Microsurgical Management of Acute Traumatic Injuries of the Hand and Fingers

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Abstract

Traumatic injuries of the hand and fingers may be devastating and can result in irreversible functional and psychological problems in individuals who sustain them. They occur in all age groups, ranging from the elderly to young children. The management of these injuries can be challenging and onerous. As a result, it is imperative that the surgeon be both knowledgeable and meticulous in order to afford the best possible outcomes. This review focuses on the anatomy, initial evaluation, and acute management of these injuries. A variety of treatment algorithms are discussed as well, including primary closure, grafting, commonly utilized flaps, and replantation.

The first successful replantation of an amputated limb was performed in 1962 by Malt and McKhann, who replanted a completely severed arm of a 12-year-old boy.[1] The first reported digital replantation was achieved by Komatsu and Tamai, who successfully replanted a completely amputated thumb at the metacarpophalangeal joint in a 28-year-old male.[2]

Nearly 50 years later, microsurgical management of these injuries has become more common; however, the foundation and its most basic principles remain the same. Proper osteosynthesis and the successful repair of nerves, tendons, and vascular structures are crucial for the survival of the limb. Microsurgical replantation survival rates have nearly doubled over the last few decades.[3,4] This improvement in outcomes can be largely attributed to improved techniques, instrumentation, and indications. Often, revascularization or replantation is not an option, and coverage of defects is required using various types of flaps and grafts. These include, but are not limited to, flaps such as the cross finger, v-y, kite, thenar, neurovascular island flap for finger and thumb injuries, and local, distant, or free flaps for soft tissue coverage in the hand.

The breadth of information available addressing the management of these injuries is vast, as are the endless techniques and possible tissue transfers (grafts and flaps) described to deal with them. As a result, we focus our attention on the anatomy, initial evaluation and acute management algorithms ranging from primary closure to grafting to commonly utilized flaps, and finally replantation. A brief discussion of prosthetics, transplantation, and future directions will conclude the review.

History of Microsurgery

In the mid-1500s, the earliest described techniques of vascular ligature and suture were developed throughout Europe.[5] In 1887, Halsted began experiments on limb replantation,[6] and in 1906, Carrel and Guthrie described the first successful canine limb replantation.[7] They had also been performing replantations and transplantations of other organs and several different composite tissues. The development of heparin by J. Mclean in 1916, along with Howell and Holt in 1918, furthered these efforts with increasing success.[8]

The first use of a monocular microscope was by Nylen in 1921 and was followed 2 years later by Holgrem, who used the first binocular microscope.[5] Over the next several decades, the development of the Zeiss operating surgical microscope, microsurgical instruments (which were adapted from tools of watchmakers and jewelers), and sutures paved the way for the development of the discipline. This was realized by the landmark work of Malt and McKhann[1] and Komatsu and Tamai[2] on humans and was gradually followed

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by the development of replantation centers throughout the world.

Anatomy

A description as well as a discussion of the management of hand and finger injuries would be incomplete without a fundamental understanding of anatomy, especially that of the vascular system. A systematic review of the vascular system and the neural structures in the forearm, hand, and fingers provides a foundation for comprehension of various techniques of soft tissue injury coverage and replantation. Discussion of osseous and musculotendinous anatomy is also vital but will not be the focus of the following discussion.

Vascular Anatomy

The radial artery arises as the smaller lateral branch of the brachial artery in the antecubital fossa and descends laterally under the brachioradialis, with the superficial radial nerve along its lateral side on the supinator and flexor pollicis longus muscles. It gives off the radial recurrent artery, which ascends proximally and anastomoses with the radial collateral branch of the profunda brachii artery. The radial artery then travels distally over radial side of the carpus, volar to the tendons of the first and third dorsal compartments, and over the surface of the scaphoid and trapezium. As it runs through the anatomic snuffbox, it enters the palm between the two heads of the first dorsal interosseous muscle and then between the heads of the adductor pollicis muscle dividing into the princeps pollicis artery and the deep palmar arch.

In the wrist, the radial artery gives off the palmar and dorsal carpal branches, which join the identically-named arteries off the ulnar artery to form the palmar carpal arch and dorsal carpal rete, respectively. The latter also receives a contribution from the dorsal terminal branch of the anterior interosseous artery. The superficial palmar branch passes through the thenar muscles and anastomoses with the superficial branch of the ulnar artery forming the superficial palmar arterial arch. The princeps pollicis artery descends along the ulnar border of the first metacarpal and divides into two proper digital arteries that run along each side of the thumb. The radial indicis artery may arise either from the princeps or from the deep palmar arch. The deep palmar arch, usually completed by the deep palmar branch of the ulnar artery, gives rise to three palmar metacarpal arteries that join the common palmar digital arteries off the superficial arch. Each digital artery dives into the pulp at the distal phalanx level, giving off a branch parallel to the paronychium. This then subdivides into several small fine branches that supply the nail bed as it traverses distally.

The ulnar artery is the larger medial branch of the brachial artery and descends the forearm lying between the flexor digitorum superficialis and profundus muscles. It enters the hand volar to the flexor retinaculum, lateral to the pisiform, and medial to the hamate.

The common interosseous artery arises from the lateral side of the ulnar artery and divides into the anterior and posterior interosseous arteries. The anterior interosseous artery courses down the forearm and pierces the interosseous membrane to anastomose with the posterior interosseous and joins the dorsal carpal network.

The deep and superficial venous arches are formed by a pair of venae comitantes, which run along each of the deep and superficial palmar arterial arches. More proximally, the deep veins follow the course of the arteries. The radial veins receive the dorsal carpal veins, and the ulnar veins receive tributaries from the deep palmar venous arches. The small veins of the fingertip run proximally in a random fashion instead of following the arteries as vena concomitants (as they do more proximally).

