Secondary Interventions for Mutilating Hand Injuries

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INTRODUCTION
Successful restoration of good hand function at the primary admission for a mutilating hand injury is uncommon. In most cases, primary treatment aims to salvage available functional units with staged reconstruction in mind.1–3 The indications for secondary interventions (Table 1) may be broadly divided into obligatory and discretionary procedures. Obligatory procedures are required to complete staged reconstructions and address complications. These interventions are time-sensitive and are undertaken based on timeline of tissue healing. Discretionary procedures, however, are undertaken to improve function and/or enhance appearance of the reconstructed hand. Outcomes of these procedures depend largely on patient expectation and motivation. It is therefore important to psychologically and physiologically optimize patients before considering discretionary procedures.

OBLIGATORY SURGICAL PROCEDURES
Completion of Staged Primary Procedures
Primary reconstruction in mutilating injuries is aimed at providing expedient skeletal stabilization, microvascular anastomosis, repositioning of functional units, and soft tissue cover of critical defects. In most situations, this entails use of external fixators, interosseous wiring, and flap coverage. As patients recover, some of the provisional measures can be modified for comfort and mobility.

Soft tissue procedures
Large soft tissue defects are usually covered with a combination of flap and skin graft. Critical defects exposing neurovascular structures, webspaces, and joints are best covered with flap, whereas other areas may be covered with skin graft (Fig. 1). Tissue quality of noncritical regions may be improved with the use of negative pressure wound therapy and

KEYWORDS
- Mutilating hand injuries
- Mangled hand
- Hand reconstruction
- Secondary reconstruction

KEY POINTS
- Secondary procedures are frequently required to improve function of reconstructed mutilated hands.
- They should be tailored to patients’ unique vocational, functional, and recreational requirements.
- Secondary procedures may be broadly divided into obligatory procedures and discretionary procedures.
- Obligatory procedures refer to interventions done to complete staged reconstructions or address complications arising from primary procedures.
- Discretionary procedures refer to interventions done to improve function or appearance of the hand. They should only be undertaken when the patient has been psychologically and physiologically optimized.
### Table 1
Indications for secondary reconstruction in mutilated hands

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Fig. 1. Defect initially covered with skin graft can be excised and resurfaced with groin flap in preparation for second stage procedure. (Courtesy of Dr A. Lahiri, MD, Department of Hand & Reconstructive Microsurgery, National University Health System, Singapore.)
Bone and joint procedures

Initial skeletal stabilization with external fixator or interosseous wiring may be performed because of limited soft tissue cover or uncertain viability of amputated parts. As patients’ physiology and local soft tissue condition stabilize, hardware internalization is advantageous to facilitate rehabilitation. Fractures through phalanges and metacarpals are often adequately stabilized with wires and usually do not require internal fixation. However, injuries through the carpus or the distal radius and ulna benefit from conversion from spanning fixators to internal fixation with plates and screws. This may be performed in tandem with skin grafting or flap cover, planned with future procedures in mind, such as bone or tendon reconstruction.

Bone loss is common in severe crush injuries and defects that are not suitable for shortening or primary bone grafting may be filled with bone cement and stabilized with an external fixator. In sufficiently vascularized wounds, a pseudomembrane forms around the cement spacer, providing a favorable condition for secondary bone grafting with cancellous chips. The formation of the pseudomembrane takes approximately 6 weeks at which point the second stage can be done. This involves elevation of tissue flaps, cement spacer extrication, packing of cancellous chips into the defect without disrupting the pseudo-membrane, and internal fixation. The elevation of fasciocutaneous flaps is easier compared with muscle flaps and this may be a consideration in choice of flap coverage. The volume of bone graft required determines the donor site. Arbitrarily, the distal radius of a young adult reliably provides up to 2 mL (measured on a 5-mL syringe) of cancellous chips, whereas the iliac crest is more reliable for larger volumes (more than 2 mL) and older adults.

Complications Resulting from Primary Reconstruction

The main physiologic changes at the zone of injury are heightened inflammatory response and tissue hypoxia. Heightened inflammatory responses predispose adhesion formation and scar contraction, leading to pain, stiffness, and deformity. Retained microscopic foreign body or foci of nonviable tissue can act as a nidus for infection. Despite successful microvascular salvage, blood supply to tissues, such as bone, periosteum, and tendon, can be tenuous, leaving these tissues at risk of nonunion or rupture of repair. These complications are broadly divided into soft tissue and bone related groups.

