Management of the Mangled Hand and Forearm

Amit Gupta, MD, and Thomas W. Wolff, MD

Abstract

In this article the authors describe the methods and procedures that have been used to help patients regain hand and forearm function after mangling injuries. Assessment of the pathophysiologic condition, careful inventory of the injured structures, and early aggressive wound excision and reconstruction, followed by expert rehabilitation, are advocated. The importance of vascular restoration, stable skeletal fixation, and provision of adequate skin cover are stressed. In addition to describing their treatment approach, the authors emphasize the need for the surgeon to be well acquainted with each phase of the treatment process.

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The intricate anatomy of the hand is the foundation for its sensibility, balanced motion, and control. Although we often take our adaptable hands for granted in everyday use, they are vulnerable to the forces of industrial, agricultural, and domestic machines. A serious, mutilating injury to the hand can be devastating, with grave implications for the life and livelihood of the patient. This article distills the philosophy of management of these difficult wounds developed and practiced at our center for over three decades.

Mechanism of Injury

A multitude of different kinds of industrial, agricultural, and household equipment can cause mangling injuries of the hands, not to mention the increasing menace of gun-shot wounds. Most mutilating injuries to the hand result from farming accidents.[1,2] In the 1950s, hand injuries caused by corn pickers were treated by minimal debridement with careful removal of dirt, foreign bodies, and detached bone only. The treating surgeons did not sacrifice length and found a tendency toward late gangrene of the whole part or late necrosis of bone. Later, Campbell et al[1] advised against primary complete wound closure in these injuries. Believing that early use of antibiotics had no proved value, they used debridement and delayed closure without antibiotics.

By 1982, when Beatty et al[2] reported a series of grain-auger injuries, management had become more aggressive, with saline irrigation, debridement, reduction and stabilization of fractures, skin and soft-tissue coverage, and revascularization or replantation. With the use of broad-spectrum antibiotic coverage for 7 to 10 days, they found no loss of parts or impairment of final outcome due to infection. In contrast, Gorsche and Wood[3] felt that salvage of digits by revascularization was not successful in their experience with corn-picker injuries; they found good results with early amputation of nonviable digits.

Hand injuries resulting in contamination are also common in motor-vehicle accidents. Roll-over motor vehicle accidents in which the hand is outside the window or passes through the open window at the time of the accident can cause severe mutilating injuries, with contamination limited to the dorsum of the hand. Road-scraping injuries can affect both the dorsal and the palmar surfaces.

Heavy contamination is not often associated with injuries caused by snow blowers, woodworking tools, and industrial machinery, such as punch presses.

Assessment

The patient's general condition is the most important factor in the initial assessment and, to a large extent, will determine the treatment that is possible for the hand injury. A great danger in dealing with hand injuries

Dr. Gupta is Clinical Instructor, Department of Orthopaedic Surgery, University of Louisville School of Medicine, Louisville, Ky. Dr. Wolff is Assistant Clinical Professor, Department of Orthopaedic Surgery, University of Louisville School of Medicine.

Reprint requests: Dr. Wolff, Christine M. Kleinert Institute for Hand and Micro Surgery, Inc, One Medical Center Plaza, Suite 850, 225 Abraham Flexner Way, Louisville, KY 40202.

is being sidetracked by the visually striking, bloody, mangled hand and not evaluating other relevant and perhaps life-threatening injuries. At best, the insufficiently vigilant surgeon will escape with the embarrassment of missed injuries[4]; at worst, hidden abdominal, thoracic, pelvic, or spinal injuries will brew to life-threatening proportions while the surgeon deals methodically with the hand injury. Patients with multiple injuries are best treated under the guidance of a trauma team.

When there are major injuries of the hand and forearm and the mangled extremity is wrapped in heavy bandages, little will be gained by subjecting the patient in the emergency room to a painful detailed examination, which may not even be accurate.[4] Nonetheless, a general assessment of circulation, sensibility, and function can be done in the emergency room along with x-ray evaluation. The potential benefits of a preview lie in the preparedness of the operating room personnel and, to some extent, in the facilitation of proper planning of procedures. In any event, most mangling injuries will have to be explored and cleaned in the operating room.

The role of prophylactic antibiotics in treating the mangled hand and forearm is unclear. Fitzgerald et al[5] do not consider prophylactic antibiotics indicated in mutilating hand injuries caused by farm implements. Briedenbach[6] recommends prophylactic antibiotics to reduce the bacterial load, which he believes is the most important determinant of postoperative infection. We tend to use prophylactic antibiotics for mutilating injuries.

Once the patient has been adequately anesthetized, the bandages are removed and the hand is inspected. The first thing that strikes the examiner on looking at the injured hand is the extent of injury. The experienced observer quickly takes in the relevant facts: the extent of devascularization, the status of the skin, the posture of the fingers, the presence of deformities signifying underlying fractures or dislocations, the presence of active bleeding, and the degree of skin maceration.[4]

The first decision involves a simple question: Is this hand reconstructable, or will better function be gained by a judicious early amputation? This necessitates extensive discussion with the patient and his or her relatives but ultimately remains a judgment that the surgeon must make on the basis of personal knowledge, belief, and experience.

Often, a judicious early amputation prevents multiple subsequent reconstructive endeavors that offer little hope of functional gain and that will frustrate both physician and patient. In a devastating injury, early amputation is not a failure, but an appropriate first step toward rehabilitation. If the surgeon believes that adequate wound excision will result in retention of little functional tissue or in a late amputation, primary amputation is indicated. In rare instances, complex revascularizations to preserve length of the extremity for proper prosthetic fitting may be followed by later distal amputation. This is done only after detailed, lucid discussion with the patient.

