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Secondary surgeries after replantation

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Abstract

Although digit replantation techniques and indications have evolved over time, resulting in improved overall outcomes, achieving ideal functional recovery remains a challenge. Secondary surgeries for replanted digits can be divided temporally into early- (weeks to months) and late-stage (months to years) procedures, with skin-coverage procedures being the most common in the early period and tenolysis being the most common procedures in the late postoperative stage. This article reviews the most common procedures, including available literature on secondary replant procedures involving nerve, tendon, bone, joint, and skin procedures. However, further larger-scale studies are necessary to establish clear guidelines regarding both postoperative protocols and indications for secondary surgery.

Keywords: Secondary surgeries, tenolysis, nonunion

INTRODUCTION

Upper extremity replantation was first successfully performed by Ronald A. Malt at Massachusetts General Hospital in 1962, followed by the first successful digital replant by Komatsu and Tamai in 1965[1]. The first replantation was performed using microvascular anastomosis on a 28-year-old patient who suffered a sharp amputation of his thumb at the metacarpophalangeal joint level. This patient was hospitalized postoperatively for 40 days but was able to return to work 4 months postoperatively[2].

Although the field of digital replantation has since advanced substantially, many challenges remain half a century later. Besides the common logistical obstacles faced by hand surgeons in hospital centers not optimized for digital replantation, other challenges involving sub-optimal postoperative function remain.

With the appropriate condition of the amputated digit, amputation level, and mechanism, digital replantations can have excellent functional outcomes and high patient satisfaction[3,4]. Indications for replantation have narrowed over the past several decades as several studies have shown poor survival in crush, avulsion, and multi-level amputations. The level of digital amputation was noted to be an important predictor of postoperative outcomes as amputations distal to Zone II had a superior range of motion compared to replanted digits involving Zone II or proximal[5-8]. Several of these contraindications do not apply to the pediatric population as they have overall improved healing abilities and outcomes[9].

Besides appropriate indications and patient selection, intense postoperative hand therapy in a motivated patient can significantly optimize postoperative outcomes. Replanted digit functionality is an important measure of ultimate replant success beyond simply ensuring replant viability.

INTRODUCTION TO SECONDARY SURGERIES FOR REPLANTED DIGITS

Despite well-established postoperative replantation protocols, secondary surgery is often necessary for successfully replanted digits as a result of immobilization necessary for appropriate bone healing. The overall incidence of secondary surgeries after replants varies widely in literature but is usually quoted at around 50%[10].

Postoperative replant rehabilitation can start as early as the 5th-7th day of replanted digit viability, with early protective motion protocol emphasizing tendon glide and joint motion while preventing micromotion of the osteosynthesis site[11].

Some of the most common secondary surgeries besides tenolysis involve bone (nonunion and malunion management), nerve (neuroma excision and nerve grafting), joint (capsulotomy, arthrodesis), skin (z-plasty/contracture release, skin grafting, flap). Finally, for a replanted digit that is painful, stiff and nonfunctional, and that has failed both therapy and secondary surgery procedures, digit or ray amputation can be offered to the patient.

Matsuzaki *et al.* reviewed a series of 70 digits in 43 patients and quoted that 56% of the digits needed secondary surgery. They noted that in this secondary surgery group - 27% needed a skin graft, 21% needed a bone graft, 19% needed tenolysis or a tendon transfer, 15% needed a web plasty/Z-plasty, 13% needed a joint fusion or capsulotomy, and 6% needed a corrective osteotomy[5].

It is important to note that the more proximal the replantation site is, the higher the likelihood that the patient will need a secondary surgery. Matsuzaki's study revealed that only 10% of Zone I replantations required a secondary surgery, whereas in Zone IV, there were 23 secondary surgeries for 23 replanted digits. Additionally, cases involving crush/avulsion mechanisms also had a significantly higher proportion of secondary surgeries (78%), while only 27% of clean amputations required a secondary surgery[5].

Secondary surgeries can also be categorized chronologically into early and late procedures, with some immediate or early procedures involving skin grafting, adjacent tissue transfers, or free tissue transfers. Late secondary surgeries involve tenolysis, most frequently followed by the management of bony nonunion and joint procedures. It is also important to counsel the patient that some replanted digits ultimately require amputation in about 12.7% of the cases[12].