Soft tissue complications

These complications include infection, adhesions, scar contracture, and neuropathic pain.

Infection

Soft tissue infections range from localized focal abscesses to widespread disseminated infection and these are strong indications for surgical intervention. Infection can arise from retained engineered dermal matrices before skin grafting. Granulation tissue formed with negative pressure wound therapy improves contour for skin graft adhesion, whereas engineered matrices allow formation of neodermis that lessens secondary skin graft contracture. Infrequently, skin grafting is required to resurface the residual defects following debridement of compromised flaps.

Pedicled groin or abdominal flaps are reliable options that can provide coverage for large defects. They have the added advantage of preserving vessels in the limb for future microvascular reconstruction. Between 2 and 3 weeks, a delay process is initiated in preparation for flap division by application of mechanical devices, such as bowel clamps and ligatures, or strategic delay by surgical incisions. After division, the edges of the flaps are trimmed and contoured to blend into the overall appearance of the hand.

Multiple tendon loss and unsuitable wound bed are indications for two-stage tendon reconstruction with silastic rods and coverage with fasciocutaneous flap to facilitate interval access for tendon grafting. During this time, passive mobilization is essential to prevent stiffness of the affects joints and prevent edema.

Nerves are invariably injured and there may be multiple nerve involvement with nerve gaps following debridement. Primary nerve repair may not be carried out because of unfavorable wound conditions, or questionable survival of target muscles. If secondary nerve grafting is planned, nerve ends can be tagged with 5/0 polypropylene sutures and placed subcutaneously to facilitate retrieval at the next procedure. Sensory nerve repair or grafting offers reasonable chance of restoring sensation of the injured digits, whereas motor nerve repair should be performed after assessing the muscles. Traumatized intrinsic muscles rarely regain meaningful function. Nerve grafts, particularly autologous, are therefore best reserved for sensory reconstruction. Motor nerve repair for intrinsic muscles of the hand is unpredictable, particularly when intrinsic muscles are injured; therefore early tendon transfers or finger joint fusions may be considered for reconstructing intrinsic hand function.
foreign material, nonviable tissue, and colonization at the primary treatment. Radiolucent contaminants and toxic chemical compounds (acid, alkali, alcohol, flame retardant, and so forth) are difficult to identify and may result in delayed tissue necrosis. Introduction of sutures and implants may further contribute to tissue trauma and escalate the risk of infection in severely traumatized wounds.

The principle of managing infection is to distinguish between deep infections arising from devitalized tissue, sequestrum, and foreign material from those arising from surface colonization. The former may manifest with discharging sinuses, and tenderness with or without surface cellulitis. Diagnosis is mainly clinical. Adjuncts, such as differential blood counts, inflammatory markers, and imaging, may be helpful. From the surgical perspective, a tumorlike approach to debridement must be undertaken with caution and attention to potentially distorted positions of neurovascular structures and flap pedicles. These structures are difficult to identify in the field of injury. Therefore, extensile incisions are recommended to facilitate identification in normal anatomy before proceeding into the zone of trauma.

**Scar contracture**

Scar contraction is mediated by myofibroblasts during the remodeling phase of tissue healing and its primary effects are reduction in mobility of mobile tissues (skin, tendon, nerve, and joints). Once primary wound healing takes place, edemalinites and silicone sheets should be judiciously applied to maintain skin hydration and suppleness, in tandem with pressure garments and splints. Dry skin causes itch, which lends itself to excoriation and fissuring that eventually limits mobility and leads to noncompliance to splinting.

Edema needs to be treated early. Left unchecked, edema fluid that is mobile and reducible in its early state develops a brawny consistency that does not reduce with compression. Skin changes in the latter state are usually permanent with little chance of reversal. Hence, edema management and compression garment must be instituted as soon as possible to avert this unfavorable state.