Pathophysiology

Büchler and Hastings[7] have classified injuries of the upper extremity into “isolated” and “combined” injuries. An isolated injury is an injury to a single structure in the hand. A combined injury is an injury of more than one functionally important structure at any given location. These authors further subdivide combined injuries into four types: crushing injuries, palmar combined injuries, dorsal combined injuries, and dorsal and palmar combined injuries. By definition, all mangling injuries of the hand are combined injuries, often involving crushing as well as having characteristics of dorsal and palmar combined injuries.

Mutilating injuries impart different types of force to the structures of the hand, including compression, shear, tension-causing contusion, crush, and burst. Additional complicating features include contamination of the wound with foreign bodies.

The wide array of pathologic changes seen in mangling injuries has been well described by Büchler and Hastings.[7] Their findings are summarized as follows:

High velocity imparted to the bone results in a multitude of fracture patterns, generally associated with ripping of soft tissues from the fractured fragments. The range of muscle damage extends from tearing of fascia to crushing of muscles to burst-type muscle injuries with rupture of the muscle substance. The origin of tendons is often stripped from the bones. Tendons generally resist crush but may be avulsed, typically at the musculotendinous junctions. They may be shredded by longitudinal interfascicular tears, resulting in devascularization. When this type of injury is combined with surface abrasion, the scene is set for tendon adherence.

Vascular injuries can result in localized ischemia due to segmental devascularization or cessation of blood supply to the distal part of the limb. Crush, rotation, and avulsion forces can cause segmental ischemia to nerves. Segmental demyelination usually results in a Sunderland type 3 injury. Grossly, the nerve appears contused over a segment, or skip lesions may result in conduction blocks.

Rupture of septo-, fascio-, or musculocutaneous nutrient vessels can give rise to devascularized skin flaps. Crushing can also result in epidermal damage. Thermal or chemical burns from the injuring agent may also be present.

Wound Excision

The idea of what constitutes proper wound debridement is highly variable. Many have advocated preservation of "viable" tissue on the basis of a belief that such tissue will "declare itself" in a few days. We consider this concept of conservative debridement to be the cause of many infections. The potential gain of a few strands of viable but nonfunctioning muscle at the risk of disastrous infection is irreconcilable with our logic of wound management. Bone ends and skin edges may die because of desiccation and infection, with the ultimate result being similar or even greater tissue defects than result from single-stage excision.

Delayed debridement leaves the wounds exposed to hospital pathogens without the protection of overlying skin.[8] Godina[9] has shown that early aggressive wound excision and flap coverage within 72 hours are associated with a postoperative infection rate of 1.5%, compared with 17.5% for delayed reconstruction (average delay, 90 days).

Thus, in this context, the historically accepted term "debridement" should perhaps be replaced by "wound excision," which resembles tumor excision in extent.[10] If aggressive reconstruction is to be carried out in the upper extremity, a thorough wound excision must remove all doubtfully viable tissue.

The process of wound excision, done or supervised in person by senior surgeons, is started under tourniquet control. All visibly nonviable and contaminated tissues are excised, except vital structures, such as nerves and vessels. Muscles that are devascularized or avulsed from bone are excised. In the forearm, the anterior interosseous artery, which carries much of the blood supply to the forearm muscles, is reconstructed proximally; restoration of the distal blood supply by merely using a bypass graft of either the ulnar or radial artery will result in a significantly devascularized forearm segment of dead muscle. Bone ends are curetted to provide clean surfaces. Structurally relevant bone fragments and fragments containing vascular attachments are saved for use either in restoring the anatomy of the fractured bone or in maintaining the structural integrity of the construct.

Intact but contused nerves are cleansed of surface dirt and contaminants but not excised. Frankly divided nerves are excised to healthy-appearing fascicles. Vessel branches are carefully excised and ligated. Major vessel ends are excised to healthy intima and held by clamps in preparation for repair. Skin and subcutaneous tissue are sharply debrided to viable, normal-looking skin.

The tourniquet is released, the wound is inspected, and further excision is carried out to bleeding tissue, if necessary. No pockets are left unexplored. The wound is thoroughly irrigated with Ringer's lactate solution. Culture swabs are taken. The role of quantitative cultures is not clear at this stage.[8,11] The process of raising the tourniquet, irrigating the wound, finding and debriding compromised tissue, and lowering the tourniquet to ensure bleeding from all surfaces is repeated once or twice. This is done while the wound is still fresh rather than later, when edema and granulation tissue obscure deeper structures, rendering decisions about their viability difficult.