Nervous Anatomy

The median nerve runs down the anteromedial aspect of the arm but first gives rise to the anterior interosseous nerve, which descends on the interosseous membrane between the flexor digitorum profundus (FDP) and flexor pollicis longus (FPL). It enters the palm through the carpal tunnel, gives off the recurrent motor branch to the thenar muscles, and terminates by dividing into three common palmar digital nerves, which then divide into the palmar digital branches.

Distal to the elbow, the radial nerve continues as the posterior interosseous and superficial radial nerves. The latter's contribution to the hand is purely sensory. The ulnar nerve enters the hand superficial to the flexor retinaculum and lateral to the pisiform. It terminates by dividing into the superficial and deep branches at the hypothenar eminence. The superficial branch innervates the Palmaris brevis and the skin over the hypothenar eminence and terminates in the palm by dividing into three palmar digital branches: two to the little finger and one to the ulnar side of the ring finger. The deep branch curves around the hook of the hamate and turns radially across the interossei, supplying the hypothenar muscles, the ulnar two lumbricals, all the interossei, and the adductor pollicis.

Each of the two digital nerves traveling down the radial and ulnar sides of the finger split just proximal to the base of the nail fold, with one branch traveling dorsally to the nail bed and the other volarly into the pulp. Many variations to the distal nerve supply exist.[9] At the finger tip lay glomus bodies, which are small collections of nerves and blood vessels that regulate blood flow to the fingertip.

Fingertip Anatomy

Understanding the fingertip anatomy provides the basis for optimal care after injury to the specialized structures that comprise it. The nail plate allows for accurate tactile movements and increased sensory perception in the pad of the finger. The parts include the eponychium, paronychium, hyponychium, lunula, matrix, and dorsal skin fold (Fig. 1). The eponychium and paronychium surround the nail plate proximally and along its side. The hyponychium is volar to the distal edge of the nail and consists of a keratinous

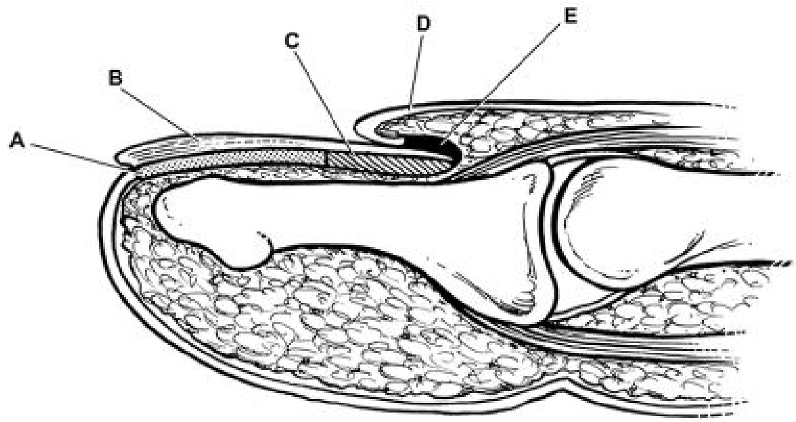

Figure 1 Anatomy of the fingertip: **A**, hyponychium, **B**, nail plate overlying sterile matrix, **C**, germinal matrix, **D**, eponychium, **E**, dorsal root.

plug. The lunula is the white arc under the nail plate and demarcates the sterile from the germinal matrix. The nail fold consists of the dorsal and ventral floors. The “nail bed” consists of the sterile (where the nail adheres) and germinal matrix (responsible for 90% of nail growth). The nail itself is made of onchyn— a keratinous material consisting of dead germinal cells.[10]

The finger pulp consists of multiple fibrous bands extending from the periosteum of the distal phalanx to the epidermis, subdividing the pulp into many small septal compartments full of fat. The distal phalanx lies closer to the dorsal aspect of the fingertip, just beneath the nail bed. The flexor digitorum profundus attaches to the volar aspect of the phalanx and the extensor tendon onto the dorsal base of the 2 mm proximal to the germinal matrix.[10]

Fingertip and Hand Injuries

Epidemiology

Every year, more than a million emergency department visits are due to work-related hand trauma. In 1976, Kiil identified 445 hand and finger amputations of which 90% were finger amputations.[11] Acute hand injuries, including laceration, crush, or fracture, were the leading occupational injuries treated in the emergency room across the United States in 1996. According to the US Department of Labor, these injuries affected 30% of all injured workers. Furthermore, finger injury ranked third after back and leg strains in the number of lost workday cases in the USA in the mid-1990s.[12] Individuals aged 24 years or less had the highest risk of hand injury. Men have been found to have higher rates of severe hand injury than women.[13]

Initial Evaluation

The history of the injury is a crucial element in the decision making process when dealing with finger and hand injuries. The exact time of the injury, mechanism of the injury, as well as the patient’s age, occupation, handedness, smoking history, and general health status are all important aspects of the history. Information regarding the last time the patient consumed any food or liquids will be vital if anesthesia will be required.

The physical examination should be performed using sterile technique when possible. The location, size, and depth of the wound should be measured, and the extent of the skin loss and injury to deep structures should be noted. In order to avoid a missed injury, the tissues should be assessed in an orderly fashion, beginning with the circulation and skin and then proceeding to the bones, tendons, and nerves. The presence of sepsis or any contamination is important to note. Radiographs of the hand are used to evaluate for any fractures, dislocations, or foreign bodies.

