

Transplantation of a Free Vascularized Joint Flap from the Second Toe for the Acute Reconstruction of Defects in the Thumb and other Fingers

Abstract

Background: This study aimed to evaluate a novel surgical method for the acute reconstruction of defects in the thumb and other fingers by transplanting a free vascularized joint flap from the second toe and to determine its clinical curative effects. **Materials and Methods:** A free vascularized joint flap from the second toe was transplanted to reconstruct a complete defect of the thumb and other fingers accompanied by the loss of the proximal finger in 10 patients. Of these patients, three had their thumbs reconstructed with a free vascularized joint flap from the second toe and with the proximal interphalangeal joint flap, one had a thumb reconstructed with a free vascularized joint flap from the second toe, and six had their finger defects reconstructed with the proximal interphalangeal joint flap. The toes of the metatarsophalangeal joint were amputated at the foot donor site. All patients underwent one-stage emergency surgery. **Results:** The composite tissue flaps, replanted thumbs, and fingers survived well in all 10 cases. Follow-up visits were conducted for 6–28 months, with an average of 9 months of follow-up. The transplanted bone joints healed over a period of 6–16 weeks. Bone nonunions and refractures did not occur, and the walking function of the foot donor site was not visibly affected. **Conclusion:** A free vascularized joint flap from the second toe can be transplanted to repair defects in the thumb and other fingers. This technique can be applied to recover the appearance and function of fingers.

Keywords: Finger, foot, joint transplantation, microsurgical technique, severed finger replantation, toe

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Introduction

Finger amputation is one of the most frequently encountered injuries in the emergency room and replantation is always the first course of action. Since William Balfour’s first successful fingertip reattachment procedure in 1814, much progress has been made in replantation procedures, especially following the development of the operating microscope in the early 1960s.¹ With further advancements in microsurgical techniques, severed finger replantation techniques have benefitted from continuous development and innovations.²⁻⁵ The survival rate of replanted fingers is reported to range from 60% to 90%.⁶⁻¹³

A replanted digit will survive if its vascular anastomoses remain patent, yet its functional utility ultimately depends on other factors, such as the restitution of bone, joint, nerve, and tendon function. In certain circumstances, a viable digit may actually impair function, and so, any determination of the “success” of replantation must

consider the patient’s ability to use the replanted finger for activities in everyday life.¹⁴ If one segment or part of a finger joint is lost, poor functional outcomes for the injured fingers have been reported after replantation.^{15,16} In some cases, amputation is necessary despite the survival of the fingers, leading to the loss of both the fingers and their functions.¹⁷ Despite advances in microsurgical techniques and instruments, replantation of digits in these cases is still contraindicated. The goals of replantation are to restore circulation and regain sufficient function and sensation for the amputated part as well as to allow patients to return to their previous employment.¹⁸ The Skoog perichondral arthroplasty only addresses the alteration of cartilage surface.¹⁹ Nonvascularized joint transfer occasionally gives good clinical results, but radiologic joint alteration is ultimately followed by stiffness. On a long term basis, only vascularized joint transfers demonstrate good cartilage preservation both experimentally and clinically. Joint reconstruction by means of a homodigital,

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island distal interphalangeal (DIP) joint transfer has been proposed.²⁰ In our practice, for some finger amputation cases in which the distal amputated portion remained intact while the middle portion was lost, the repaired finger was very short after replantation and sometimes could not be used afterward. To salvage these digits, we used a free foot composite tissue flap through foot joint replantation to repair the thumb and other fingers. This technique yielded satisfactory clinical results.