In a large review of secondary surgeries after digit replantation, Shaterian *et al.* conducted a pooled analysis of 1,124 secondary procedures performed on 1,485 replants, derived from 19 articles. They noted that tendon-related secondary surgeries were the most common, but quoted a lower rate - 27.1%. For other surgeries, the frequencies of secondary surgeries after replantation were, in descending order, bone and joint procedures (16.1%), soft tissue coverage (15.4%), nerve-related (5.4%), and scar contractures (4.5%)[12].

SECONDARY SURGERIES AFTER DIGIT REPLANTATION

Nerve - neuroma management

Replanted digits overall can have a fair sensory recovery with static 2-point discrimination (S2PD) reaching 8 mm in fingers and 9 mm in thumbs on average for clean mechanism amputations. This is similar to sensory recovery in non-replant digital nerve injuries. The replanted digit sensory recovery is significantly worse in crush/avulsion mechanisms (15 mm in fingers, 12.1 mm in thumbs)[13].

In addition to poor sensory recovery, crush mechanism-related replanted digits also encounter a higher painful neuroma prevalence. Eberlin *et al.* reviewed 1,083 patients who underwent revision amputation and found that 6.6% developed a painful neuroma, with an average duration of 6.6 months, and 4.35% (47 patients) required surgery for painful neuroma management. They noted that the avulsion mechanism and index fingers were at higher risk of developing neuromas[14,15].

Managing neuromas in replanted digits can be very challenging due to a technically more difficult dissection through aberrant anatomy, the risk of injuring anastomosed arteries, and less predictable outcomes after secondary nerve revision and/or neurolysis[16]. These patients frequently require nerve grafting after neuroma excision due to significant gapping after the excision of unhealthy scarred nerve[17]. The graft options include various autografts (MABC, sural, PIN, *etc.*) *vs.* allografts with optional additional nerve wrapping. Some authors have highlighted that nerve wrapping with autologous (piece of muscle, short vein graft) or allogeneic material (collagen nerve wrap) may have some benefit in the prevention of neuroma recurrence[18-21].

Tendon-flexor and extensor tenolysis

Flexor tendon adhesions after replantation are very common and tenolysis is frequently necessary. Yu *et al.* noted that in the late stage of secondary surgery for digit replants, tendon tenolysis is the most common procedure (67%)[22]. Given the functional limitations of replanted digits, preoperative counseling and discussion of recovery are important. The surgeon and patient should have similar expectations about the likely outcomes and the knowledge of possible complications. The frequency and severity of tendon adhesions are dependent on several factors. The level of amputation and the mechanism of injury can limit the success of secondary tenolysis. Zone II and crush injuries frequently have the worst adhesion rates and also the worst post-tenolysis outcomes[5,22,23].

A study by Jupiter *et al.* reviewed 37 replanted digits and 4 thumbs for secondary procedures. All of the digits underwent tenolysis at an average of 10 months. They measured the outcomes with total active motion (TAM), potential active motion (PAM), and with the Strickland formula {[(pip flexion + dip flexion)-(pip extension lag + dip extension lag)] × 100/175}. They had statistically significant improvement in both total AROM and potential active motion. With the Strickland formula, they calculated that out of 37 digits, 13 had excellent results, 11 good, 6 fair, and 11 poor results. While the average digital TAM improvement was 65 degrees (77 to 142 degrees), the average thumb TAM improvement was only 2 degrees (25 to 27 degrees). They concluded that tenolysis is worthwhile for digital replants but not thumbs[23].

Jablecki *et al.* had similar outcomes in a larger group of patients (161 tendons in 36 patients) who underwent tenolysis at an average of 6.9 months. Statistically significant improvement ($P < 0.05$) was found in total active motion (75%) and potential active motion (48.7%). Using the Strickland formula, they also found that most fingers had far, good or excellent outcomes, while the results for the thumbs were less conclusive. They noted a 4% complication rate, including tendon rupture after tenolysis, some of which required secondary tendon reconstruction[24].

Secondary tendon reconstruction in replanted digits requires a two-stage procedure with silicon rod insertion and secondary tendon graft. It is important to ensure that a patient has harvestable donor tendons, especially in the setting of generalized hand/ipsilateral upper extremity trauma.