Reconstruction

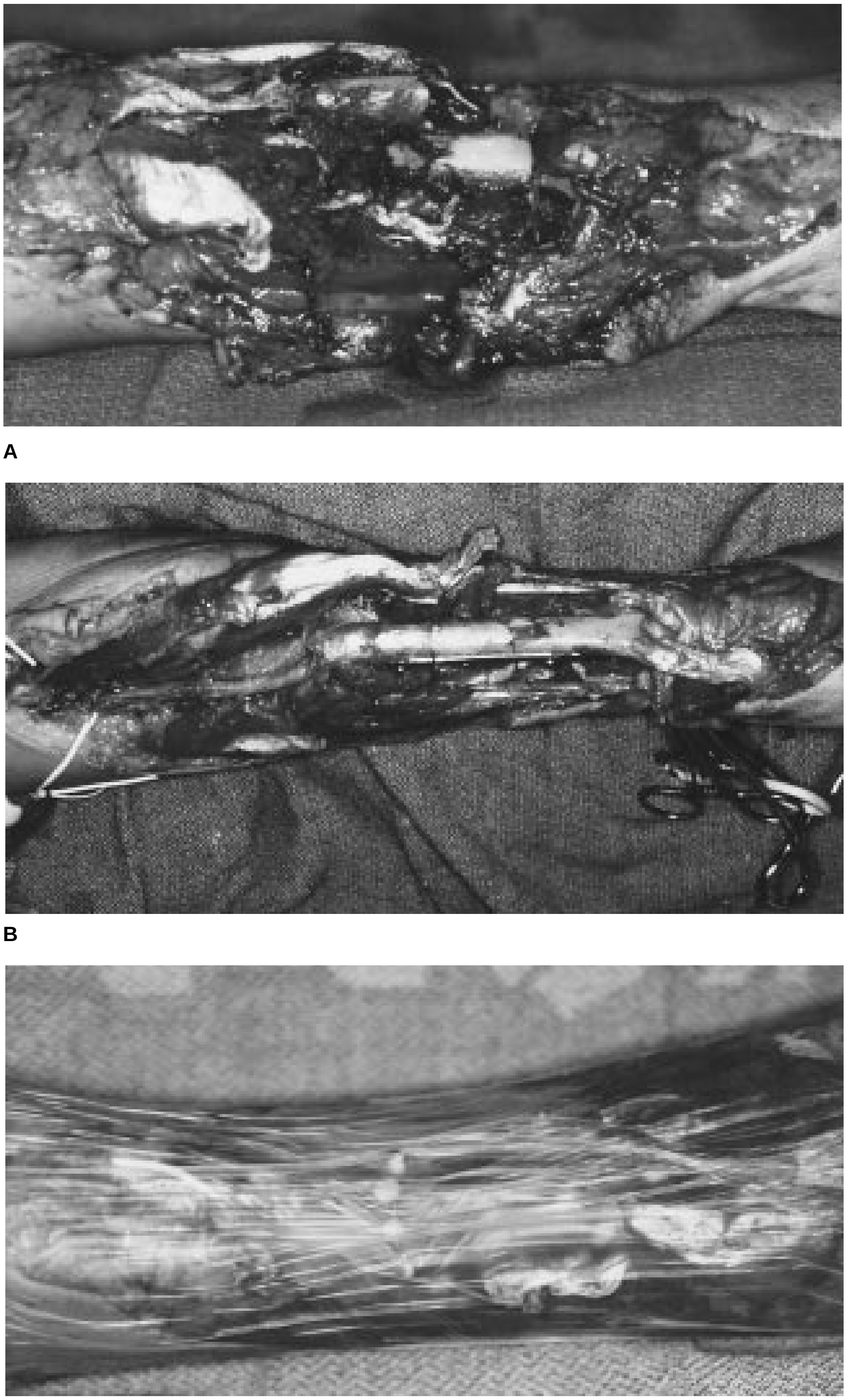
It is difficult to imagine that just over three decades ago the concept of immobilization after hand injuries held sway over surgical thinking. Kleinert pioneered the idea of primary flexor tendon repair and early mobilization shortly after the development of anatomic reduction and rigid internal fixation, which has had a profound impact on modern fracture and wound management.[12]

Except when the patient is too ill to undergo prolonged reconstruction or the wound has been heavily contaminated by sewage, farm effluent, or soil, it is unwise to defer primary reconstruction because loss of hand function increases geometrically with the duration of immobility. When reconstruction is delayed up to 72 hours, we use the antibiotic bead-pouch technique[13] after wound excision (Fig. 1). The bead pouch keeps the wound moist and sealed from the hospital environment, obviating frequent dressing changes and preventing nosocomial infections.

A free flap, if used, is technically much easier to perform primarily than secondarily.[9,10,14] Delay causes edema, which obscures tissue planes. Vessels become more friable and difficult to handle, forcing the use of long vein grafts to escape the zone of injury.

The results of internal fixation of open tibial fractures with plates and screws, which are poor,[15] should not be extrapolated (as is often done) to the upper extremity. The upper extremity has excellent collateral circulation and vascularity, allowing far more aggressive management of fractures (Fig. 2). Any form of immobility, especially when combined with postoperative edema, results in rapid loss of motion and function. Therefore, in the upper extremity, early anatomic restitution by means of plating with immediate commencement of protected motion becomes a primary goal.

Every mangled hand should be analyzed and reconstructed in an individual manner using the guidelines of Büchler and Hastings.[7] Fas-



A

B

C

Fig. 1 **A,** Dirty crush wound of the wrist and forearm caused by a motor-vehicle accident, with fracture of the radius and loss of segments of the radial artery and multiple extensor and flexor tendons. The patient also had a splenic tear and an acetabular fracture. **B,** Immediately after debridement and internal fixation of radius. **C,** Bead-pouch management of the wound.

ciotomies are done when signs of impending compartment syndromes are present in the forearm or in the intrinsic compartments.

