Thumb Reconstruction with Toe Transfer

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Abstract Microsurgical toe transfer has become a gold standard option for amputated thumb reconstruction. It can be used to correct almost any thumb defect. However, for optimal functional and esthetic results, proper initial care, preoperative planning, proper selection of suitable techniques, adjunct or secondary procedures and proper, postoperative rehabilitation are important.

Keywords Thumb amputation · Microsurgery · Toe-to-thumb transfer

The transfer of a toe to replace an amputated thumb represents one of the first applications of microsurgical techniques [1, 2], yet to this day remains an epitome of reconstructive surgery, restoring critical function and form to the hand-injured patient. While techniques have greatly evolved to permit the treatment of multiple finger amputations [3, 4], dystrophic nails and pulps [5–7], and traumatized or arthritic joints [8], the amputated thumb retains its status among the most indubitable indications for toe transfer. For it is the loss of the thumb—“the king of the digits”—that most debilitates the hand, and therefore best justifies the great skill and rehabilitative effort attendant to the procedure. In this review we shall focus on the rationale, methods, and outcomes of toe transfer as they apply to the isolated amputation of the thumb.

Indications and Patient Selection

Microsurgical techniques have been refined to such a degree that almost any ablative deformity of the thumb

could be corrected with some form of toe transfer. The question, therefore, is not *if* a defect could be reconstructed, but whether the patient is *willing* to undergo reconstruction. The concepts of “adequate function” and “optimal function” are therefore of central importance when discussing treatment options with a patient. Obviously, these parameters will be different for each patient depending upon his/her vocation, avocations, and desires. For many people, adequate function might be expected with an amputation that retains some length of the proximal phalanx (assuming sufficient soft tissue coverage is present or can be provided). For those with marginal length, web space deepening and/or metacarpal distraction can improve their grasping capacity. However, for patients who require full length of their thumb, or who desire optimal rather than adequate function, toe transfer should be considered.

The benefits of toe transfer are numerous. The specialized tissue of the fingertip—with skin that is glabrous, durable, and highly sensitive; a septated pulp that balances conformability with sturdiness; and a nail that provides a sharp pincer while stabilizing and enhancing the function of the rest of the fingertip [9]—can be replicated only by another digit. Bone, mobile joints, and tendons can also be restored. If missing tissue is to be replaced with like tissue, only a toe transfer will do.

But toe transfer is not without its drawbacks. The procedure is lengthy, requires considerable technical acumen, and carries with it the risk of complete failure. A relatively long hospitalization is necessary. The appearance of the foot will be abnormal (although the deformity, at least in the case of second toe transfer, can be quite inconspicuous, and the functional deficit, even in the case of great toe transfer, will be negligible) [10]. Finally and most importantly, it is mandatory that the patient be motivated to comply with a rigorous and time-consuming rehabilitation, and accepting of the fact that full function will not be attained for many months. Obviously these

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drawbacks must be thoroughly explained to the prospective toe transfer patient, but they should not be overstated, for the potential benefits far exceed the risks. Photographs demonstrating the typical appearance of a transferred toe and donor site defect can be invaluable for patients considering the procedure.

A brief mention should be made about the use of toe transfer for congenital thumb defects. While pollicization of the index finger remains the standard treatment for severe hypoplastic conditions of the thumb, constriction ring syndrome is actually an excellent indication for toe-to-thumb transfer, as the joints, muscles, and tendons proximal to the amputation site are typically present and normal [11]. Technical considerations are similar to those outlined elsewhere in this review. The procedure should probably not be attempted until after the age of 2, when the vessels are of adequate caliber for microvascular anastomosis [12].

Initial Management of the Injury

It is safe and in some ways desirable to perform toe transfer acutely or subacutely (i.e., during the initial hospitalization). Convalescence is shortened, and the procedure itself may be technically easier as dissection of the amputation stump is not impeded by fibrosis. Large series from experienced surgeons demonstrate no difference in complications or outcomes between acute and delayed transfers [13, 14].

Nonetheless, in many cases of thumb amputation, immediate transfer is not feasible or practical, and the initial management is instead preparatory. The familiar paradigm of revision amputation, in which bone is shortened and tendons and nerves are resected proximally, is diametrically opposed to what is desirable for toe transfer. Every effort should be made to preserve the length and integrity of bone, joint structures, tendons and their sheaths, vessels, and nerves, even if local skin is deficient.