The approach for a tenolysis is largely determined by the previous injury scars that are extended with Bruner incisions to maximize flexor tendon exposure and enable thorough lysis of tendon adhesions and scar tissue. Tenolysis can be done through a WALANT approach which allows intraoperative patient participation and immediate assessment of the amount of TAM improvement. Patient participation can significantly decrease post-tenolysis tendon rupture rate by ensuring no gapping in the tendon with active motion[25]. Tendon reconstruction after tenolysis-associated rupture can be challenging even without the additional complicating factors of a replanted digit.

Senior author prefers to use a tenolysis-specific instrument set with “tenolysis knives” that resemble freer elevators/periosteal elevators, are double-headed, and have moderately sharp edges that cut through scar tissue but are dull enough to avoid injuring surrounding structures. Some of the instruments have curved narrow necks for easier access into planes between pulleys and flexor tendons.

Bone - nonunion treatment

Nonunion rates in digit replant have remained consistent over the past several decades, despite improvements in replant techniques and postoperative protocols and are cited to occur in 3%-31% of replanted digits[24-27]. Balancing osseous healing with initiating postoperative therapy remains a challenge and an area without complete consensus amongst hand surgeons in the USA. While some allow full osseous healing and start ROM therapy at 6 weeks, others start this process earlier - as early as 1-2 weeks[11].

The methods of fixation also vary amongst surgeons, with K-wires being the most commonly used type. In a study conducted by Lee *et al.*, they reviewed 1,247 successful replantations performed at their institution and compared the various methods of fixation, which involved the use of K-wires and/or interosseous wiring[26]. After applying their exclusion criteria, 103 digits remained and they observed nonunion in 32 patients (31.1%), of which 13 required secondary surgery with bone grafting or corrective osteotomy. Their subgroup nonunion rates ranged from 25%(intraosseous wire) to 36%(crossing K-wires), but no statistical difference was found among the five groups examined.

Some studies used radiographic definitions of nonunion and reported much lower nonunion rates ranging from 3% to 19%, with some data trending towards lower nonunion rates in fixations involving intraosseous wiring, but without any of the methods showing statistically significant difference in union rates[28-30].

Touliatos *et al.* reviewed outcomes of 108 replantations and revascularizations involving plates, screws and K-wires, and found that simple intramedullary K-wiring followed by a second securing K-wire at the end of the procedure was their preferred method. Their preferred method was due to simplicity, speed and ability to rotate the finger on the existing wire[31].

Overall, the nonunion rates in replants tend to be higher than in open finger fractures without arterial injury, and a possible reason for this may be decreased blood supply to the injured bony segment as the digital artery injury also frequently involves loss of arterial branches supplying a segment of phalangeal periosteum and bone[11].

Prevention of nonunion involves ensuring adequate and viable bony edges of the replant and its target for replantation. This can be achieved with light debridement, but also with bone shortening, especially if there is a need to slightly shorten to achieve adequate vascular anastomosis and nerve repair[32].

Secondary surgeries for correction of nonunion or malunion in a replant involve bone grafting and corrective osteotomy, respectively, but are technically more challenging due to the risk of injuring the repaired arteries. Careful dissection must ensue, and if only one artery was repaired, it is more advisable to access the bone from the non-repaired side. The additional challenge with dissection is the frequent nonanatomic location of the digital nerves and arteries, further increasing the risk of inadvertent injury[10].

Joint - capsulotomy, arthrodesis

Poor joint mobility can be a significant contributing factor to overall post-replant stiffness. Over time, replantation techniques have improved and care is taken with intraoperative considerations, such as avoiding crossing joints with axial K-wires if possible. Additionally, postoperative therapy is important not only for the replanted digits but also for the surrounding uninjured digits, which can also become stiff due to immobilization[11,32].

A combination of a motivated patient, a hand therapist knowledgeable with replant recovery, and a surgeon involved closely in postoperative follow-ups can significantly impact the ultimate total active range of motion achieved by the patient.

With patients that do develop joint stiffness and reach a plateau with hand therapy, capsulotomies can be performed in either a closed fashion or open in combination with tendon tenolysis. However, Jupiter *et al.* did note that the need for open PIPJ capsulotomy during tenolysis, unsurprisingly, is associated with a lower total active range of motion achieved postoperatively[23].