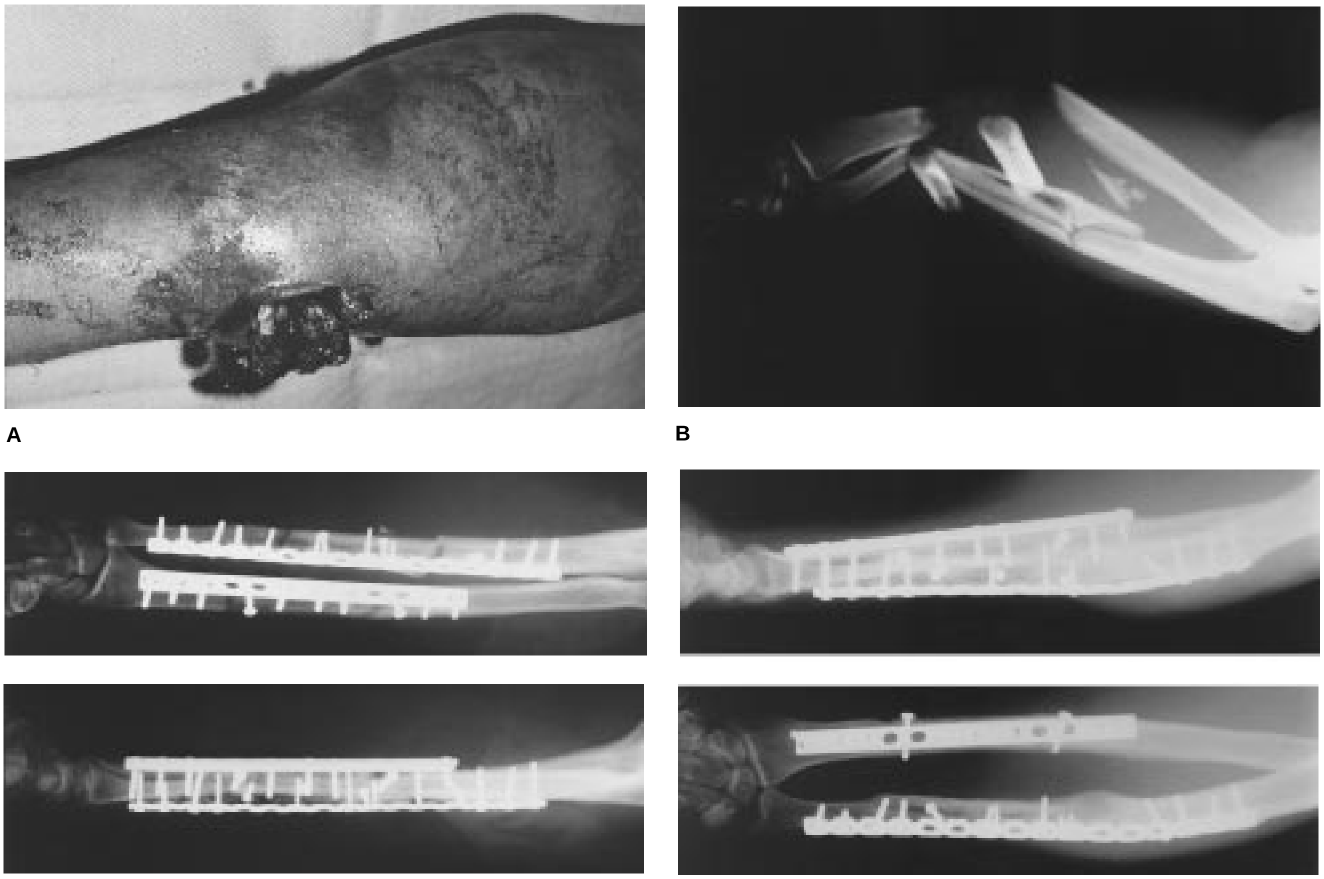
Bone

Bone is usually the first structure to be addressed in the reconstruction process. Anatomic reduction and rigid and stable fixation are essential for early joint motion.

Intra-articular fractures are anatomically reduced. Depressed articular fragments are elevated, fixed with Kirschner wires, and supported in place with cancellous bone grafts. Buttress plates are used to maintain such constructs.

Diaphyseal fractures are reduced, fixing structurally important bone fragments. Either 1.5-mm or 2.0-mm miniplates or condylar plates are used for metacarpal or phalangeal fractures; 3.5-mm dynamic compression plates are used for forearm bone fractures. Bone loss is made good with compression-resistant cortico-cancellous bone graft. If gross bone defects are present, vascularized bone grafts can be used, often with skin and a flow-through vessel segment. The lateral arm flap provides a generous supply of bone from the lateral ridge of the humerus. A scapular flap,[16] radial forearm flap, or posterior interosseous flap may also be used. If larger pieces of vascularized bone are required, a fibular graft or an iliac-crest flap will provide adequate substance.

In the finger, every attempt must be made to maintain proper rotation, as malrotation results in reduced function, stiffness, and tendon adhesions. When multiple fractures of metacarpals and phalanges are present, maintaining rotational alignment is difficult. In this situation, temporary Kirschner-wire fixation stabilizes the skeleton enough to allow proper assessment of rotation. If the proximal interphalangeal (PIP) and metacarpophalangeal (MCP)



A B C D

Fig. 2 **A,** Severe crush injury of the forearm, resulting in a crush / burst injury of the forearm muscles and musculotendinous junctions. **B,** Radiograph depicts severe comminuted fractures of both forearm bones. The ulna shows segmental fracture with longitudinal strips in the fractured segment. **C,** After thorough debridement, both bones were rigidly fixed. Fasciotomy was performed with primary skin grafting. **D,** The fractures are fully healed. The ulna required one bone-grafting procedure.

joints, especially those of the index finger and the thumb, are destroyed beyond repair, early fusion is done instead of keeping a painful joint that will limit hand function. An alternative to fusion in the MCP and PIP joints is palmar-plate arthroplasty.

Blood Vessels

Restoration of peripheral vascularity is preferably done through direct end-to-end vessel repair or, if this is not possible, a vein graft. When a vein graft is used, a segment of tissue that has borne some of the force of injury will often be bypassed. Thus, provision must be made to provide adequate vascularity to the segment, either by direct anastomosis or vein grafting of branches serving this area or by a flow-through flap or free flap bringing fresh blood supply to the area. Moreover, sufficient venous drainage must be restored; otherwise, postoperative edema will result in compromise of hand function.