To this end, it is often necessary to recruit soft tissue coverage from elsewhere. While regional flaps, such as the radial forearm flap, may seem convenient, they may also expend valuable recipient vessels for future toe transfer. For this reason it may be preferable to use a pedicled groin flap, which provides an abundance of tissue that not only covers the acute wound but also can later be utilized to cover the transferred toe, protect the pedicle, deepen the first web space, and minimize the amount of skin that must be taken from the foot [15]. A groin flap can also be harvested in conjunction with an iliac crest bone graft for reconstruction of the first ray in cases where a significant length of the metacarpal has been lost [16], as an alternative to harvesting the metatarsal from the foot (Fig. 1a, b).

Fig. 1 Provision of initial coverage with a pedicled groin flap. **a** Coverage defect involving the thumb and dorsum of the hand. **b** Hand appearance after pedicled groin flap reconstruction and before secondary toe transfer.

Selection of the Donor Toe

Gait analyses and clinical experience have shown that the foot functions quite adequately without a full complement of toes [10, 17]. Nonetheless, the fear of donor site morbidity often ranks among the prospective patient's greatest concerns. The choice of the donor toe—for transfer to the thumb, usually either the great or the second toe—must therefore be made thoughtfully so as to maximize the patient's perceived outcomes at both the recipient and donor sites.

Although the toes represent the body's best substitute for a missing thumb, they are admittedly crude facsimiles, as the great toe is typically much larger and the second toe much smaller and more bulbous (Figs. 2a, b, c). Nonetheless, when the great toe is trimmed, it can be made to look remarkably thumb-like and is therefore usually preferable, at least from the perspective of the appearance of the hand (Figs. 3a, b). Unfortunately, a tradeoff must be accepted at the foot, where harvesting of the great toe creates a highly conspicuous deformity. A slight decrement in the foot's push-off power might also be detected. For this reason,

Fig. 2 Thumb reconstruction with a second toe. **a** Four flaps elevated in the amputation stump. **b, c** Appearance of the second toe-to-thumb reconstruction

donation is usually made from the non-dominant foot, typically the left (non-driving) foot.

The major limitation in harvesting the great toe (besides the aesthetic impact on the foot) is that the functionally critical first metatarsophalangeal joint must be preserved [17]. In other words, the great toe cannot be taken proximal to the base of the proximal phalanx. The second toe, then, offers two advantages: the ability to include the metatarsophalangeal joint and a substantial length of the second metatarsal, if needed; and a very subtle donor site deformity. (As mentioned earlier, the need to take metatarsal bone can be eliminated if the first metacarpal is reconstituted with iliac crest bone graft. Thus, the great toe can remain an option in cases of very proximal thumb amputation if a staged approach is undertaken.)

Preparation of the Recipient Site

The skin overlying the amputation stump is incised in cruciate fashion, permitting later inset of the toe's skin (which itself is harvested with a fish mouth pattern) and providing wide exposure of the recipient vessels, nerves, tendons, and bone.

Fig. 3 **a, b** Appearance of the trimmed great toe-to-thumb reconstruction (volar and lateral views)

Either the common digital artery, the princeps pollicis, or the radial artery in the anatomic snuffbox can be used and may be skeletonized in the sub-adventitial plane to minimize vasospasm. A sizable vein on the dorsum of the hand is isolated. Nerve stumps should be prepared under the microscope, carefully resecting neuromas while preserving as much length as possible. The tendon sheath, if still present, should be preserved. Periosteal stripping should be minimized. The bone stump can be cautiously smoothed to permit good bone-to-bone contact; however, it must be remembered that only 5 mm of bone is required for interosseous wire fixation [18], so even a tiny stump of proximal phalanx is worth saving (Fig. 4a). If

Fig. 4 **a**. A 5-mm stump at the base of the proximal phalanx is preserved and interosseous wire is inserted for osteosynthesis. **b** Composite metatarso- (metacarpo-) phalangeal joint repair

no length of proximal phalanx is salvageable, the cartilaginous surface of the metacarpal head should be maintained, as the joint can be reconstructed with a second toe that has been disarticulated at the metatarsophalangeal joint (Fig. 4b) [19].

Harvest of a Toe: General Principles

The dorsal first web space constitutes the anatomic keystone of the harvest of either the great or the second toe and is where dissection begins [20]. In this area, just above the intermetatarsal ligament, the dorsal and plantar metatarsal arteries merge and then immediately diverge into proper digital arteries of the great and second toes (Fig. 5). The larger of the metatarsal arteries—the dorsal in 70% of feet [21]—is chosen as the pedicle and is traced in retrograde fashion [22]. Dissection is easier dorsally and can be carried all the way to the dorsalis pedis if necessary. Plantar dissection is more difficult and if continued beyond the mid-metatarsal level can cause substantial morbidity. In these cases, a vein graft should be used if additional pedicle length is required. Plantar incisions are kept lateral to the weight-bearing first metatarsal head. A dorsal vein is identified and included with the flap. The extensor and flexor tendons are dissected and cut proximally, and the bone is divided at the appropriate level. The tourniquet is released and the toe is inspected for vascularity. Topical lidocaine or papaverine is utilized to mitigate vasospasm. The toe is allowed to perfuse on the foot for at least 20 min prior to dividing the vessels. Great care is taken to leave enough skin to allow primary closure at the donor site.

