

Basic Principles on Toe-to-Hand Transplantation

Barbara S. Lutz, MD; Fu-Chan Wei¹, MD

Within the last three decades, toe-to-hand transplantation has become a well-established method for function and appearance reconstruction after trauma and in congenital hand anomalies.

An otherwise healthy and cooperative patient is the ideal candidate for toe transplantation after trauma. In such patient, even primary toe transplantation is possible, if the stump is clean and viable. If secondary reconstruction after completed wound healing is considered, emphasis should be laid on tissue sacrifice during the acute management of non-replantable amputations at the hand. Specific considerations regarding selection of toe(s) to be transplanted, technique of toe harvest and inset, sequence of transplantations if more than one digit is to be reconstructed such as in the metacarpal hand, and postoperative regimen are important to achieve satisfying functional and aesthetic results on both recipient and donor sites. A trimmed great toe is ideal for thumb reconstruction if the amputation is located at or distal to the middle metacarpal shaft. However, in more proximal amputations a second toe may be more suitable as it allows transmetatarsal harvest without increasing donor site morbidity. Distal finger reconstruction with partial toe or second toe wrap around flap gives most gratifying result to those patients who are critically concerned about their body images and also those who need distal fingers for jobs or recreation activities. Combined second and third toe or third and fourth toe transplantations are particularly useful in metacarpal hand reconstruction to provide tripod pinch. The role of toe-to-hand transplantation in the new millennium assuming progress in tissue engineering, gene transfer, and the development of new immunosuppressive drugs is discussed. (*Chang Gung Med J* 2002; 25:568-76)

Key words: digital amputation, microsurgery, toe transfers.

"All men have a mind which cannot bear to see the suffering of others"

(Mencius IIa, 6)

The first reported two-stage toe-to-hand transplantation was performed in 1897 by Nicolardoni. In 1969, Cobbett⁽¹⁾ transplanted a great toe to replace an amputated thumb in a human following successful microsurgical one-stage toe-to-hand transplantations in monkeys done by Buncke in 1966.⁽²⁾ Improve-

ment of instruments and knowledge rapidly progressed the development of microsurgery. In toe-to-hand transplantation, various combinations of toe transplantations and refinements in the technique have been decried since then.⁽³⁻¹⁹⁾ Primarily employed for thumb reconstruction as alternative to the politicization⁽²⁰⁾ or bone lengthening,⁽²¹⁾ toe-to-hand transplantation became a well established method for reconstruction of single or multiple digits,⁽²²⁻³⁵⁾ of distal digits,⁽³⁶⁻⁴⁰⁾ and of congenital

From the Department of Plastic Surgery, Medical Centre Orebro, Sweden; ¹Department of Plastic Surgery, Chang Gung Memorial Hospital, Taipei; Chang Gung University, Taoyuan.

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Address for reprints: Dr. Fu-Chan Wei, Department of Plastic Surgery, Chang Gung Memorial Hospital, 5, Fu-Shin Street, Kweishan, Taoyuan 333, Taiwan, R.O.C. Tel.: 886-3-3281200 ext. 3355; Fax: 886-3-3287260; E-mail: fcw2007@cgmh.org.tw

deficits.⁽⁴¹⁻⁴⁵⁾ With progress in rehabilitation such as early motor rehabilitation and sensory reeducation, coordination, dexterity, and sensory recovery of the reconstructed hand could be improved.⁽⁴⁶⁻⁵¹⁾ Thorough section of toes to be transplanted and specific considerations in harvest techniques helped avoiding major donor site morbidity especially in multiple toe transplantations.^(47,50,52,53) Secondary procedures such as pulp plasty enhanced the appearance and function of the transplanted digits.^(54,55) In this article, based on the experiences of more than 1350 toe transplantations guidelines are proposed for toe-to-hand transplantation with emphasis on specific technical procedures. Extensive reconstructions such as the metacarpal hand^(50,52,53) which needs formulation of a thorough reconstructive plan before any toe is harvested and detailed rehabilitation programs^(46,47,50) are beyond the scope of this article.