In the forearm, the radial and ulnar arteries may be repaired using a reversed vein graft. Sometimes a segment of uninjured local vein, such as the cephalic vein, is harvested. Some authorities have observed late aneurysmal dilatation following this procedure. Therefore, a reverse saphenous graft is preferable. Care must be taken not to create a size imbalance between the artery and the vein. The vein graft must be matched to the defect; too long a graft will form loops and kinks, which are predisposed to thrombus formation, and too short a graft will cause tension. We carry out all anastomoses under the microscope with 9-0 or 10-0 nylon sutures. This enables atraumatic vessel apposition, thus minimizing the risk of thrombosis. Arterial or venous thrombosis can seriously jeopardize a revascularized extremity.

The superficial palmar arch provides a particular challenge for reconstruction. This can be met in one of the following ways[10]: (1) If an extensive arterial defect exists, an arterial graft from the subscapular artery may be used for reconstruction (Fig. 3, A). The multiple branches of this system provide an adequate conduit for the common digital vessels (Fig. 3, B). (2) A reversed vein graft from the dorsal venous arch of the foot provides a good source of vein graft for the palmar arch (Fig. 4). (3) A reversed saphenous vein graft may be used, usually anastomosed to the radial or ulnar artery. The common digital vessels are anastomosed in an end-to-side fashion.

If a flow-through vascular anastomosis is required in the forearm, the peroneal artery is ideal for the graft, especially if combined with a vascularized bone or composite flap. In the fingers, we recommend using vein grafts for defects in the digital vessels. The usual source of vein grafts is the palmar distal forearm. Often a flow-through vascular anastomosis is required. A dorsal middle phalangeal finger flap from an uninjured finger may be used after performing a digital Allen test in the donor finger. Alternatively, a venous flap from the dorsum of an uninjured digit may be used.

Tendons

Primary tendon repair is possible only in the presence of a clean wound or a suitable bed. If primary flexor tenorrhaphy is done, we use a Kirchmayr (modified Kessler) suture[17] of 4-0 braided polyester or double-loop sutures and an epitendinous suture of 6-0 Prolene.

In mutilating hand injuries, the tendon ends are usually frayed and require shortening to normal tendon. A small tendon graft is used in this situation, especially if the bed appears normal. If the bed is compromised, if the tendon defect is excessive, if a pulley reconstruction is done concomitantly, or if protected controlled mobilization is not possible, the flexor tendon is excised, and a Silastic rod is inserted primarily, followed by later grafting after full passive mobility of the digit has been regained. This is particularly true of the flexor pollicis longus tendon. Occasionally, it may be pos-

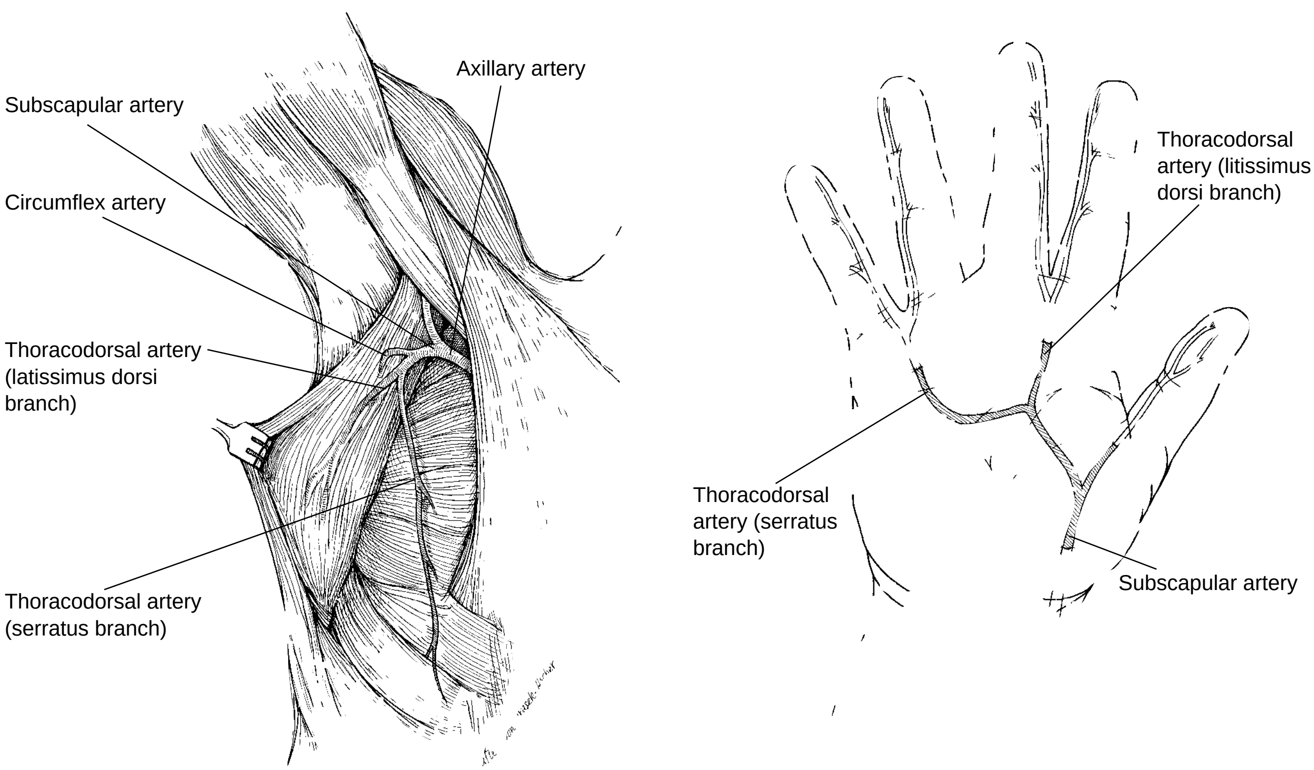
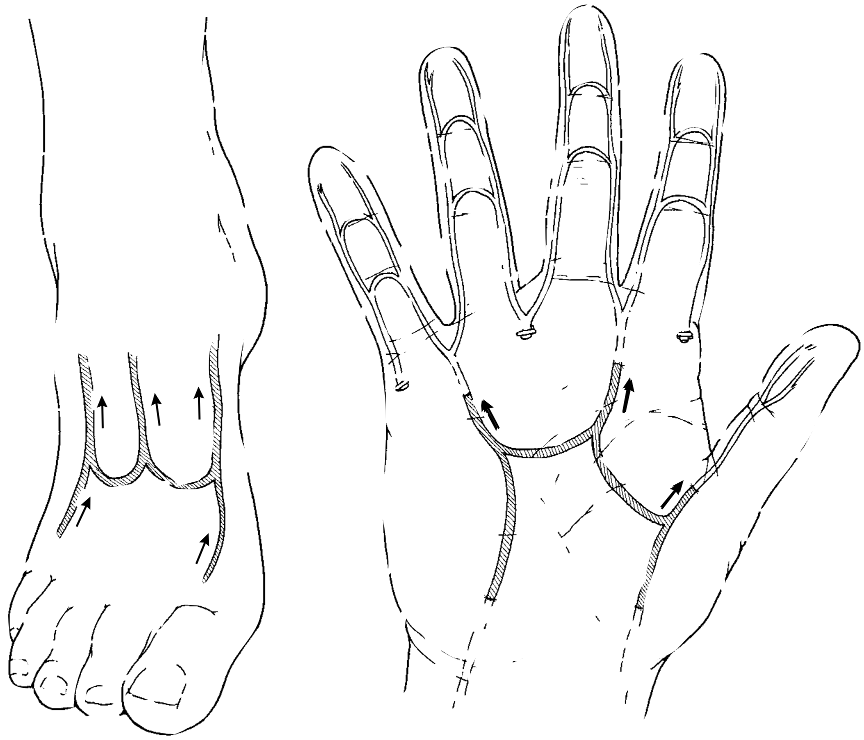