Linear scars across joints and webspaces limit joint mobility and web span. Scars that fail to soften with conservative measures are considered for Z-plasty lengthening and use of dermal substitutes or full-thickness skin graft. Split-thickness skin grafts are best avoided for palmar and webspaces regions because of its propensity for secondary contracture. Scars in the palm may contract centripetally, drawing radial and ulnar digits toward each other, limiting grasp span and digitopalmar grip. Scar excision followed by fasciocutaneous flap interposition may be required to prevent future contracture and improve hand function.

**Neuropathic pain and neuroma**

The sequelae of neurapraxic and axonometric injuries are epineurial scarring and formation of neuroma in continuity. Resultant motor and/or sensory deficits may improve spontaneously or require surgical intervention. Serial examinations over 3 to 6 months with monofilament sensory mapping and Tinel percussion test provides a general idea of nerve recovery and useful milestones for surgical intervention. Lack of improvement after an observation period of 6 months is an arbitrary time-frame for intervention for pain or paresthesia relief. The role of motor reconstruction in the mutilated hand is limited by the lack of functional muscle units. At 6 months, tissues in the zone of injury should have equilibrated and surgical intervention is manageable.

In most cases, nerves with diameter of less than 2 mm are difficult to identify in a traumatized field and microscope magnification is recommended. The surgeon should identify three key features during nerve exploration: (1) surrounding scar tissue, (2) epineurium, and (3) overall nerve morphology. Scar release without neurolysis would suffice if the epineurium of the nerve exhibits minimal or focal thickening corresponding to scar bands, whereas neurolysis is indicated if there were segmental thickening and narrowing of the nerve. Segmental narrowing and hourglass-shaped nerves may indicate presence of lesion in continuity and neurolysis allows internal examination of the nerve for intact fascicles. Stretched-out fascicles without clearly identifiable neural elements are excised and replaced with autografts or allografts, with or without conduit. The outcome of neurolysis and nerve grafting is fairly variable, and it is best to manage patients’ expectations from the outset. One hopes for the best while expecting the worst.

Neuromas may develop from transected nerve ends, causing exquisite contact pain and tenderness that severely limits activities of daily living. Nerve repair or grafting may be considered if distal end of the nerve is identifiable, whereas end neuromas without distal stump may be buried within muscle or bone to avoid further symptomatic nerve sprouts. Another possibility is to perform centrocentral union type coaptation between cut ends of nerves or looping it onto itself to mitigate the risk of neuroma formation. A multitude of...
technique has been reported with satisfactory but unpredictable outcomes.26

**Bone and joint complications**
These complications include osteomyelitis, joint stiffness, malunion, and nonunion.

**Osteomyelitis**
The high-energy trauma causes impaction of foreign material, such as gravel or soil particles, deep into the medullary canal that evades detection. Periosteal stripping and physical insult of hardware insertion during fracture fixation further embarrasses blood supply to bone and periosteum, setting the stage for osteonecrosis and osteomyelitis. Acute osteomyelitis may present with pain and swelling and is best treated expeditiously with excision of sequestrum, drainage of pus, coverage with vascular tissue, and parenteral antibiotics.29,30 Hardware removal is indicated only if the screw holes are involved, rather than routinely, to avert the situation of concurrent instability and infection. Conversion to external fixator is often not practical and thermal damage from insertion of fixator pins can be considerable, given the size and scale of hand bones. Principles that apply to a tibia do not necessarily hold true for non-weight-bearing metacarpals and phalanges. In the presence of extensive bone involvement, salvage procedures and amputation should be discussed. Successful bone salvage does not always imply good functional outcome and ray amputation may return patients to function earlier (Fig. 2).

Inadequately treated osteomyelitis may lead to chronic infection that is difficult to eradicate.31–33 Methicillin-resistant *Staphylococcus aureus* infection can assume latent stages with infrequent

![Fig. 2. Severely comminuted metacarpal neck reconstructed with cortical struts and cancellous chips collapsed caused by local infection, osteonecrosis, and graft resorption. Although successfully salvaged, there was little motion of the small finger.](image-url)
exacerbation despite aggressive treatment. Biofilm formation and bony lacunae provide sanctuary sites for microbial colonization, necessitating radical bone excision to achieve complete eradication. However, the impact of radical surgery needs to be weighed against manifestations of chronic osteomyelitis before embarking on the arduous reconstructive journey that could last for months.