Classification

Several classification systems have been described addressing the extent and type of injury. One of the most basic is that of Buchler and Hastings, who divided simple single structure injuries from combined injuries involving more than one important hand structure. These are further subdivided into crush injuries, palmar combined, dorsal combined, and palmar and dorsal combined injuries.[14,15] In an amputation, two main categories exist: complete and incomplete. In an incomplete injury, the distal segment is still connected to the proximal stump. These can be further subdivided into viable and non-viable. In incomplete non-viable amputations, the circulation is inadequate and microvascular reconstruction is necessary.

In avulsion type injuries, there is extensive damage to the nerves and vessels when they are stretched and are found at various distances from the level of the skin avulsion. The presence of a “ribbon sign” suggests a longitudinally transmitted injury to the wall of the vessel, bunching it up like a ribbon. This makes it unsuitable for replantation and carries a poor prognosis[16] (Fig. 2). Urbaniak[17] classifies ring avulsion injuries based on circulation and viability, and Beris[18] modified this based on proximal interphalangeal (PIP) joint involvement.

Clean-cut, or guillotine-type, injuries are sharp injuries to the hand or fingers without damage to the surrounding tissues. The nerves, tendons, and bones are found at the same

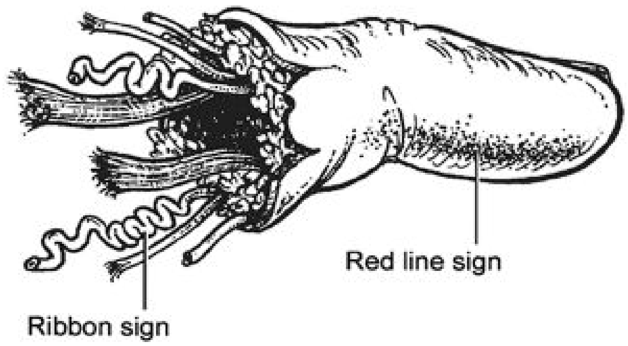

Figure 2 The ribbon sign indicates longitudinally-transmitted injury to the wall of the vessel, rendering it unsuitable for replantation. The corresponding red line sign indicates extravasation of blood from the vessel distally. (Reprinted from: Kaplan FT, Raskin KB. Indications and surgical techniques for digit replantation. Bull Hosp Jt Dis. 2001;60(3-4):179-88. With permission.)

level of injury. With crush mechanisms, the trauma affects tissues beyond the obvious area of insult, resulting in a larger zone of injury and a more difficult entity to manage.

Initial Treatment

In the emergency department, the wound should be irrigated thoroughly with normal saline, and gross debris should be removed. If a tourniquet will be used, it is preferable to elevate the extremity, rather than use an elastic bandage to exsanguinate it, so as to minimize secondary injury. A regional block may be selected for pain control; however, it is important to remember to perform a thorough neurologic exam prior to this. Further detailed inspection is vital when characterizing this injury during the initial washout.

In the case of an amputation, the injured hand should be wrapped in a clean dressing and elevated with direct pressure applied to control bleeding. Direct ligation of bleeding vessels should be avoided acutely as this will cause further damage to the tissue.[19] The amputated part should be wrapped in saline soaked gauze and then placed into a sealed plastic bag containing a second bag filled with ice. This maintains moisture with cooling but without risking freezing and further damage. Finally, antibiotics and tetanus should be administered upon arrival.

General Surgical Considerations

A general algorithm can help guide management of an acute hand or finger injury. It is important to reiterate the vast breadth of management options available for coverage, replantation, and reconstruction. The focus of this discussion will address the most commonly-used methods of treatment for these often devastating injuries. A schematic of treatment options is presented in Figure 3.

The type of injury is one of the most important predictors in determining outcome. For example, complete amputations that are clean-cut are better indications for replantation than extensively crushed or avulsed amputations.[20] On the opposite end of the spectrum, a simple laceration can be treated with primary closure.

Injuries to the finger (depending on its specific characteristics) can be treated with primary closure; skin grafting (if the injury involves only the integument); composite grafting (if the distal segment is well vascularized); completion amputation or resection (if the finger or ray is non-reconstructable or if the patient wishes to avoid further attempts at salvage); flaps for coverage; replantation; and toe transfers. Similar options exist for the thumb.

In the hand, amputations in the mid palm or wrist are indicated for replantation. If the injury is localized to the soft tissues or is non-replantable, several flaps exist for coverage, which will be discussed.

Treatment of Finger Injuries

Primary Closure

Direct closure of a simple laceration or wound can be completed with simple suturing of the skin. If a small dorsal

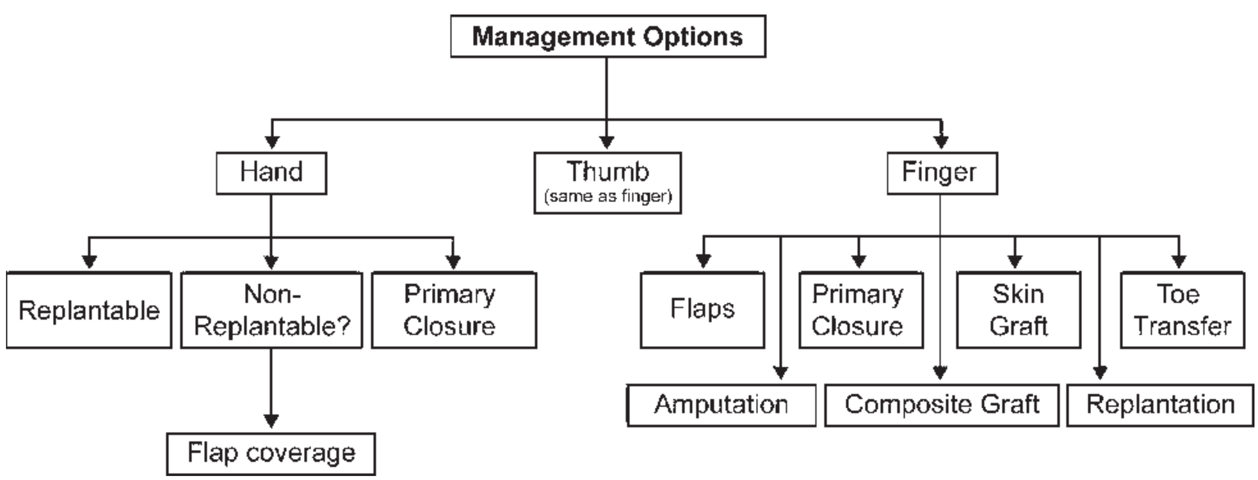

Figure 3 General algorithm illustrating the breadth of management options available for coverage, replantation, and reconstruction.