Harvest of the Trimmed Great Toe: Detailed Description

If, as is usually the case, the great toe is substantially larger than the thumb, it can be reduced to the appropriate size. One method of reducing the toe is the “wrap-around” flap, in

Fig. 5 A dorsal metatarsal artery-dominant vascular pedicle, exposed through a retrograde dissection

which the soft tissue of the toe is elevated off its bony skeleton and wrapped around a conventional bone graft at the thumb [23]. Another is the trimmed great toe [24], in which a swath of skin, subcutaneous fat, and bone is removed from the side of the toe at the time of harvest. Trimming the toe is advantageous because it provides a mobile interphalangeal joint and avoids damage to the nail matrix and septae of the pulp.

The trimmed great toe procedure begins with measurements of the circumference of the thumb at the levels of the eponychium, interphalangeal joint, and mid-proximal phalanx. These values are transposed to the great toe (adding 2–3 mm to each measurement to permit tension-free closure) such that the excess skin is located along the medial (tibial) aspect. The medial strip of skin, usually measuring 5–8 mm in width, is tapered to a point at the tip of the toe and is positioned 2 mm from the nail to avoid distortion of the paronychial fold (Fig. 6a).

After identifying the vascular pedicle in the first web space and dissecting the tendons and neurovascular bundles, the medial skin strip is excised. The incision along the plantar margin of the strip extends through skin and subcutaneous fat but preserves the medial collateral ligament. The dorsal margin incision extends through periosteum. The periosteum, capsule, and collateral ligament are then elevated together as a plantar-based “peri-joint flap” (Fig. 6b). Subperiosteal dissection proceeds to the mid-volar line of the proximal and distal phalanges. While protecting the neurovascular bundles, a longitudinal osteotomy is made with a saw, removing a 2–4 mm-thickness of the phalangeal shafts and a 4–6 mm-thickness of the joint (Fig. 6c). The peri-joint flap is redraped and trimmed of excess tissue and secured with non-absorbable sutures (Fig. 6d).

The proximal phalanx is divided 1 cm from the metatarsophalangeal joint, preserving the joint and its peri-articular structures. Transfer and inseting of the toe proceeds as described later in this review.

Harvest of the Second Toe: Detailed Description

The skin is marked with dorsal and plantar V-shaped flaps centered over the second ray, with the apices 5–10 mm proximal to the planned osteotomy site. Dissection starts as usual in the first web space. Vessels and nerves are identified, and the transmetatarsal ligament is transected. Vessels in the second web space are ligated and divided. A dorsal vein is isolated. The extensor retinaculum is opened and the extensor digitorum longus and brevis tendons are followed proximally and cut.

Fatty tissue is removed from around the nerves and vessels to minimize bulk and maximize joint motion in the reconstructed thumb [24]. The nerves are dissected proximally as far as necessary, utilizing internal neurolysis of the

Fig. 6 Harvesting a trimmed great toe. **a** Design of the skin incision. **b** Peri-joint flap is elevated and a longitudinal osteotomy is made through the interphalangeal joint and both proximal and distal phalanges. **c** Excess peri-joint flap is trimmed and a stable joint is reconstructed

common digital nerves if required. The flexor sheath is opened at the level of the planned osteotomy, and the long and short flexor tendons are pulled distally and cut. The bone is divided at the appropriate level, or the toe is disarticulated.

There is no need to repair the intermetatarsal ligament. The skin should close easily without tension; if primary closure is difficult, the metatarsal can be shortened. Skin grafts should be avoided.

Transfer and Inset of the Toe

At this point the procedure resembles a “planned” replantation. The sequence of repairs is: bone (or joint capsule, if

the toe was disarticulated), extensor tendon, flexor tendon, nerves, artery, vein, and skin.

An excellent method of bone fixation is interosseous wiring, which requires minimal stump length and provides stable fixation, permitting early mobilization [18]. Two 26- or 28-gauge wires are used, passed through carefully-aligned 1-mm drill holes placed 2 mm from the osteotomized edge.

