L. Morphology of the finger 7 months after pressure treatment. M. Flexion and extension of the reconstructed finger 7 months after surgery.
tissue on 1 or 2 sides of the second toe to narrow the finger pulp for improving the shortcoming of finger pulp enlargement. However, the technique cannot eliminate the stenosis in the neck of the finger pulp. Two-stage spindle-shaped excision at the side of the finger pulp is a simple and safe procedure with short operative time [13]. However, it does not improve stenosis in the neck of the finger pulp and it also involves a second surgery.

The safety of harvesting a flap based on terminal branches of the toe artery is primarily based on 2 aspects. The first is whether flap harvesting affects the blood circulation of the reconstructed finger. The toe artery distribution was observed in 24 toes from 6 cadavers after lactoprene infusion previously, and we found that the proper plantar digital artery divides into many fine branches to form anastomoses with the dorsal digital artery. The plantar digital artery of the second toe has constant communicating branches at the proximal and distal one third of the proximal phalanx and at the second half of the middle phalanx. In addition, the dorsal digital artery and the plantar digital artery have constant communicating branches at the plantar side and dorsal side. We consider that if the vascular pedicle does not exceed one half of the middle phalanx of the toe, the blood supply of the reconstructed finger will not be affected. The second aspect is whether flap harvesting affects the blood supply to the flap. The flap containing terminal branches of the toe artery is an axial flap, and in addition the area of the flap is limited.

During flap harvesting, the rotation point of the flap should not exceed the proximal interphalangeal joint plane in the reconstructed finger to prevent damaging the anastomotic branches of the artery, which can affect the blood supply to the reconstructed finger. The proper digital nerve and its branches should be protected carefully when harvesting the flap to prevent poor sensory recovery after surgery. A concept of full reconstruction should be established during surgery to produce a finger extremely close to the normal finger. The finger pulp enlargement and neck stenosis should be trimmed. Remodeling the skin at the anastomotic junction between the finger and the toe is also very important. The subcutaneous tissue should be trimmed delicately and the enlargement due to the plantar tissue thickening should be removed. Early rehabilitation can reduce swelling and enhance wound healing, and during the middle and late stages active and passive joint movements and sensory training should be carried out.

Remodeling the morphology of the reconstructed finger using an island flap containing terminal branches of the toe artery has a number of advantages. The surgical procedure is simple, safe, and effective with satisfactory outcomes [13]. The morphological transition after repair is natural, and a second procedure is not needed. This method not only eliminates the enlargement in the finger pulp and the neck stenosis of the reconstructed finger, but also reduces the enlargement in the anastomotic junction between the finger and the toe.
In this study, we used a pressure sleeve for the treatment of fingers that were noted to be swollen. Pressure treatment is widely used in the plastic surgery and burn scar prevention it prevents and restricts scar formation by imposing appropriate pressure on the body surface [26]. We have found it useful for enhancing wound remodeling in cases of free-flap transfer.

Reconstruction of an index or second finger, as done in this report may be questioned. Nowadays, the aesthetic requirements of people are particularly high. The hand is not only a functional unit, but also is an important aesthetic component, and it has the second largest exposed area in the human body following the face. If the morphology of the hand is relatively poor after surgery, this can affect daily interactions; the patient may subconsciously hide the hand, and the hand function may be underused despite an excellent recovery. Thus, function is somewhat less important than an aesthetic outcome.

The primarily limitation of this study is the short follow-up period. The mean follow-up was only 8 months, which is short to quantify the quality of the results, especially regarding sensation. The results of sensation return were somewhat poor, and this is likely due to the short follow-up duration, i.e., sensation increases with duration of time following surgery.

5. Conclusions

We have presented a novel island toe flap based on the terminal branches of the toe artery for finger reconstruction. The method provides good aesthetic and functional outcomes and overcomes aesthetic difficulties associated with other methods of toe transfer for finger reconstruction, particularly neck stenosis due to the influence of the rotation angle of the local triangular flap and the “cat ear” deformity produced by transfer of the triangular flap.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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