wound exists, one can convert it to an ellipse and subsequently close it as a transverse line. This is possible due to the mobility of the dorsal skin and can be facilitated with wrist extension.

A Z-plasty can also be utilized to transfer skin over small defects. Often, multiple Z-plasties can be used in succession to cover larger defects or release a long scar. It is important to remember that the ideal angles that the central limb of a Z makes with the other two limbs are between 45° and 60°. A more acute angle than 45° will have compromised vascularity, whereas an angle greater than 60° will not be transposable without tension.[21]

Skin Grafts

Skin grafts can be either split thickness (STSG) or full thickness (FTSG). If there is skin loss without any exposure of deep structures (tendon, nerves, bones or joints), a STSG can be acutely applied if the wound bed is clean. Skin grafts can be harvested from the hypothenar eminence; however, it is important to note that STSG have a higher degree of secondary contracture and should thus be reserved for larger defects.[22] In general, investigators have shown inconsistent outcomes with skin grafts for distal finger injuries, specifically cold intolerance and tenderness.[23] The use of skin grafts over larger superficial wounds more proximally, however, should indeed be considered, especially with FTSG that may provide some return of sensation.

Skin Flaps

When skin grafts do not provide sufficient coverage of a defect, a skin flap may be used. Flaps are named according to location, blood supply, and the technique of transfer. The blood supply will determine whether a flap is random or axial. Random flaps receive their vascularity from the subcutaneous bed without a specific named artery supplying it. An axial flap receives its circulation from a named artery. Axial flaps are then subdivided based on the main type of tissue in the flap, namely cutaneous, fasciocutaneous, and musculocutaneous.

Local flaps consist of advancement, rotation, and transposition types. In an advancement flap, a small flap of skin is mobilized and used to cover an adjacent defect without the use of STSG for the donor defect. These are typically useful in the coverage of fingertip injuries. Rotation flaps are raised using a curved incision and mobilized under tension to cover a defect without a donor defect (Fig. 4). Transposition flaps are often rectangular and are moved around a fixed pedicle base without tension to cover adjacent defects. The donor area is then covered by skin graft. Transpositional flaps are usually moved over normal skin to cover an adjacent area defect. These flaps require the donor site to be skin grafted (Fig. 5).

A basic advancement flap is the V-Y, which utilizes a V shaped incision to create a triangular shaped skin flap that can be advanced distally to cover a defect. The donor defect is then sutured longitudinally along its axis until it meets the base of the flap, and the remaining limbs are sutured. The V-Y advancement is a commonly used technique for dorsal oblique and some transverse fingertip injuries.

Local Flaps

Several other local flaps can be used in the hand and fingers, including cross finger flaps, thenar flaps, and other transpositional flaps such as neurovascular island flaps. The thumb is exceptionally important in hand function. As a result, injuries to it and the adjacent web space are treated using a variety of unique flaps, including local rotation flaps from the dorsum of the hand.

Cross Finger Flap. Cross finger flaps are useful for coverage of defects on the volar aspect of the finger when there

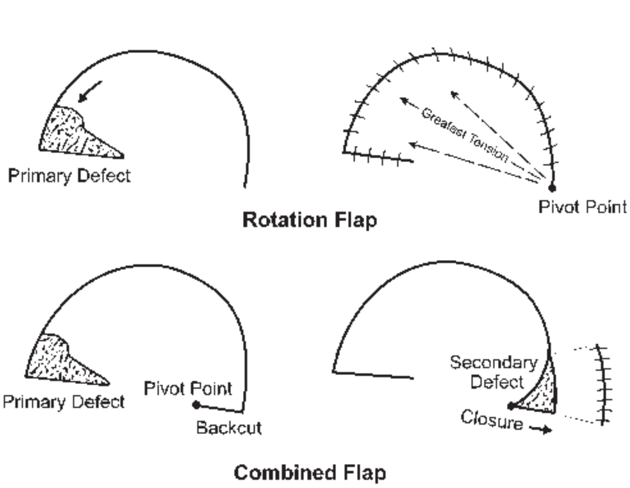

Figure 4 A rotation flap is created using a curved incision and is mobilized under tension to cover a defect without any residual donor defect.