If the metacarpophalangeal joint is to be restored, the volar plate must be attached under tension to avoid hyperextension deformity [25]. The interphalangeal joints of the second toe are prone to flexion contracture after transfer; thus, the extensor tendon is repaired under tension with all joints held in extension, and the interphalangeal joint(s) are pinned in extension after flexor tendon repair for further reinforcement (Fig. 7). Flexor tendon coaptation occurs in the palm or distal forearm. Ideally, a grasping suturing technique should be employed, using at least 4 core strands and an epitendinous layer, to permit early active motion [26]. Standard microscopic techniques are used for the nerves, artery, and vein. The skin is tailored and loosely closed.

Postoperative Care

The postsurgical dressing is a matter of surgeon’s preference. In our opinion it is better to use a light dressing in order to avoid the accumulation of blood and creation of a “blood cast” that could constrict the transferred toe. While many surgeons apply a splint at the end of the procedure, we prefer not to do so, at least for the first several days (again, to avoid constriction of the toe), and have not encountered a tendon rupture in the early postoperative period.

The patient is monitored in the intensive care unit for the first few days (usually 3–5 days in our practice). Color,

Fig. 7 Both interphalangeal and metacarpophalangeal joints are kept in extension for 2–4 weeks after transfer

turgor, capillary refill, temperature, Doppler signal, and continuous pulse oximetry can all be used to assess the transplant [27]. Early failure is usually a consequence of vasospasm, which can be minimized by keeping the patient warm and well-hydrated and forbidding nicotine, caffeine, chocolate, and excessive stimulation. Indwelling supra- or infraclavicular pain pumps may also mitigate the potential for vasospasm. Daily aspirin (325 mg) is administered and continued for at least two weeks. Venous insufficiency can be treated with leeches. One should maintain a low threshold for re-exploration should conservative measures fail to ameliorate the condition within 1 h.

Rehabilitation

The great effort, stress, and expense of toe transfer will all be for naught if a rigorous rehabilitation protocol is not followed. Assuming stable bone fixation was achieved, gentle mobilization can begin as early as 4 days after the procedure. Active exercises can also begin fairly early, depending on the strength of the tendon repairs. A lightly compressive sleeve is applied at 3 weeks to control edema. Strengthening and vocational activities can begin at 2 months.

Sensory rehabilitation is also critically important, not because it can hasten axonal regeneration, but because it can help the patient interpret the altered sensory impulses reaching the central nervous system [28]. Sensory re-education begins with exercises facilitating the perception of touch submodalities with correct localization. In the later phase of re-education, the patient focuses on size and shape discrimination and object identification [29]. This program is begun following the recovery of touch sensation. It consists of touching several objects with different texture, size, and shape, the nature of which the patient attempts to appreciate with the tip of the transplanted toe instead of the adjacent normal finger surface. It can be implemented as a home rehabilitation program with significant improvement in the final result.

Outcomes

As with most examples of free tissue transfer, the overall success rate in toe-to-thumb transfer for experienced surgeons is well over 95% [17, 30, 31]. Re-exploration is required in roughly 10% of cases. Secondary procedures are commonly performed, mostly in the form of minor pulp-plasties or tenolyses.

Toes are relatively immobile in situ, and so a normal range of motion is not likely, although a functional arc is to be expected [32]. Sensory recovery is generally good in

comparison to the sensibility of toes in situ and fair in comparison to normal fingertips, with moving two-point discrimination of less than 10 mm [33, 34]. The majority of patients perceive the transplanted toe as a finger within 6 months of surgery [35]. This observation is consistent with functional MRI studies showing that motor and sensory tasks involving the transplanted toe evoke enhanced activation and cortical recruitment in the hand area of the primary sensorimotor cortex [36]. This may also be related to the observation that phantom finger phenomena often resolve after toe transfer [35].

At Chang Gung Memorial Hospital, the Michigan Hand Outcomes Questionnaire (MHQ) has been used to assess outcomes among a group of patients who underwent toe transfer for thumb amputation compared to a cohort with similar injuries who did not undergo reconstruction [10]. MHQ scores of the toe transfer group were over 50% higher than those of the non-reconstructed group for overall function, activities of daily living (ADLs), and satisfaction, and nearly 100% higher for aesthetic outcome. Looking only at the cohort who underwent toe transfer and comparing the reconstructed hand with the uninjured contralateral hand, MHQ scores were 93% of normal for overall function and ADLs, and 80% of normal for aesthetics and satisfaction. Thus, although normal motion and sensation should not be anticipated, toe transfer can restore function and appearance to near normal levels.

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