Materials and Methods

General data

The indications for the procedure were as follows: the general condition of the patient was good enough to receive the microsurgery and postoperative treatment, the distal amputated finger remained intact and its blood supply could be reconstructed, and the sensation of the injured digit had to be restored. However, it also had its excluded criteria: patient refused to perform this operation, the condition of the patient was unable to stand the surgery, and the distal part of the finger was mutilation. Before the operation, informed consent was explained to the patient completely. The details of informed consent were as follows: anesthetic risk, reconstruction of the joint can restore joint movement, appearance and function of the hand to the utmost, failure of the surgery and then amputation would be adopted, the reconstructed joint with a risk of necrosis after the operation, the patient should lie flat on the bed for a week after the operation in case of vascular crisis, other unforeseen risks. This was a high-risk-high-return treatment, so the informed consent should explain completely and rapidly. First of all, the wound should be hemostasis with gauze, and then, we provided some available operations for patient to choose and explained “informed consent” to the patient.

This study included 10 patients, eight males and two females, aged 19–43 years (average age 26 years). Table 1 shows the patients’ information and results. Among these cases, four involved severed thumbs, two involved severed index fingers, one involved a severed middle finger, one involved a severed ring finger, and two involved severed little fingers. These injuries were caused by the following: punching press injury in five cases, machine gear injury in three cases, crushing injury in one case, and traffic accident injury in one case. In the four cases involving a severed thumb, the distal phalanx of the thumb was amputated, the proximal end of the metacarpal bone and the proximal phalanx were lost or destroyed, and skin, tendon, and other complex tissue defects were observed. The scope of the skin defect was approximately 6 cm × 4 cm to 10 cm × 6 cm. In the six remaining cases, the severed fingers of three patients were completely amputated. The fingers of the other three patients were incompletely amputated, but the blood circulation in the fingers was disrupted. The proximal and middle phalanges, skin, tendon, and some complex tissues were lost. The scope

of the skin defect was 3 cm × 2 cm to 5 cm × 4 cm. The bone defect was 3–8 cm long. This group of patients underwent one-stage emergency surgery. The metatarsophalangeal joint of the second toe was used to repair the digital metacarpophalangeal joint, while the interphalangeal joint of the second toe was used to repair the digital interphalangeal joint. Of the four patients with a severed thumb, three were bridged and repaired using the composite tissue flap of the second metatarsophalangeal joint and the proximal interphalangeal joint, and one was bridged and repaired using the composite tissue flap of the second metatarsophalangeal joint. At the foot donor site, amputation of the second metatarsal distal bone and toe was performed followed by free dorsal skin grafting. The severed fingers of the six patients were bridged and repaired using the composite tissue flap of the proximal interphalangeal joint, and metatarsophalangeal joint toe amputation was performed at the foot donor site. In one case with a severed middle finger caused by a proximal interphalangeal joint defect and a distal phalanx defect of the index finger, the middle and distal phalanges of the second toe were reconstructed.

Surgical procedure

To evaluate viability of the distal part was necessary in this operation. Saline perfusion with heparin was used to assess distal vascular condition, besides we detected the damage of the adventitia and endangium under a microscope. This operation was adopted if the distal vascular and the adventitia were integrity. The distal and proximal ends of the severed fingers of the patients were thoroughly debrided to flatten the broken end and to mark the blood vessels and nerves for later use. The following parameters were accurately measured: length of the bone and joint defects, position of the joint, and length of the required tendon, blood vessel, and nerve. After the distal end of the fingers was debrided, the fingers were stored in a refrigerator at 4°C.

An incision was made at the foot donor site. The length of the damaged bone joint and tendon and the area of the skin defect were determined. The incision area was drawn on the skin and the incision plane of the bone joint was marked. Taking into consideration the position of the joint for the patients with a metatarsus and dorsal skin flap, the surgeons incised a flap along the dorsal artery and the second metatarsus. During incision, the skin was incised according to the design line of the second toe and the periosteum branch and the joint branch of the blood vessels were preserved. Dissection was performed from the edge of flap and the composite tissue flap with an interphalangeal joint in the proximal end of the second toe was incised according to the length of the bone joint and the surrounding skin area. The length of the distal and proximal ends of the tendon, vessels, and nerves was confirmed to be sufficient. The distal end of the second toe