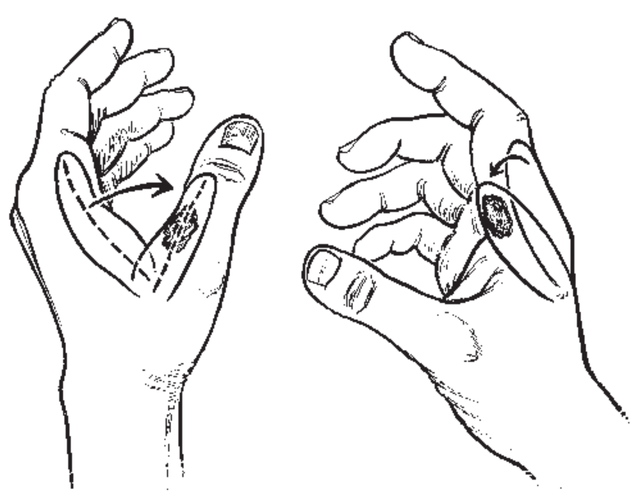

Figure 5 A transposition flap is mobilized to cover adjacent defect flaps, requiring the donor site to be skin grafted.

is exposure of tendon or neurovascular structures. The flap provides a small amount of subcutaneous fat that is necessary for protective coverage. Usually, a laterally based pedicle flap is raised from the adjacent digit and applied to the distal pad of the injured digit. The main complication of this flap is finger stiffness and is thus often avoided in patients who are over 50 years old or who have arthritis of the interphalangeal or metacarpophalangeal joints. The remaining defect that is left on the donor finger is typically covered with a skin graft, resulting in minimal disfigurement (Fig. 6).

Thenar Flap. The thenar flap, originally described by Gatewood[24] and then modified into its present form by Flatt in 1957,[25] is commonly used to address volar oblique injuries of the middle and index finger. A full thickness subcutaneous flap is elevated from the thenar eminence where the recipient digit meets the palm. The flap is raised approximately 1.5 times longer and wider than the defect needing coverage.[21] The fingertip is then flexed to meet the flap and sewn into place and subsequently divided after 2 to 3 weeks. The donor site can then be grafted, closed primarily, or allowed to heal by secondary intention. Proximal interphalangeal joint stiffness is a known complication in patients who have a propensity for joint contracture; however, it is typically well tolerated in patients of all ages.[26]

Neurovascular Island Flap. Neurovascular island flaps are based on named arteries and their associated bundle. They often include the dorsal and volar metacarpal artery as well as digital arteries and have a large amount of versatility in coverage of larger injuries to the digits and hand (Fig. 7). The reverse island flap is based on the same principle; however, the flap is turned so that the direction of arterial blood flow is opposite.

Thumb Coverage Flaps

Injuries to the volar aspect of the thumb are treated using a number of techniques; many of which are possible solely due to its unique anatomy. The Moberg flap[27] is favorable given its ability to preserve length, restore pulp contour and normal sensation, cause low donor site morbidity, and can be done in a single stage.[28] The radial and ulnar incisions are made dorsal to the neurovascular bundles, and the flap is elevated just volar to the flexor sheath and is carried back proximally to the level of the proximal metacarpophalangeal crease. The flap is then advanced distally to cover the defect (Fig. 8). Several modifications exist that allow for more advancement. Volar advancement flaps are effective in the thumb because of the dedicated dorsal blood supply from the princeps pollicis artery. This unique characteristic prevents dorsal skin necrosis. In the other digits, the blood supply to the dorsal surface originates from perforating vessels off the digital arteries and can be compromised.

Pedicled neurovascular island flaps can be used for cover-

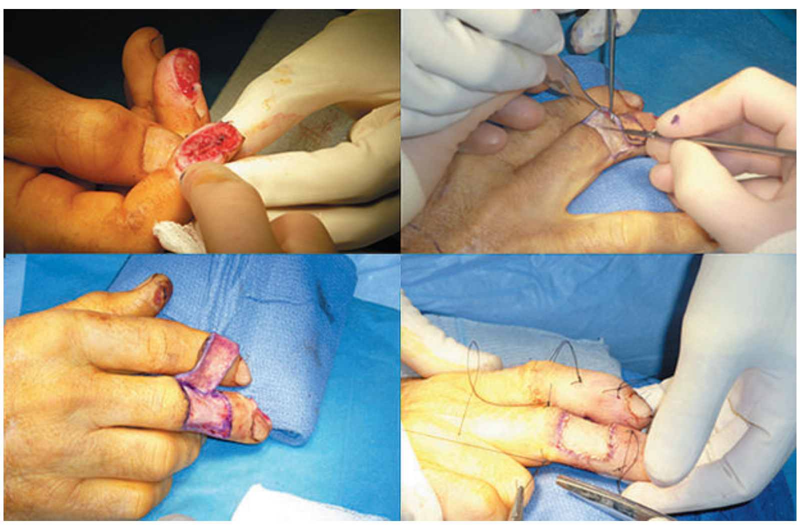

Figure 6 Clinical photo illustrating cross finger flap. (Images courtesy of David E. Ruchelsman, M.D., Boston, MA.)

Figure 7 Clinical photo illustrating a first dorsal metacarpal artery based kite flap used to cover defect of the dorsal aspect of the thumb following a burn injury (preoperative, immediate postoperative, 1 year postoperative).

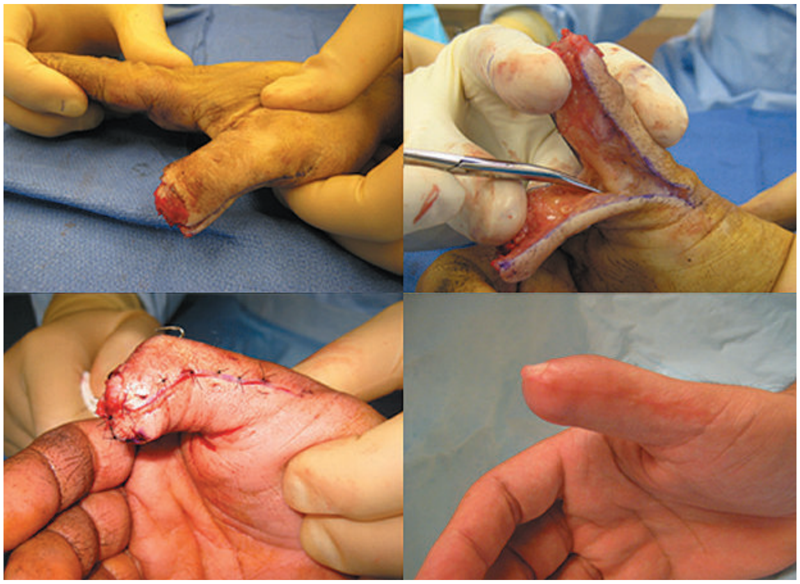

Figure 8 Clinical photo illustrating a Moberg advancement flap (preoperative, intraoperative, immediate postoperative, 1 year postoperative). (Images courtesy of David E. Ruchelsman, M.D., Boston, MA.)