Selection of patients

An otherwise healthy, cooperative and interested young patient is the ideal candidate for toe transplantation. In such case, a primary toe transplantation before completed wound healing of the stump can be considered, if the stump is clean and viable.⁽⁵⁶⁾ Contraindications to primary or secondary toe transplantation include all conditions which may impair microsurgical procedures such as vascular diseases, major illness, severe mental diseases with lack of compliance, or trauma to the foot and arteriosclerosis that prevent toe harvest.⁽⁵⁰⁾

Prerequisite for toe transplantation

In the acute management of non-replantable amputations of the hand when future toe-to-hand transplantation is considered, emphasis should be laid on tissue preservation instead of tissue sacrifice. This serves three purposes: (1) To enable a good match in length of the toe transplanted to the remaining digits of the hand, (2) To achieve the best possible function of the new toe-digit-unit, and (3) To avoid extensive dissection at the foot which is associated with increased donor site morbidity.

Skin

All viable soft tissue should be retained. Local flaps should be avoided, whereas the pedicled groin

flap is recommended for most cases requiring imported tissue for stump coverage.

Tendon

(1) Flexor tendon: Preservation of viable tendon length even in zone II helps to maintain the integrity of the pulley system and to avoid future tendon grafts. (2) Extensor tendon: Whenever possible, the extensor apparatus should be left in situ on the digital stump to preserve the balance between intrinsic and extrinsic extensor mechanism.

Vessels

Preserving the length of a healthy artery at the base of the proximal phalanx or in the distal palm allows reliable anastomosis with good size match of donor and recipient arteries. The same accounts for a healthy vein at the dorsum of the hand.

Nerve

Debriding the nerve back to normal or near normal looking architecture instead of excising it far proximally allows a relatively distal nerve repair resulting in earlier sensory recovery.

Bone and joint

Wherever possible, the skeleton should be preserved distal to the insertion of the flexor digitorum sublimus. Excessive bone shortening may preclude a good match in length of the toes transplanted to the remaining digits. If possible, the most distal mobile joint should be preserved since a 5 mm metaphysis of a phalanx is sufficient for toe fixation using intraosseous wiring technique.⁽⁵⁷⁾ If joint salvage is not attainable, conservation of the articular cartilage and the local capsular tissue in the metacarpophalangeal joint will facilitate a composite joint reconstruction.

Operative technique

Simultaneously two teams prepare the donor site and the recipient site. Both preparations are performed under tourniquet control.

Specific considerations

(1) If two adjacent fingers need to be reconstructed, the combined second and third toe transplantation^(58,59) is recommended whenever the recon-

structionis performed proximal to the web space and the remaining fingers are not longer than that of the little finger. Separated second and third toes or two second toes are better when the web space between the fingers is preserved.

(2) In thumb reconstruction a total or trimmed great toe⁽³³⁾ is usually chosen for reconstruction in patients with more proximal amputations. In such cases, transmetatarsal harvest of the second toe is necessary for compensation of length.⁽⁶⁰⁾

(3) Harvest of the great toe and the second toe in the same foot should be avoided for maintaining foot balance.

Toe harvest

Pedicle dissection

Dissection of the pedicle starts distally in the first web space. After identification of the lateral digital artery of the great toe and the medial artery of the second toe, proximal dissection continues both plantar and dorsally for 1-2 cm. Either the first dorsal metatarsal artery (FDMA) is dominant or the FEMA and the first metatarsal plantar artery (FPMA) are of equal size in approximately 70% of patients. If this is the case, the FDMA is traced further proximally until enough length is obtained. If the FPMA is the dominant vessel with either hypoplastic or aplastic FDMA, the FPMA is dissected from the plantar side of the foot. Use of a vein graft for inadequate pedicle length is recommended when a long pedicle is necessary. This avoids extensive dissection proximal to the middle of the metatarsal bone resulting in increased donor site morbidity, because the artery becomes deep at this point.

Trimmed great toe harvest

Toe harvest starts with a wedge-shaped skin incision both dorsally and plantarly.⁽³¹⁾ At the medial aspect of the toe, 1.5 cm skin strip, tapering to a point at the tip of the toe, is elevated, leaving 2 mm of skin beneath the nail to facilitate closure. The medial collateral ligament, capsule, and periosteum are elevated as a hemicircumferential flap. The medial joint prominence is reduced 4-6 mm, and the phalangeal shafts are reduced 2-4 mm with a longitudinal osteotomy through the distal and proximal phalanges, and through the interphalangeal joint. The medial hemicircumferential flap is resutured after hav-

ing trimmed the excess tissue to restore stability of the interphalangeal joint. Retrograde dissection of the artery is performed as described above. Dorsal superficial veins are traced proximally until adequate length is obtained. During dissection, both vein and artery are skeletonized gently with instruments to prevent vessel spasm and allow smooth passage of the pedicle through skin tunnel for vascular anastomosis at a more proximal site (Fig. 1). Flexor and extensor tendons are harvested as long as necessary. The lateral plantar nerve is carefully split to preserve continuity of the nerve to the second toe and traced proximally until enough length is gained. Osteotomy can be performed at any level but distal to the metatarsophalangeal joint leaving 1 cm of the proximal phalanx to preserve push-off function of the foot. During osteotomy, all important soft tissue structures are held back for protection using a wet sponge. The medially elevated skin strip can be employed for stump coverage.⁽⁵⁰⁾