Table 1: Demographic and operative data

Patient	Injured digit	Injury pattern	Operative time (h)	Length of phalanx defect (cm)	Reconstructed phalanx and joint	Complete amputation	Donor joint of second toe	Area of skin defect	Vessel and nerve anastomosis	Followup time (months)	Two point discrimination (mm)	Treatment of donor site
1	Thumb	Machine twist injury	8	8	Metacarpal and metacarpophalangeal joints	Complete amputation	Metatarsophalangeal joint	8 cm × 6 cm	Radial artery with dorsalis pedis artery Digital proper arteries and nerves of thumb with ones of second toe	23	5	Amputation and full-thickness skin graft
2	Thumb	Machine press injury	6	3	Interphalangeal joint	Complete amputation	Proximal interphalangeal joint	6 cm × 4 cm	Digital proper arteries and nerves of thumb with ones of second toe	16	>20	Amputation
3	Thumb	Machine press injury	7	7	Metacarpal and metacarpophalangeal joints	Complete amputation	Metatarsophalangeal joint	7 cm × 5 cm	Radial artery with dorsalis pedis artery Digital proper arteries and nerves of thumb with ones of second toe	22	10	Amputation and full-thickness skin graft
4	Thumb	Machine press injury	8	8	Metacarpal and metacarpophalangeal joints	Complete amputation	Metatarsophalangeal joint	10 cm × 6 cm	Radial artery with dorsalis pedis artery Digital proper arteries and nerves of thumb with ones of second toe	18	>20	Amputation and full-thickness skin graft

Contd...

Table 1: Contd...

Patient	Injured digit	Injury pattern	Operative time (h)	Length of phalanx defect (cm)	Reconstructed phalanx and joint	Complete amputation	Donor joint of second toe	Area of skin defect	Vessel and nerve anastomosis	Followup time (months)	Two point discrimination (mm)	Treatment of donor site
5	Index finger	Traffic accidents injury	7	5	Proximal interphalangeal joint	Incomplete amputation	Proximal interphalangeal joint	3 cm × 2 cm	Digital proper arteries and nerves of finger with ones of second toe	20	>20	Amputation
6	Index finger	Machine press injury	7	4	Proximal interphalangeal joint	Complete amputation	Proximal interphalangeal joint	5 cm × 3 cm	Digital proper arteries and nerves of finger with ones of second toe	17	>20	Amputation
7	Middle finger	Machine twist injury	8	5	Proximal interphalangeal joint	Complete amputation	Proximal interphalangeal joint	5 cm × 4 cm	Digital proper arteries and nerves of finger with ones of second toe	23	12	Amputation
8	Ring finger	Machine press injury	8	4	Proximal interphalangeal joint	Incomplete amputation	Proximal interphalangeal joint	4 cm × 3 cm	Digital proper arteries and nerves of finger with ones of second toe	19	>20	Amputation
9	Small finger	Machine twist injury	7	4	Proximal interphalangeal joint	Complete amputation	Proximal interphalangeal joint	5 cm × 3 cm	Digital proper arteries and nerves of finger with ones of second toe	21	>20	Amputation
10	Small finger	Machine press injury	6	3	Proximal interphalangeal joint	Incomplete amputation	Proximal interphalangeal joint	4 cm × 2 cm	Digital proper arteries and nerves of finger with ones of second toe	24	>20	Amputation

can be used to reconstruct the middle and distal ends of the fingers. This report includes the description of a case involving middle finger reconstruction. After the proximal interphalangeal joint of the second toe was transplanted, the middle and distal ends of the second toe were used to reconstruct the middle and distal ends of the index finger because of defects in the middle and distal portions of the index finger.