**Joint stiffness**
Edema, pain, and inadequate therapy lead to poor hand position and joint stiffness. Interphalangeal joints (IPJ) followed by metacarpophalangeal joints (MPJ) are the most vulnerable. Both joints rely on intrinsic muscles for its mobility and the constrained ginglymoid architecture of the former compounds the problem of stiffness. Analgesics, anti-inflammatory medications, and passive stretching with therapy modalities (massage, heat, ultrasound, and so forth) should be maximized before surgical intervention. MPJ and IPJ releases are indicated in the presence of functioning intrinsic muscles and should be undertaken with caution if the interossei are damaged. The long-term results of IPJ release are unpredictable, whereas MPJ release offers better outcomes. An intrinsic minus hand with stiff joints poorly responsive to therapy should be evaluated for the possibility of improving position with IPJ fusions, given the poor results of contracture release.

**Malunion**
The severity of tissue distortion and loss in these injuries may complicate judgment and assessment during the initial treatment. Digit position or length following heterotopic replantation or pollicization may not satisfy patients’ activity requirements and surgery may be indicated to improve hand function. Thumb ray lengthening is helpful to increase grasp span and reach of opposition to the ulnar digit. In its anatomic positions, the thumb opposes the small finger at a tangent, in a pincer manner. Although this is sufficient for manipulation of medium to large objects, patients wishing to manipulate fine objects with these digits may be offered rotation osteotomy of the small finger metacarpal to alter the direction of pulp-to-pulp contact between the thumb and little finger (Fig. 3).

**Nonunion**
Fracture nonunion may be atrophic because of wound bed hypovascularity, whereas inadequately stabilized fractures are inclined to hypertrophic nonunion. Atrophic nonunion is treated by biologic augmentation with vascularized bone graft or flap transfer is indicated to improve vascularity of the fracture site, in addition to stable osteosynthesis. Regional carpal-arch-based vascularized bone grafts are often not available because of vessel damage, hence free osteocutaneous or osteomyocutaneous flap options from medial femoral condyle, fibula, iliac crest, and so forth may be considered. Hypertrophic nonunion

Fig. 3. In its anatomic position, the small finger and thumb oppose diagonally. A shortened thumb may be considered for lengthening or toe transfer to improve pincer grip mechanism. A rotation osteotomy of the fifth metacarpus is an alternative consideration to improve precision of the pinch.
is caused by inadequate stability for mineralization of fracture callous and the principles of treatment are excision of fibrous callous to obtain bone contact between fracture ends. Plates and screws are more rigid as compared with wires or external fixators and whenever possible the former is the construct of choice in treatment of nonunion. Autologous cancellous bone chips may be used to bridge small gaps following revision fixation.

**DISCRETIONARY SURGICAL PROCEDURES**

These procedures are undertaken to augment function or improve appearance of the reconstructed hand. These procedures are patient dependent and not time dependent. The most important aspect of discretionary procedures is to determine patient suitability for these procedures. The patient must be psychologically and physiologically optimized for the procedure and local tissue condition should have equilibrated before embarking on discretionary surgical procedures.

**Psychological Assessment**

Physical and psychological pain often coexist and it is vital to distinguish one from the other. Psychological optimization is as important as surgical intervention to relieve pain. Patient assessment following primary reconstruction begins with psychological profiling to determine social and vocational coping mechanisms. Characteristics of a well-adjusted patient include good self-grooming and hygiene, awareness and acceptance of physical limitation with lifestyle and workplace activity modification and neutral to positive outlook on life after injury. Red flags of poor adjustment include neglect of injured hand and personal grooming, reference to the injured hand as third party, overwhelming focus on the injury, anger with circumstances leading to injury, and negative outlook on life with signs suggestive of potential for self-harm or suicide. The most common cause is workplace trauma and it afflicts blue collar workers with limited financial means. Hence, financial concerns for self and their families weigh heavily in decision making. Psychiatric assessment and/or social worker involvement early in the recovery period is helpful to aid psychosocial adaptation and reintegration into society. Secondary surgical intervention in the latter group is fraught with difficulties that may be beyond the surgeon’s control, and should be undertaken with caution. A strong indication for intervention is infection that threatens the hand or life. Discretionary procedures for functional refinement are contraindicated for patients still undergoing psychological adjustment.