Fig. 3 **A,** The subscapular arterial system. **B,** The subscapular artery and its branches provide good material for arch reconstruction.



A B

Fig. 4 Reversed vein graft from the dorsal venous arch of the foot **(A)** is a good source for palmar arch reconstruction **(B).**

sible to transfer a flexor digitorum superficialis tendon from the ring finger primarily to replace the flexor pollicis longus.

Especially in zone 2, partial flexor tendon lacerations of up to 25% of the substance of the tendon are repaired with only epitenon suture. For lacerations of up to 50% of the substance, a single core suture is used only in the region of the laceration and is reinforced with an epineurial suture. Partial lacerations of 10% or less can be safely trimmed to provide proper gliding and avoid triggering in the pulleys. A segment of the extensor retinaculum is used for pulley reconstruction in the acute setting to provide a smooth gliding surface.

The extensor mechanism is a complicated system that produces coordinated motion at three digital joints. This complex mechanism and motion must be respected, and correct anatomic restitution is required. It is necessary to provide proper opposition and adequate gliding of all components of the extensor system if flexion of the finger is not compromised. In the rehabilitation phase, due respect must be paid to this system as well.

Interosseous Muscles

If the metacarpal region of the hand sustains extensive crushing, a thorough wound excision will necessitate removal of some of the interosseous muscles. This course is preferable to allowing the development of fibrous contracture of, or adhesions to, these muscles. In replantation at the metacarpal level, we routinely excise the interossei to prevent contracture, later replacing their function by judicious tendon transfers as required.

Nerves

Primary end-to-end epineurial repair will yield the best results if no defect is present, because the nerve ends can be brought together without tension after they have been cut back to healthy-looking fascicles. If a nerve defect is present, a nerve graft is required. In the fingers, digital nerves can be grafted. The posterior interosseous and medial antebrachial cutaneous nerves are usually used; the lateral antebrachial cutaneous nerve is rarely selected, as unacceptable sensory loss has been observed in the area supplied by it. In segmental defects in a mixed nerve, such as the median or ulnar nerve, the fascicles are aligned while performing nerve grafting. We have found the modification of Karnovsky's method by Kanaya et al[18] helpful in these situations to identify the motor and sensory fascicles (Fig. 5).

Skin

Although skin grafts are the first choice in reconstruction, they are avoided over bone, where unstable scar with frequent bleeding will result; over nerves, where perineurial fibrosis will limit gliding of the nerve; over tendons, where gliding will be limited and will thus restrict motion; over exposed hardware; or when secondary reconstruction, such as tenolysis or capsulectomy, is likely to be necessary. Generous use of mesh grafts without distention, especially in patches, prevents tight closure of a wound and the resulting compromise of circulation.