Before the pedicle of the flap was dissected, the tourniquet applied to maintain blood flow in the harvested tissue was released to check the blood supply to the flap. The pedicle was dissected 10 min after the release of the tourniquet to prevent ischemia-reperfusion injury. Full-thickness skin graft was used to cover the wound at the foot donor site. After the distal and proximal bone joints were accurately ground and flattened, a cross wire or cross Kirschner wire was used to perform an internal fixation: the bone shaft fracture was fixed using a cross wire, and the bone fracture near the joint was fixed using a cross Kirschner wire. The tail of the Kirschner wire was exposed to the skin, which enabled easy removal of the wire after the operation. Using a C-arm machine, anastomosis of the distal and proximal bones of the transplanted joint was confirmed. The tendon was sutured after the bone was confirmed to be securely attached. Under a microscope, anastomosis of the blood vessels and nerves was confirmed. In four cases with a severed thumb, the dorsal artery in the transplanted tissue was anastomosed with the superficial branch of the radial artery of the anatomical snuff box and one-to-two accompanying veins. The digital artery of the toe in the distal end of the transplanted tissue was also anastomosed with the double finger artery of the distal end of the thumb. After blood circulation was restored, other vessels and nerves were anastomosed. In the other six cases with severed fingers, the digital artery of the toe on the dominant side of the transplanted tissue was anastomosed with the digital artery on the proximal end of the finger on the same side. The digital artery of the toe in the distal end of the transplanted tissue was anastomosed with the digital artery of the finger on the distal end [Figure 1]. After blood circulation was restored, other vessels and nerves were anastomosed. The operation time ranged from 4.5 to 8.5 h, with an average of 6 h.

Postoperative treatment

Anti-coagulant, antispasm, and anti-inflammatory agents were administered after surgery to observe the blood circulation in the transplanted tissues and replanted fingers and to ensure timely identification and prevention of adverse vascular conditions. 1–2 weeks after surgery, passive exercises for the transplanted joints and replanted fingers were initiated, and the amount of exercise was gradually increased. Three weeks after surgery, active exercise involving the transplanted joints and replanted fingers was gradually introduced. 6–8 weeks after surgery,

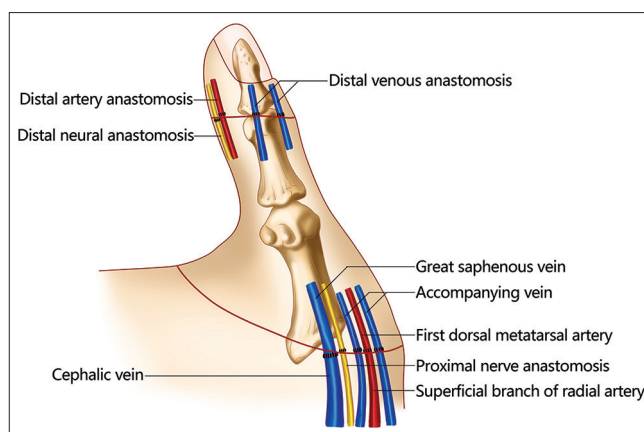


Figure 1: Schematic diagram of neurovascular anastomosis

the Kirschner wire was removed after the bone healed. The patients then underwent systematic rehabilitation therapy. For 3 months after the surgery, X-ray examination was regularly conducted to monitor bone healing. After the bone healed, the wire was removed. Follow-up visits were scheduled regularly to observe the recovery of hand function and the healing of donor sites as well as to perform functional evaluation.