The mainstay of secondary interventions for psychologically adjusting patients is medications, physical therapy, and psychotherapy. Severe physical trauma and its treatment leave massive psychological footprints. Pain is a major issue and it originates from inflammation and tissue healing, nerve injury, and cortical psychic pain. A cocktail of analgesics, anti-inflammatory drugs (nonsteroidal anti-inflammatory, cyclooxygenase-2), neuroleptics, antidepressants, and anticonvulsants, with or without psychological counseling, is often required. Early review by pain specialists is helpful, and if signs of depression or posttraumatic stress disorder are present, psychiatry review is helpful. Apart from pain, enquiry about patients’ sleep pattern and observation for signs of insomnia or hypersomnolence, blood shot eyes, or poor attention span may elucidate unresolved issues. A short course (5–10 days) of benzodiazepine to facilitate sleep could completely transform a patient for the following review.

Psychological recovery is uncertain and often confounded by other circumstances, such as limited social support, financial means, and communication barrier with health care providers caused by cultural differences. Hence, the objectives of nonsurgical secondary treatment are psychological and social support, expedited rehabilitation, and payout of workers’ injury compensation. Interpreters are an invaluable resource in establishing rapport with patients of diverse cultural backgrounds to foster understanding of their motivations and challenges and setting rehabilitation goals. An additional consideration is the vulnerability of these patients to opportunistic lawyers, legal representatives and interest group lobbyists that often delay the final assessment for settlement of injury compensation. Licensed migrant workers are often subjected to employment permit conditions and face repatriation if their injury disability exceeds a predetermined percentage.

**Functional Assessment**

Physical assessment of psychologically adjusted patients begins with morphologic assessment of the reconstructed extremity. It is imperative to establish patients’ understanding of the “ideal beautiful normal” and their appreciation of the baseline function. Function does not always follow form and vice versa in hand reconstruction. An unsightly hand with a bulky flap and functional thumb may work better than an “acceptable hand” with a thumb and three digits. The next factor to consider in designing intervention is the
availability of functioning intrinsic muscle units. Hands devoid of intrinsic musculature are characterized by intrinsic minus posture with stiff joints and function primarily as the assist hand. Finger reanimation is unrealistic and the priority is therefore aimed at wrist joint mobility or stability, improving sensation of the hand, pain alleviation, and correction of gross deformities.

The final consideration before surgical intervention is pain and tissue equilibrium state. Pain management is important to facilitate therapy and the approach is similar to the previously discussed method. Tissue healing transits from inflammatory to remodeling in the weeks and months following trauma, achieving an equilibrated state where signs of inflammation, such as tenderness, edema and erythema resolve. Salmon pink or purplish, raised, painful scars indicate ongoing inflammatory and remodeling processes. Tissues in this state are unsuitable for elective intervention because of the risk of inducing further inflammation and dissection through friable tissue in transition state is difficult. This phase is reported to last between 3 and 6 months and only time-sensitive obligatory procedures are considered. Reconstruction to augment function is best undertaken after tissue equilibrium is achieved. Interim measures that may expedite the transition include edema control by compressive garments, splinting, active-passive mobilization, and topical/systemic anti-inflammatory medications.

**Discretionary Procedures to Augment Function**

**Tendon transfers**
The permutation and choice of tendon transfer is determined by the extent of injury and the resultant deficits. Tendon transfer and grafting may be part of a primary procedure or indicated later to strengthen remaining musculotendinous units that are weak. Opponensplasty-type transfers may be performed to strengthen the thumb ray grasp, whereas multislip flexor sublimis transfer can partially restore function of damaged intrinsic muscles. Further refinements include calibration of grasp by side-to-side tenodesis of flexor profundus slips or functional gracilis transfer in situations where the extrinsic muscles are severely damaged.