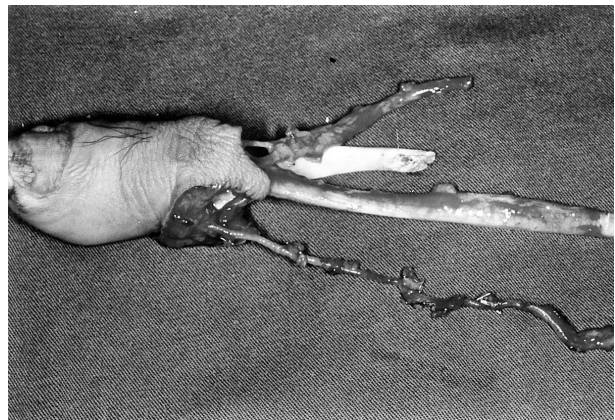


Fig. 1 Harvested trimmed great toe with skeletonized vascular pedicle.

Lesser toe harvest

As in the trimmed great toe harvest, dissection starts with a wedge-shaped skin flap. Skin incisions should not extend beyond the middle of the first and third web spaces to allow primary closure of the donor site in combined second and third toe harvest. To avoid a bulky anteroposterior diameter of the toe resulting in impaired metatarsophalangeal joint flexion, thinning of the plantar skin flap is recommended. Artery, vein, tendons, and nerves are dissected as described above. However in lesser toe harvest, both

lateral and medial nerves are split to maintain sensation of the adjacent toes. In combined second and third toe harvest, in addition to either the FDMA or FPMA, the second and third plantar metatarsal arteries are dissected and preserved for possible need of second anastomosis, if the blood supply to the third toe is doubtful after first anastomosis between either FDMA or FPMA and the recipient artery.⁽⁶²⁾ Transmetatarsal osteotomy can be performed if indicated.

Preparation for the amputation stump

At the time of toe harvest, careful stump preparation is performed.⁽⁴⁷⁾ Two cruciform (anteroposterior and transverse) incisions over the amputation stump (Fig. 2) open the stump for dissection of tendons, nerves, and arteries. This way skin incision followed by adequately undermining, thinning, and trimming of the resultant four skin flaps prevents and ugly "cobra" appearance of the junction between the digital stump and the transplanted toe.⁽⁶³⁾ Venous anastomosis is usually performed at the dorsum of the hand or at the dorsum of the phalanx. Digital or common digital arteries in the palm commonly serve as recipient arteries. To avoid a long skin incision in distal transplantations, recipient artery and vein are dissected through a separate incision in proximal phalanx or distal palm. The donor artery and vein reach them through a tunnel underneath the skin. Bone shortening is performed when indicated.



Fig. 2 Two cruciform incisions over index finger amputation stump with adequate flap undermining.

Toe inset and fixation

At the level of the metacarpophalangeal joint (MPJ), composite MPJ reconstruction is possible whenever the metacarpal articular surface and capsular tissue are preserved. The metatarsophalangeal joint (MTP) capsule, the plantar plate, and the collateral ligaments of the toe are connected to the corresponding structures on the metacarpal head with nonabsorbable sutures.⁽⁴⁷⁾ For amputations proximal or distal to the MPJ, osteosynthesis using intraosseous wiring is performed. In a dorsal-palmar direction, two parallel 1 mm holes are made through both cortices of either the phalanx or the metacarpal bone. After determining the angle and rotation of the toe, the same procedure is repeated at the toe. Two stainless steel wires are pulled through the holes and twisted dorsally. The wire ends are cut short and turned away from the extensor tendon. The extensor tendon of the toe is sutured to the finger extensor tendon with nonabsorbable material in full extension position. In flexor tendon repair only deep flexor tendon is performed. To prevent a claw deformity in lesser toe transplantation, sometimes the extensor digitorum longus attachment needs to be released from the capsule of the MTP joint and the extensor digitorum brevis is sutured to the dorsal expansion or the interosseous tendon if possible. A two weeks lasting K-wire fixation of the interphalangeal joints in complete extension additionally helps to prevent clawing. Then, donor artery, vein, and nerves are placed close to the recipient structures. The skin flaps are adjusted to the local skin. The skin is closed before microanastomoses are performed to optimize the appearance of the reconstructed digit as it is difficult to make perfect tailoring of skin flaps at the junction of the transplanted toe and the amputation stump once microvascular anastomoses are completed. Finally, microanastomoses and coaptation of the nerves are performed as usual. A loose bandage with sponges is used for wound dressing.⁽⁵⁰⁾