Results

The composite tissue flaps, replanted thumbs, and fingers of the 10 patients survived after surgery. The wounds in the hands healed in Stage 1. All the toes in donor sites were amputated because of insufficient blood circulation after the joint was harvested. The foot donor site for one patient healed after dressing drugs were applied several times. The remaining replanted skin and amputated toe also healed in Stage 1. The follow-up period for 10 patients was 6–28 months, with an average of 9 months of follow-up after surgery. In the four cases with thumb replantation, the extension of the palm and the finger joint ranged from -10° to 0° , and the inflexion reached 20° – 50° , with an average of 35° . Of the 10 patients, three achieved 2-finger–5-finger function, one achieved index finger-to-middle finger function, and one could perform radial abduction. In the six cases with finger replantation, the extension of the transplanted proximal interphalangeal joint ranged from 10° to 0° , and the inflexion ranged from 30° to 90° , with an average of 50° . The degree of activity for the DIP joint ranged from 10° to 40° . Results for the recovery of the sense of touch were as follows: in one case, the sensation was normal and the two-point discrimination was recovery to 5 mm. According to the British Medical Research Council evaluation criteria (1954), it was S4; two cases in S3+, light pain and tactile sensation were recovery completely, and the two-point discrimination was 10 mm and 12 mm. Five cases in S3, light pain and tactile sensation were recovery completely, and there was no hypersensitivity and the two-point discrimination was >20 mm. Two cases in S2, light pain and tactile

sensation recovery a little and the two-point discrimination was >20 mm [Table 1]. The transplanted bone joints healed over a period of 6–16 weeks. Bone nonunions and refractures did not occur and no further surgery was performed. In the four cases with skin replantation at the donor site, no scar, contracture, or ulceration was observed in the replanted area. The walking functions of the patients were not affected. In contrast, the walking functions of the six remaining patients with toe amputation were affected. According to the standards for functional evaluation defined by the Chinese Medical Association, the following grades were assigned: one case, excellent; eight cases, good; and one case, poor. The excellent and good ratings comprised 90% of cases.

Case 1

A 42-year-old male patient was admitted to the emergency unit for 1 h because of a left thumb defect caused by machine gear injury [Figure 2a]. Physical examination revealed that the left thumb was completely disconnected at the base of the first metacarpal bone in the distal end. The proximal middle portion of the severed thumb was intact, but the first metacarpal bone and the proximal end of the thumb were lost. The bone defect measured approximately 8 cm, and the skin defect covered approximately 8 cm × 6 cm. This defect was accompanied by extensor tendon and blood vessel defects. Surgery was scheduled to transplant the composite tissue flap of the second toe joint and to bridge and repair the severed fingers. After surgery, the transplanted tissue and replanted finger survived [Figure 2b and c]. Internal fixation was removed 8 weeks after surgery and functional excision was initiated. Postoperative follow-up visits lasted for 5 months, and satisfactory bone healing was achieved [Figure 2d]. Within 23 months of the last follow-up visit, the appearance of the replanted fingers and transplanted tissues improved, with the recovery of finger-to-palm and finger-to-finger functions. The sense of touch in the transplanted and replanted fingers recovered to S3+. The patient returned

to his original job, with good walking function and satisfactory thumb-index web [Figure 2e]. No scars and contractures were observed in the transplanted skin at the foot donor site [Figure 2f]. The patient was satisfied.

Case 2

A 23-year-old male suffered an industrial machine-press injury to the right little finger. One hour later, the patient was admitted to the emergency unit. The finger was amputated at the proximal interphalangeal joint level, with 0.8 cm of skin tissue attached. The distal amputated finger lacked a blood supply and had a joint defect. The length of the phalanx defect was about 3 cm, while the area of the skin defect was 4 cm × 2 cm [Figure 3a and b]. A composite tissue flap with the proximal interphalangeal joint taken from the second toe was used to repair the injured finger [Figure 3c]. The donor toe was amputated. The replanted finger and transplanted joint both survived after the operation [Figure 3d]. The patient was followed up for 2 years. The appearance of the repaired finger was good, and it could achieve digital opposition with the thumb. The range of flexion motion for the proximal interphalangeal joint was up to 70° [Figure 3e and f].