age of larger thumb soft tissue defects. Possible donor sites include the dorsal skin over the proximal phalanx of the index or flaps from the middle and index fingers. The Littler flap involves raising a flap off the ulnar side of the middle finger or radial side of the ring finger, which is based on the ulnar digital neurovascular bundle. This flap is dissected proximally to its common digital origin and transferred to the thumb defect.[29]

The skin over the dorsum of the index finger is supplied by the first dorsal metacarpal artery and can be transferred to the thumb with good sensation when taken with a branch of the superficial radial nerve. This heterodigital flap carries the disadvantage of violating a normal donor digit for the reconstruction of an injured one.

Figure 9 provides an algorithmic approach to help guide decision making in the management of finger injuries based on the geometry of the injury, the location and size, as well as the particular digit. It is vital to remember that these injuries all carry special characteristics that require special consideration. The primary goal of treatment is to safely

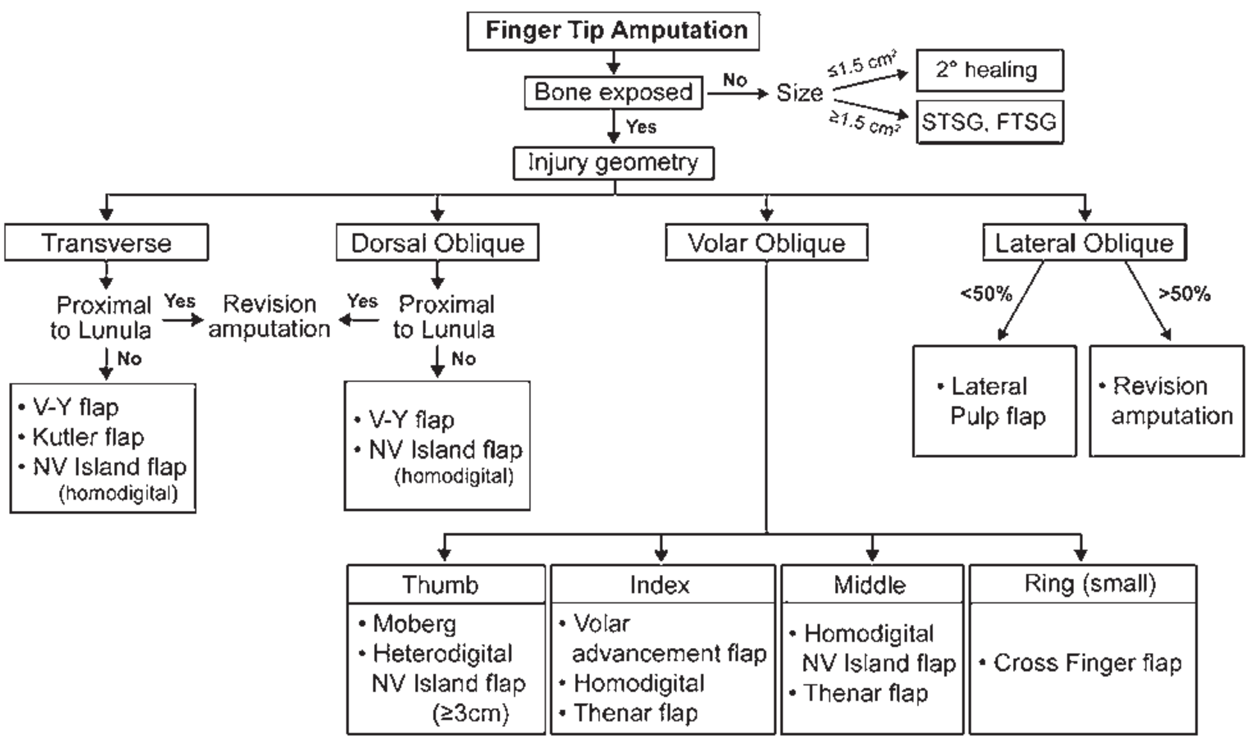

Figure 9 A detailed algorithm to help guide decision making in the management of finger injuries based on digit, the geometry, location, and size.

restore a pain-free and functional digit and hand.

Finger Replantation

There are many factors that play a role in the decision to perform replantation of an amputated digit. These factors are based on the expected overall outcome and chance for finger viability. They include both patient factors and injury pattern factors. Even though a replantation may technically be a success, this does not necessarily correlate with the clinical outcome. The patient's ultimate outcome should be the guiding force in the surgeon's decision-making process.

Indications for replantation include amputation of the thumb, amputation of multiple digits, amputation distal to the insertion of the flexor digitorum superficialis, partial hand amputation (mid-palm), and wrist and forearm amputation. The thumb is very important in overall hand function, as it is essential for the ability to oppose, and every effort should be made to preserve it. The indications for single digit amputation are less clear-cut. In general, replantations of single digits distal to the FDS insertion have favorable outcomes. However, proximal to this level poor function has been reported.[19,30] Replantation is especially important at or proximal to the lunula because it is the only procedure that can salvage the nail.

Pediatric replantation is indicated for any amputated part including single digit, avulsion, and crush injuries. This is due to the increased ability for pediatric patients to heal and recover.