A secondary arthrodesis is an option in attempts to achieve a more functional position for DIPJs, PIPJs and MCPJ. Patients requiring secondary joint fusion have often failed therapy and capsulotomies, and usually have a history of crush mechanism and significant comminution. One way to prevent this outcome is performing acute arthrodesis, although this can be challenging to incorporate due to operative time constraints. In a small series of primarily fused finger joints, Mark Tan *et al.* noted that all patients achieved very satisfactory DASH scores (10.8-22.5), with an average time of return to work being around 104.3 days[33]. Fujioka *et al.* also found very satisfactory DASH scores (average 37/100) in his series of patients that all underwent acute PIPJ arthrodesis during the time of the replantation[34].

Arthrodesis as a secondary surgery follows the principles mentioned before, ensuring careful dissection and joint positioning to avoid inadvertent vascular/nerve injury. Recommended fusion angles for finger joints ideally imitate the natural finger flexion cascade, with the radial digits being less flexed than the more ulnar digits- for example, the index finger MCPJ and PIPJs are usually fused at 25° of MCPJ flexion and 40° of PIPJ flexion, while the small finger is fused at 40° of MCPJ flexion and 55° of PIPJ flexion. The recommended arthrodesis angle for DIPJs is 0-5° for all fingers[35].

Hardware used for arthrodesis has evolved over the past several decades, with headless compression screws, modified plates, and screw-plate combinations being important advancements. One of the older but still commonly used techniques involves tension banding using K-wires and interosseus wires. Tension banding provides a stable, reliable fusion with comparable union rates and a similarly low complication rate to other more modern techniques[36].

Skin procedures -skin grafting, web space deepening, scar release/z-plasty

For the early stage of the post-op replantation course, barring the immediate OR return due to ischemia or congestion, the most common procedures involve soft tissue coverage (92%)[15]. Some of these skin defects can be obviated using spare parts from other injured non-replantable digits during the initial replant surgery[37]. Skin grafting or dermal substitutes, such as Integra, can be used if spare parts are not available. For larger areas requiring additional soft tissue coverage, a staged approach can be used with adjacent tissue transfers, pedicled flaps, or free tissue transfers.

Another option for soft tissue coverage is a venous flow-through flap (VFTF), which is especially suitable when both skin and arterial reconstruction are needed[38].

Toe pulp flap can serve as a microsurgical option when a significant skin/soft tissue deficit is present. The toe pulp flap is harvested with a corresponding nerve which is then coapted to the recipient digital nerve. Sensory recovery in the flap can range from protective sensation to diminished light touch when measured with a Semmes-Weinstein monofilament[38,39]. Additionally, a small piece of vascularized bone can also be taken from the toe middle phalanx. The flap is typically harvested from the first web space area – either the lateral aspect of the great toe or the medial aspect of the second toe. Unless there is delayed donor site healing, donor morbidity is typically well tolerated and there is minimal, if any, negative effect on foot function[39,40].

Some pedicled flap options that do not require a microsurgical anastomosis include the groin flap, while some local options include the FDMA flap, Quaba flap, and the Littler flap.

Later-stage secondary operations usually involve scar release, web space deepening, and skin lengthening procedures, such as Z-plasty. These procedures can be performed on their own or in the setting of tenolsyis/capsulotomy in an effort to improve finger stiffness/total arc of finger motion.

CONCLUSION

Although digit replantation techniques and indications have evolved over time, resulting in overall improved outcomes, achieving ideal functional recovery remains a challenge. Secondary surgeries for replanted digits can be divided temporally into early- (weeks to months) and late-stage (months to years) procedures, with skin-coverage procedures being the most common in the early period and tenolysis being the most common procedures in the late postoperative period. Most common procedures are reviewed in this article, including nerve, tendon, bone, joint, and skin procedures, based on the available literature on secondary replant procedures. However, further larger-scale studies are needed to establish clear guidelines for both postoperative protocols and secondary surgery indications.

DECLARATIONS

Authors' contributions

Made substantial contributions to the conception and design of the study and performed data analysis and interpretation: Mujadzic MM, Prsic A

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