Discussion

Finger severance, which is accompanied by complex tissue defects, particularly large segments of bone joint defects, is a clinically common injury.²¹ Affected fingers can survive after direct replantation is performed. However, the replanted fingers may be shortened and exhibit poor functioning. In some cases, a finger stump is left attached, but fingers and functions may be lost. In some cases, bone graft with venous flap can be used for reconstruction. However, the venous flap is without tendon and joint, what's worse, venous flap can lead to delayed union of bone and nonunion. In other cases, the second toe can be directly transplanted for reconstruction.²²⁻²⁴ Nevertheless, patients are often unsatisfied with the final appearance of

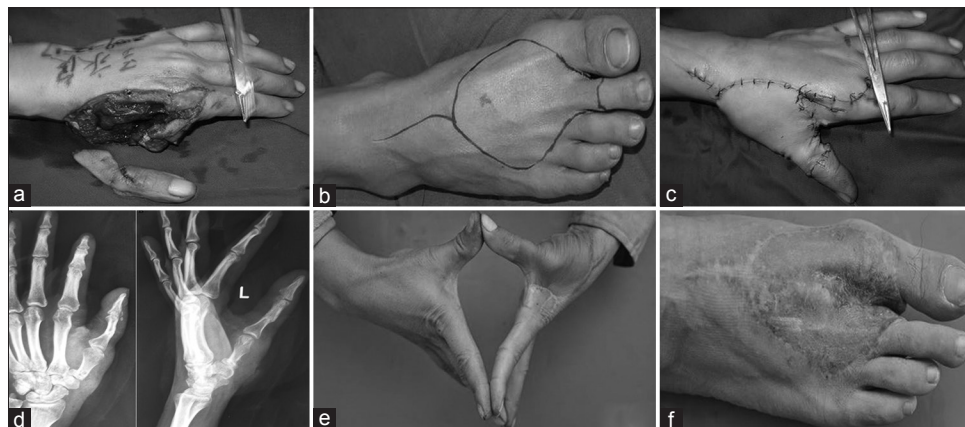


Figure 2: The images of Case 1. (a) Left thumb amputation with metacarpal bone and proximal and distal end defects (dorsal). (b) Design of a complex tissue flap with joint. (c) Appearance after replantation and tissue transplantation. (d) Good bone healing 5 months after surgery. (e) Postoperative thumb-index web in 23 months. (f) Recovery of foot donor site 23 months after surgery

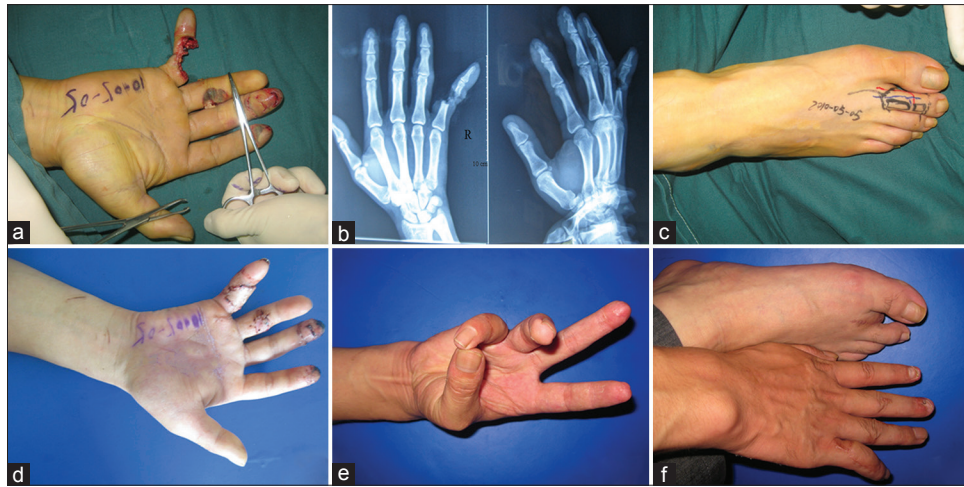


Figure 3: The images of Case 2. (a) Pre-operation of the amputation of right small finger. (b) X-ray suggested that the finger lacked of proximal interphalangeal. (c) Design of a composite tissue flap with the proximal interphalangeal joint from second toe. (d) The replanted finger and transplanted joint both survived after operation 12 days after operation (Volar vision). (e) Digital opposition function of the finger 2 years after operation. (f) Appearance of the repaired finger and donor toe 2 years after operation

the reconstructed fingers and patients are reluctant to show their hands.^{25,26}

In contrast to these techniques with unsatisfactory outcomes, bridging the severed thumb and fingers using a composite tissue flap with a joint can achieve satisfactory results.