Contraindications can be either absolute or relative and take into account both patient and injury characteristics. For example, absolute contraindications include mangled or severely crushed digits, multiple level amputations, and grossly contaminated parts that are likely to have a poor outcome following replantation.[19] Relative contraindications include patient factors such as advanced age (although there is no accepted limit to age), psychiatric illness, medical illnesses and comorbidities deeming surgery unsafe, self-inflicted amputees, and patients unable to follow post-operative protocols and therapy. Injury characteristics that are relative contraindications include single digit injuries proximal to the FDS insertion, single border digits, and prolonged warm ischemia time. Warm ischemia results in an increase of anaerobic metabolism, causing an increase in cellular metabolites, propagation of the inflammatory response, and ultimately cellular edema.[31]

Salvage of amputated parts can be attempted if the warm ischemia time is less than 6 hours when muscle is present or less than 12 hours when there is no muscle present. Cold ischemia time (ideally at 4° C) allows for 12 hours of ischemia and 24 hours when there is no muscle present such as in the digit.[32]

Technique

The initial preparation of the amputated part allows for identification and mobilization of the neurovascular structures and smaller vessels and subsequent tagging. Bone fixation follows, using a variety of techniques that include K wires, bone screws, or small plates. It is important to achieve rigid bony stability and to take care to ensure correct rotation. The next step involves repair of the extensor and flexor tendons. Arterial repair is achieved using tension free technique or a vein graft if necessary. In the distal phalanx, a search for the artery on the palmar side will likely reveal the terminal branch of the digital artery that runs close to the midline, which is known as the central artery of the pulp.

Digital nerve repair is performed after trimming back to healthy fascicles using an epineurial, tension-free repair. If direct repair is not possible, a nerve graft can be used (another digital nerve that is not replanted, sural nerve, lateral antebrachial cutaneous). Another option is delayed nerve grafting after replantation and healing. Venous anastomosis is performed following arterial anastomosis in a minimum of one vein for each artery ratio (ideally 2 to 1).[19] Because the walls of the veins are thin and easily collapsible, continuous drip with heparinized saline is used for visualization and to prevent thrombus formation. The wounds are closed loosely, and incisions are made accordingly in the fingertip if there appears to be evidence of congestion.

Postoperative Care

A non-compressive dressing is applied with the fingertips exposed for monitoring. The extremity should be strictly elevated, and watched closely (hourly for the first 24 hours, bi-hourly until 48 hours) in a warm room kept between 75° and 80° F to minimize to minimize the risk for cold induced vasospasm. 5,000 to 10,000 U of heparin and 500 mL of low molecular weight dextran are given intravenously for 3 to 5 days continuously following surgery to prevent clot formation. The patient should avoid any caffeine, chocolate, and nicotine due to their vasoconstrictive properties.

Outcomes and Complications

The overall outcome of replantation surgery most importantly depends on the restoration of function. The survival rates range in the literature but overall are relatively high, approaching 90% in most studies.[4,30,33,34] The functional results are most dependent on the level of injury, with significantly increased stiffness following replantation of fingers amputated proximal to the FDS insertion compared to those distal to it (Zone 2 injury).[30] Waikakul and colleagues[4] prospectively surveyed survival and correlated it with the type of injury, with sharp lacerations having higher survival rates, while regular use of cigarettes and prolonged ischemia time worsened chances for viability. In agreement with Urbaniak's findings, injury at Zone 2 resulted in poor range of motion. Other factors negatively correlated to patient outcome include an increasing age of the patient, an increasing number of vessels anastomosed, and less years of surgeon experience.[30] It will be emphasized again that the ultimate success of replantation surgery is based on the overall satisfaction of the patient, and that a viable but stiff, painful, and unusable digit or extremity is essentially a failure.

Early complications include infection and vascular (both venous and arterial) occlusion in the postoperative period. Late complications include decreased joint motion, tendon adhesion, tendon rupture, bony malunion or nonunion, and cold intolerance.

Infection can be minimized by performing a thorough initial surgical debridement and through the appropriate use of antibiotics. Venous congestion can be treated with elevation, dressing release, external bleeding through nail plate removal, or with the use of leeches or heparin soaked pledgets. Arterial thrombosis or spasm should be treated with warming, pain control, sympathetic blockade, or surgical exploration and repair of anastomoses (if they are found to be disrupted).

Decreased joint motion can be secondary to joint contracture and tendon adhesion. If passive range of motion is maintained with loss of active motion, this is indicative of tendinous adhesions, which can be treated with tenolysis. If both are lost, capsular releases may be indicated. Tendon ruptures occur most commonly due to tension placed on repairs in the postoperative period and are often missed due to the prolonged immobilization that occurs after replantation. Ruptures can be repaired in a delayed fashion, so as not to disturb healing and compromise the vascularity of the replanted part. Bony malunions are typically rotational and can be fixed with corrective derotational osteotomies. Nonunions are treated with bone grafting and revision fixation. Cold intolerance following replantation has been reported to be as high as 80% to 100%.[35,36] This phenomenon is thought to result from vasospasm caused by the cold, which decreases perfusion and eventually becomes painful. It has been shown by Glickman and associates that symptoms improve and can approach normal as the digital nerve recovers pain and touch sensibility (two point discrimination < 15 mm).[36]

Treatment of Hand Injuries

Complex hand injuries pose a unique problem to the surgeon. Structural osseotendinous reconstruction of the intricate anatomy of this part of the body also requires an adequate soft tissue envelope to effectively and functionally cover it. Due to the potential size of the defect following trauma, a new set of tools may be necessary in addition to local flaps, including regional, distant, and even free flaps. Skin grafts have a high contracture potential with limited sensibility.[37] In the past, the use of free flaps was often considered a last resort effort for coverage. However, more recent literature, such as Godina's series, shows that early microsurgical reconstruction with a free flap (within 72 hours) following debridement can lower morbidity, infection, and reoperation rate.[38]