Local or regional flaps are next considered in the reconstruction ladder. Proper utilization of local flaps for small defects reduces the operating time and minimizes complica-

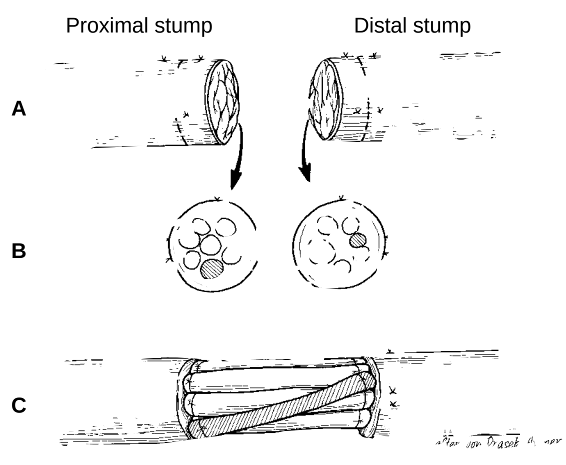


Fig. 5 Modification of Karnovsky's method by Kanaya et al.[18] **A,** Placement of orientation sutures in the proximal and distal stumps. Two sutures are placed on the palmar aspect and four sutures on the lateral aspect of each stump. Transverse incisions are made at the midpoint between corresponding sutures of each stump. **B,** Cross-sectional views of the nerve stumps show the sensory and motor fascicles. **C,** Interfascicular sural nerve graft connects corresponding proximal and distal fascicles.

tion rates. Commonly used are the dorsal middle phalangeal finger flap, a distally based dorsal hand flap, the posterior interosseous artery flap, the ulnar artery flap, and the reversed radial forearm flap.

In choosing a free flap, one must clearly define whether a space filler is required; if so, a muscle flap is used. If surface cover is the main requirement, a fasciocutaneous flap is used. A muscle flap will not provide as smooth a gliding surface for underlying tendons as a fasciocutaneous flap. Moreover, donor sites must be taken into account. The workhorse at our institution is the lateral arm flap,[14,19] except in female patients, who have difficulty accepting the donor defect and tend to prefer a free groin flap.[10,16]

One-Stage Composite Reconstruction

Scheker et al[20] recently published their results in a case series in which they used a new method of primary one-stage reconstruction of dorsal hand defects. Corticocancellous bone grafts stabilized with plates and screws are used to reconstruct metacarpal defects. The flap is placed in position and sutured securely to the dorsal periosteum or skin over the intact bone. A channel is created through the subcutaneous tissue of the flap, through which an individual tendon graft for each extensor tendon is passed, to be woven to the primary tendon on either side.

In a modification of this method, a layer of vascularized periosteum from the lateral aspect of the humerus is taken with the composite lateral arm flap. This vascularized periosteum is placed over the bone grafts on the dorsal skeleton of the hand. The tendon grafts are then positioned in the gliding tissue so that they glide between the periosteum and the fascial layer.

Salvage of Viable Tissue

Amputated and nearly amputated tissue may substitute for parts lost in the injury. Distal viable portions of a finger to be amputated because of unreconstructable proximal injury, including joints, tendons, nerves, and skin, may be used to reconstruct another finger or even to fashion a needed thumb (Fig. 6).

Postoperative Considerations

Rehabilitation

Nowhere in hand surgery does proper rehabilitation play a more influential role in final outcome than after immediate reconstruction of complex injuries. Each patient's rehabilitation program must be individualized according to the type of injury and the type of surgical reconstruction performed. Generally, therapy is directed toward achieving early tendon gliding and joint range of motion to decrease edema and stiffness.[12]

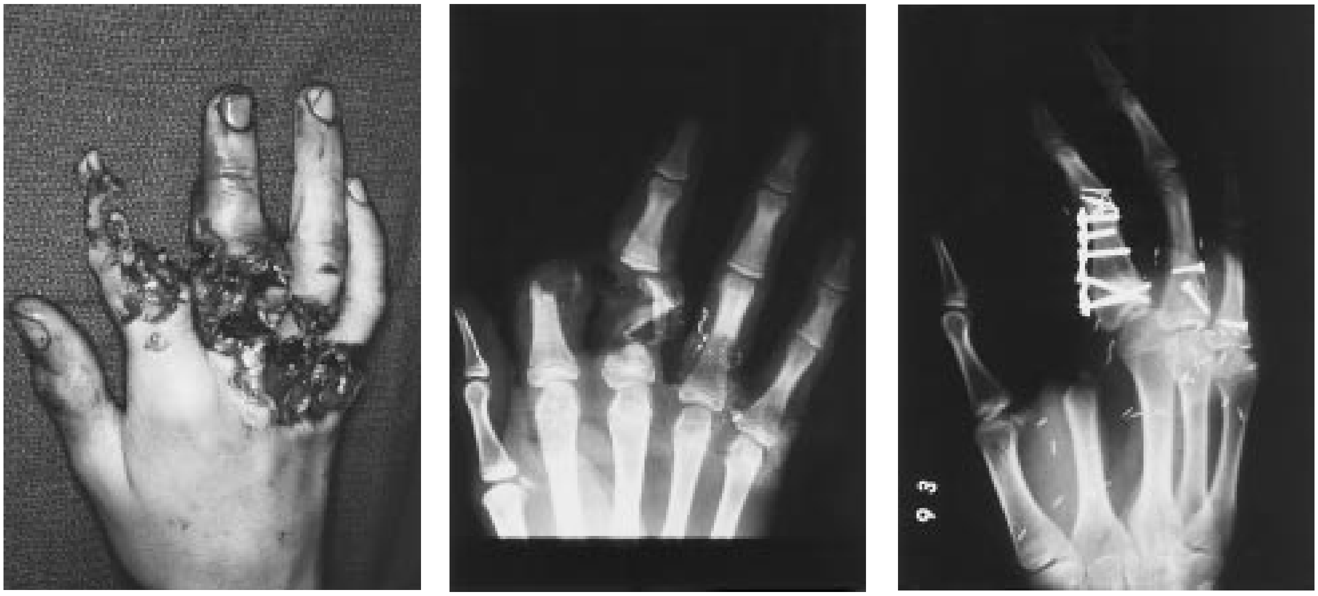
For palmar combined lesions, a dynamic splint, as proposed by Kleinert et al[12] or Werntz et al,[17] is used. This is only contraindicated when concomitant ulnar nerve injury results in the inability to extend the PIP joints. Under these circumstances, the use of Kleinert traction will result in flexion contracture of the fingers. In these situations, we use passive protected motion.