Secondary procedures

Most common secondary procedure is the pulp plasty which can be performed as soon as three months postoperatively in under local anesthesia⁽⁵⁴⁾ (Fig. 3). A longitudinal wedge resection of the pulp of the transplanted toe is performed. This results in improved appearance and function since the reduction of the bulky pulp reduces the shearing move-

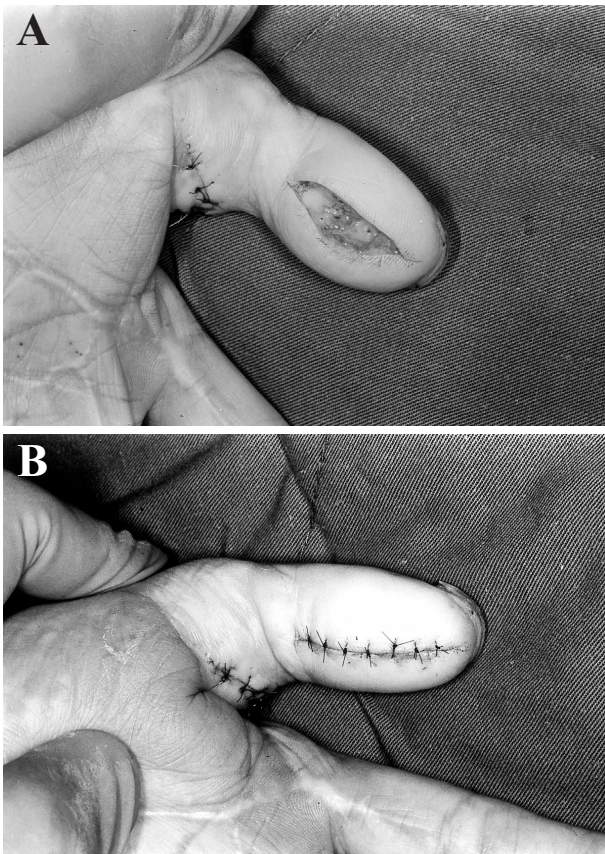


Fig. 3 Pulp plasty of transplanted toe. (A) Central pulp excision; (B) Immediate after wound closure.

ment with pinch. Other secondary procedures include tenolysis, arthrodesis, and web space deepening. However given adequate operative techniques and early motor rehavilitation, such procedures are rarely needed.⁽⁶⁵⁾

Perspectives

"We still have to go forward with the present. We cannot keep ourselves still."

(Commentary on the Chuang-tzu, ch. 6)

Functional results of toe-to-hand transplantations are insurmountable by other conventional reconstructive methods. Survival rate in a large series of 400 cases was 96.5%.⁽⁶⁴⁾ Donor site morbidity is negligible after one lesser toe harvest and