**Toe transfers**
Toe transfer is an integral part of functional refinement of the mutilated hand. Primary indications for toe transfer are thumb loss and reconstruction of an ulnar post for pincer grip. The thumb ray is offset from the hand, providing exceptional mobility and versatility, accounting for nearly 50% of total function of the hand. Hentz proposed a practical classification that guides treatment of thumb ray loss. Moderate functional impairment is expected with injuries around the IPJ of the thumb and can be improved with thumb lengthening, or partial toe transfers. The toe transfer is indicated for thumb loss between the MPJ and the carpometacarpal joint and pollicization considered when the thumb loss includes the carpometacarpal joint. The next priority following reconstruction of the thumb post is to reconstitute an opposition post for pinch and grip. A toe positioned along the fourth or fifth rays provides wide hand span at the cost of precision and strength. A wide hand span is advantageous to patients whose primary activity with the injured hand is handling medium to large objects. Toes positioned at the second or third rays provide strength and precision while forgoing hand span (Fig. 4). Double toe transfers to the intermediate rays provide strong and precise chuck pinch suitable for activities that demand these grip attributes.

Although it is possible to reconstruct all five digits with toe transfers, this approach is not often undertaken because the additional functional gain probably does not outweigh the morbidity of doing so. A special consideration for hands amputated at the level of the wrist is the Vilkki procedure, where a toe is transferred to the distal forearm for pinch reconstruction in patients with amputated stumps.

**Amputation**
Another area of functional improvement is the assessment of the function of reconstructed digits. Stiff, nonfunctional fingers may impede the contact between the thumb and the ulnar digits. In select cases, shortening of the afflicted segments of the digit may be discussed. Ray amputation is not favored because this narrows the span of the hand, thereby limiting their repertoire of possible activities.

**Hand transplant**
Hand transplant represents the frontier of composite tissue allotransplantation, and should be kept in mind as an option in patients with mangled stumps without suitable tissue for toe transfers, or patients seeking functional improvement without resorting to toe transfer. The ethical barrier to hand transplantation is the feasibility of lifelong immunosuppression for a functional rather than life-saving procedure and the yet unresolved risks of immunosuppression.
Discretionary Procedures to Improve Appearance

**Flap debulking**
A slightly oversized flap may be designed to provide soft tissue cover or prepare the traumatized region in anticipation of toe transfer or osteoplastic thumb reconstruction. In some instances, the bulk of the flap may obstruct digit opposition and movement, requiring debulking or partial excision to improve function and appearance. This is achieved by liposuction techniques or partial excision to achieve desired shape and thickness. Thick fat pads of fasciocutaneous flaps impede fine object manipulation and are improved by thinning and tightening the flap (Fig. 5).

**Scar/skin graft revision and tissue expansion**
Skin grafted areas often become hyperpigmented especially in nonwhite populations. In addition, these areas are often depressed in comparison with the surrounding skin because of a lack of dermal support and subcutaneous fat. A serial excision of the skin grafted areas can lead to a significant improvement of the appearance. Similarly, wide depressed scars are improved by de-epithelizing the scar and suturing the adjoining skin flaps over the de-epithelized scar using subcuticular nonabsorbable sutures. This addresses the depressed scar and helps in keeping the scar narrow. The technique of subcision can be considered in narrow depressed scars. Other options include the use of dermal fillers and fat grafts. Finally, the use of tissue expanders may be considered. It is infrequently used in the upper limb because of anatomic constraints, but may be considered if there were available adjacent expandable skin.49,50

**Prosthesis**
Short digits with inadequate reach may be considered for prosthesis. The overall aesthetic is greatly improved with prosthesis. Commercially available prosthesis offers highly realistic skin tones and subtle docking interfaces (Fig. 6). Although short-term patient acceptance is excellent, patients may be discouraged in the longer term because of inconvenience and costs of replacement. Osseointegrated implants show promising results to improve aesthetics and function.51,52 The advantage of stability from bone docking is weighed against the challenge of obtaining a long-term seal at the soft tissue–implant interface (Fig. 7).
Fig. 5. Bulbous flap interposed between thumb, index, and middle fingers partially excised and trimmed to deepen second web space and thenar crease to improve dexterity of radial digits.

Fig. 6. Severe distortion of hand structures by grenade explosion required pollicization and skin grafting. Secondary procedures were performed to contour and span for prosthesis fit. (Courtesy of Mark Puhaindran, MD, Singapore.)
SUMMARY

Secondary intervention for mutilated hand is a complex undertaking, with varied goals and individual specific outcomes. Surgeons’ and patients’ ability to continuously improvise and adapt the remaining functional units of the hand to the travails of life is paramount to achieving long-term satisfaction from reconstruction of the mutilated hand.

REFERENCES