The blood supply in the transplanted tissue and severed fingers must be reconstructed simultaneously. To reduce the ischemic period of the transplanted tissue and distal finger, blood flow must be maintained in the transplanted and replanted tissue via a tourniquet. For patients with a severed thumb, the main artery for the transplanted tissue is the dorsal artery of the foot. This artery is anastomosed with the superficial branch of the radial artery of the nasopharyngeal fossa. Anastomosis is also performed on the veins and arteries of the distal severed finger and transplanted tissue. The dominant artery can be initially anastomosed on one side to regain blood flow as early as possible. Afterward, the distal finger artery on one side can be anastomosed with the finger nerve on both sides and then with the proximal artery, vein, and nerve. Thus, the blood supply in the transplanted tissue and the severed finger lacking a distal portion can be recovered as early as possible to increase the survival rate of replanted and transplanted tissues.³

In this paper, satisfactory clinical results were obtained for 10 patients, with excellent and good ratings in up to 90% of cases according to the Chinese Medical Association standards. However, further evaluation revealed that one case was excellent, eight cases were good, and one case was poor. Moreover, the scores for the cases with good ratings were mostly below 70. The main deduction items included activities of daily living and sensory recovery. Some patients are traumatized by activities that trigger memories of the event that caused severe injury. For

example, they are unwilling to undergo early excision if this procedure causes pain. As such, researchers should develop strategies to urge patients to undergo early excision under painless conditions. In sensory recovery, some cases recovered to S2–S3 because of a short follow-up period. Sensory recovery and scoring improve over time. In addition, the transplanted joints of five patients experienced slight extension lag, possibly due to the following reasons: thick joint capsules in the lateral palm, thin dorsal joint capsules, postoperative fixation performed with flexion, and flexor tendon force higher than that of the extensor tendon.^{4,5,27} A thicker joint capsule in the lateral palm and the palm plate can be properly incised, or the joint can be fixed with a Kirschner wire for 2 weeks.¹⁷

This procedure offers the following advantages: (1) The recovery of the shape of the thumb and other fingers can be maximized and similar outcomes can be achieved in hand functions.²⁸⁻³⁰ (2) This technique applies the principles of microsurgical reconstruction. In this procedure, missing components are restored by adding appropriate amounts of a substitute.³¹ Not only are the severed fingers replanted but defective tissues are also repaired. (3) The transplanted joint exhibits good compatibility with no pain and refracture is prevented.³² (4) The shape of the transplanted tissue from the foot is flexible and vessel variation is not affected. The tissue can be shaped according to the condition of the thumb and other fingers, enabling the bridging of various tissue defects.

Despite these advantages, this procedure is limited by several disadvantages. For instance, the incision of the metacarpophalangeal joint greatly damages the foot. Using an exact design for the composite flap and the surgeon's level of experience can reduce the donor site damage. The difficulty and risk of the surgery are therefore higher.

Considerations

The following points should be considered during treatment. (1) The bone should be fixed simply, quickly, and firmly using a cross steel wire. If necessary, joint fixation should also be performed. However, the fixation time should not be longer than 2 weeks to avoid joint stiffness.²¹ (2) The design used for the operation must be accurate. For patients with severed fingers, the position of the joint should be noted to avoid placing the joint in a forward position and to prevent impairments to the formation of a clenched fist.⁷ (3) For patients who require skin transplantation in the foot donor site, transplanted skin necrosis should be prevented. The flap should also be repaired if necessary. (4) Postoperative excision should be enhanced and performed under painless conditions. Postoperative functional recovery should be ensured.^{23,33}

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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