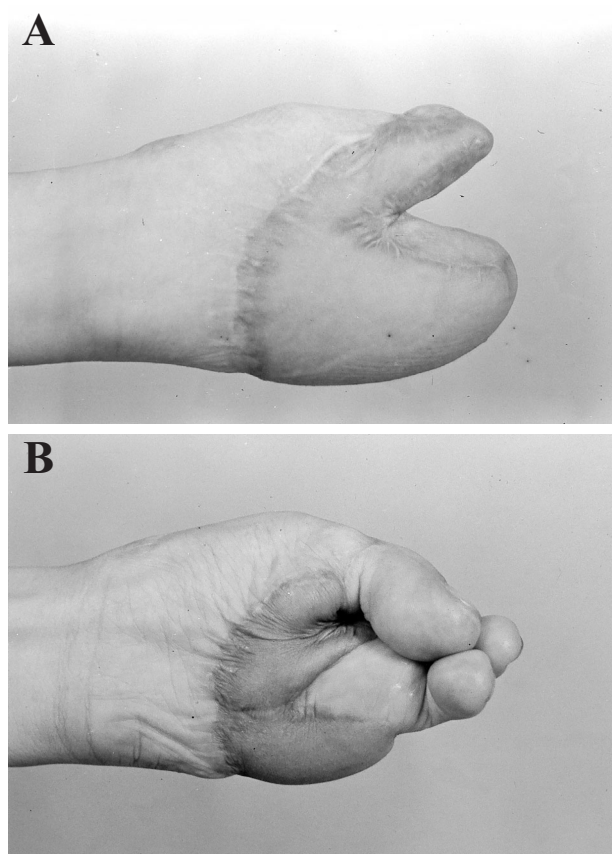


Fig. 4 Metacarpal hand reconstructed with multiple toe transplantations. (A) Before reconstruction; (B) Function and appearance one year after reconstruction.

acceptable after multiple toe transplantations if guidelines as mentioned above are considered. However, so far a donor site with one or more missing toes remains. Electromechanical prostheses lack of sensitivity. The recently performed allograft hand transplantation⁽⁶⁵⁾ may solve this problem, but still bears a high risk owing to possible side effects of immunosuppressive drugs. Whether locally placed immunosuppressive genes at the junction between finger and transplanted allografted toe will replace the need for systemic administration of such agents needs to be awaited. Besides, so far functional results are pending. Except for the donor site morbidity, the basic principles in toe harvest and inset remain the same, if this option should become popular in future. An engineered new digit using a scaffold imitating the lost digit would be optimal.

However up to now and most likely in the near future, the microsurgical toe-to-hand transplantation has its established place in reconstructive microsurgery for the benefit of the patients. Its demand for severe mutilating hand reconstruction may decrease with increasing safety measures in industrial plants, but as single and distal digit amputations from leisure activities or out of work are still often seen distal toe transplantation shall remain a useful method for finger reconstruction. Such kind of reconstruction may be more demanded in countries with moderate climate and stable social system than in countries with cold weather and with low social care. Although, toe-to-hand transplantation for single or distal finger reconstruction at present time still remains controversial among surgeons, our ongoing outcome research has shown result in favor of reconstruction. In distal lower arm amputation, single toe transplantation can provide a pinch grip (unpublished data, 66) or help controlling an electromechanical prosthesis.⁽⁶⁷⁾ In metacarpal hands with loss of all fingers with or without thumb or in severe congenital deficits, multiple toe transplantations can provide prehensile function in children^(41-45,68) (Fig. 4) and adults^(7,16,18,19,22-23,28-30,34,35,50,52,53,64) better than any other method so far. Also in the new millennium, multiple toe transplantations are a great challenge requiring adequate experience that usually starts with the transplantation of one toe as described in the operative technique section above.

Footnote: Quotations from FungYu-Lan. A short history of Chinese philosophy. Der Bodde, ed., New York: The Free Press, pp. 75, 223.

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腳趾移植至手的基礎原則

Barbara S. Lutz 魏福全

顯微腳趾移植手術近三十年來已成為手部外傷缺損及先天畸型重建的重要方法。在健康而合作的病人如果手指截斷的傷口乾淨而沒有壞死組織殘存，則可以進行立即性之腳趾移植重建。如果考慮傷口癒合後再進行腳趾移植則急診處置時包括指骨、關節、肌腱神經、血管等組織都要儘量保留，不應輕易切除或裁短。手術時應考慮要使用那些腳趾，腳趾移植之順序、技術以及手術後復建的方法，以便達到手部最佳功能與外觀重建以及足部最小病變的雙重目的。

經修剪變小並保留腳趾趾節間關節活動功能的大腳趾 (trimmed great toe) 為重建發生於掌指骨中段或較遠端之截肢拇指的理想重建方法。然而發生於更近端之截肢則以第二腳趾移植重建較適當，因為移植之第二腳趾可以較長而不增加足部之術後病變，在一些非常在意身體形象或特別需要末稍手指 (distal finger) 功能的人，不同形式的第二腳趾移植可以提供最滿意的重建。合併第二、三腳趾移植因為可以提供較有用的三指捏功能 (tripod pinch) 因此成為重建掌手 (metacarpal hand) 的最佳選擇。組織工程、基因轉殖、異體肢體移植的繼續發展，可能在本世紀會為這些不幸的病患帶來更有衝擊性的福音。(長庚醫誌 2002;25:568-76)

關鍵字：手指截肢，顯微手術，腳趾移植至手。