Local flaps are useful in coverage of focal defects involving the digits. However, in severe hand injuries with involvement of several regions, availability of local flaps is limited due to potential damage to the donor site areas. The two most well-known pedicled regional flaps in the upper extremity are the radial forearm flap and the posterior interosseous flap. These are useful for covering defects in the hand due to their consistent arterial blood supply. The radial forearm flap can only be used if both the radial and ulnar arteries are patent; a preoperative Allen's test or arteriography should, therefore, be performed. Many surgeons avoid using this flap because it sacrifices the radial artery and leaves a large donor defect. The posterior interosseous flap is a fasciocutaneous flap based over the dorsal aspect of the forearm between the radius and ulna. It is supplied by the posterior interosseous artery, which is a branch of the common interosseous artery or by the ulnar artery directly. This flap can cover defects of the elbow, wrist, forearm, and hand.[39]

One of the most important distant flaps utilized is the groin flap. It is typically an ipsilateral pedicled flap and is divided at 3 weeks. It can also be used as a free flap. The groin flap can be used to cover defects in the hand and distal forearm and has minimal donor site morbidity as it can be closed primarily and the scar easily hidden.

For very severe injuries involving the upper extremity, microvascular free flaps may be used. These are very versatile and can cover defects of different sizes and character. They arise from distant donor sites and bring their own blood supply and lymphogenic potential, thus improving the drainage of traumatized areas. They can be performed in a single stage, which is a potential advantage of this flap. Described examples of free flaps used in the upper extremity include scapular, parascapular, latissimus dorsi, lateral arm, and radial forearm flaps.[39]

Hand Replantation

The goals of hand replantation are similar to those discussed for the digits while the risks and complications are also shared. The level of injury, ischemia time, history of diabetes, age, sex, and smoking history have been implicated as confounding factors.[40] However, there is conflicting evidence in the literature as to whether the effect of some of these factors is significant in survival and functional outcome.[4,20,41,42] Replantation at or proximal to the wrist continues to remain a challenge with additional difficulties than those presented with digital replantation. Several reports have shown favorable outcomes following hand replantation, including those of Hoang, in which five consecutive hand replants in young men with clean-cut injuries at the radiocarpal level resulted in 70 to 80% of total active motion in the digits and thumb and 8 mm to 12 mm of static two-point discrimination.[43,44] The best outcomes are seen in children, who have been found to recover as much as 90% of total active motion and 5 to 7 mm of static two-point discrimination.[45]

Prosthetics

Amputation of a digit or hand can lead to significant functional, social, and psychological problems. Many prostheses exist which range from simple finger caps for aesthetic purposes to osseo-integrated and myoelectric prostheses that can also serve functional benefits.[46] There is much in the literature addressing different types of prostheses (which is outside the scope of this discussion). However, it is important to be aware of their existence and potential use in appropriate patients. Osseo-integrated prostheses are implanted with a two-stage reconstruction procedure using titanium fixtures that firmly integrate in the bone, onto which the prosthesis is later attached. This addresses the serious problem of prosthetic instability seen in other designs.[47] Long-term outcomes of osseo-integrated digital prostheses for proximal amputations show that it is a stable, long-term reconstructive option[48,49] with patient satisfaction both cosmetically and functionally. It also results in osseoperception in most patients. This is believed to occur based on the transfer of tactile stimuli to endosteal nerves via the titanium fixture.[50]

Toe Transfers

In the patient with a non-reconstructable or non-replantable finger or thumb amputation, toe transplantation can be a potential valuable option for restoring form and function. As stressed by Wallace and Wei,[51] the preservation of viable tissue is key during the initial management of these injuries to allow for maximal coverage and enhance the function of the transplanted toe and minimize the need for grafts. Depending on the level of injury, options include pulp and hemipulp transfers, onycho-cutaneous transfers, vascularized nail and wraparound flaps, as well as total toe transplants. Though the details of these are beyond the scope of this discussion, it is important to be aware of them and their potential uses. They become even more important in the management of multiple finger amputations, especially in reconstructing the thumb, where an amputation causes a 40% to 50% loss of global hand function.[52]

Future Directions

There have been several attempts to develop multifunctional prostheses that are controlled by electromyographic signals (myoelectric hand), harnesses (kinematic hand), and dimensional changes in the remaining muscles, but these devices have not attained control of more than two degrees of freedom.[53] However, promising approaches aimed at establishing a direct connection with the nervous system through invasive and non-invasive neural interfaces are under investigation. If the phenomenon of neuroplasticity following an amputation can be harbored and forced to create new natural interfaces restoring neural connections that once controlled the lost limb to the new cybernetic prosthetic system, then bidirectional information could be transferred allowing for more physiological performance.[54]

The use of tissue engineering to create anatomic and physiologic replicates to restore tissue loss is also under investigation. Constructions made of the patients own cells would negate the need for anti-rejection therapy routinely necessary for composite tissue allografts. This research is underway and has been prominent in addressing reconstruction of the hand and recently the face.[55]

Conclusions

The management of acute traumatic injuries of the hand and digits is complex and requires several elements that are necessary for a successful outcome. These include but are not limited to injury characterization, initial management, patient selection, surgical decision making and expertise, postoperative protocol, and patient cooperation. Each patient must be managed according to the overall evaluation and consideration of these factors. Most importantly, as stated by Ch'en Chun-Wei, "survival without restoration of function is not success."[56]

Disclosure Statement

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