In dorsal combined injuries, an extension outrigger splint is used to protect the complex extensor mechanism, which is difficult to reconstruct. In dorsal and palmar combined injuries or crush injuries, the extensor outrigger splint is modified to provide both passive extension to protect the extensor system and early active flexion. This is used in conjunction with an outrigger splint that provides static MCP joint flexion.

Early use of transcutaneous electric nerve stimulation to prevent the onset of reflex sympathetic dystrophy in susceptible individuals has yielded good dividends in our unit. Muscle stimulation is used prior to reinnervation. Early work hardening is beneficial to both the patient and the workplace.

Late Reconstruction

Occasionally, complete reconstruction is not possible. Moreover, many reconstructive procedures are done only secondarily. For instance, after complete amputation of unreplantable fingers and thumb, initial treatment usually consists of



A B C

D E

Fig. 6 **A,** Severe crush injury of the right hand caused by a chain saw. The index finger was amputated at the distal proximal phalanx. The long finger had dorsal tissue loss between the MCP and PIP joints. The ring and small fingers had dorsal tissue loss over the MCP joints. **B,** Radiograph shows amputation of the index finger, bone loss in the long finger, and dorsal cortical defects of the proximal phalanges of the ring and small fingers. **C,** The index finger was surgically amputated at the metacarpal neck. The proximal phalanx of the index finger, with overlying extensor tendon and skin, was transferred to the long finger, where osteosynthesis was done with a condylar plate and tension-band wires. Dorsal cortical defects of the proximal phalanges of the ring and small fingers were reconstructed with nonvascularized cortical bone held with compression screws. **D** and **E,** Demonstrations of function of the reconstructed right hand 6 months after reconstruction.

debridement and coverage of the stump with a groin or lateral flap. Later, toe-to-hand transfers are done to restore function. As a second example, severe crushing burst-type injuries of the forearm may render the muscles nonfunctional or may necessitate their complete excision. Later, gracilis-muscle transfer may provide some measure of hand function. Also, patients referred from other facilities days or weeks after their initial management may need to undergo vascularized bone transfer, skin flaps, nerve grafting, and tendon transfer.

We prefer early tendon transfers, which keep joints mobile and strengthen the hand. Tendon transfers are commonly done to restore opposition in cases of median nerve palsy, to correct claw deformities, to restore pinch in ulnar nerve palsy, and to provide extension of the thumb, finger MCP joints, and wrist in radial nerve palsy. Tenolysis is often necessary after severe crush injuries where the injured tendon adheres to the surrounding tissues. After tenolysis, early active motion is generally beneficial.

If proper rotational alignment of the phalanges or metacarpals has not been achieved, rotation osteotomies of these bones, often combined with tendocapsulolysis, may be necessary to correct the deformity and regain motion.[21] Many mutilating injuries convey a high-energy impact to the skeletal system, causing devascularization of bone fragments. Even after adequate internal fixation, secondary bone grafting may be necessary, especially in the forearm bones.

Outcome Determinants

The most important determinants of final function are (1) the nature and severity of injury; (2) reconstruction technique; (3) rehabilitation technique; and (4) patient compliance with the rehabilitation program. Obviously, the more severe the injury, the worse the projected outcome. Proper reconstruction and rehabilitation reduce postoperative edema and stiffness and enhance early motion, thereby motivating the patient. Patient compliance during rehabilitation, however, governs the success or failure of any reconstructive process. Because a well-motivated patient can have a functional result even after a severe injury, the surgeon will do well to educate patients regarding their responsibilities for recovery.

Management Pitfalls and Complications

Missing the golden period for reconstruction immediately after injury results in reconstructive compromises and diminishes the final result. This effect is exacerbated if the patient has multiple injuries or systemic complications that delay reconstruction attempts, thus leading to swelling, stiffness, and decreased function in the hand.

Inadequate debridement is another cause of many complications. Sophisticated training and expertise are necessary before undertaking wound excision. In the absence of skilled, trained reconstructive surgeons and adequate support services, it is perhaps wise not to undertake such bold reconstruction and instead to go the route of secondary reconstruction, albeit with some compromise in function. Under these circumstances, early transfer of the patient to a hand center may be the best option.

Deep infection dooms intricate reconstructions. Infection not only can become chronic, especially in the bones, but also can jeopardize vascularity and cause tendon adhesions, joint stiffness, and loss of skin flaps. At any sign of impending infection, aggressive retaliatory steps should be taken.

Providing adequate postoperative pain relief encourages patient cooperation in rehabilitation and reduces the incidence of reflex sympathetic dystrophy. In addition, the emotional needs of the patient must be addressed with compassion and understanding. Having sustained a major injury that will in all likelihood affect life and livelihood, patients normally undergo periods of depression, especially when a plateau is reached in rehabilitation. The surgeon and therapist should constantly encourage and motivate the patient to a high level of performance. An early conversation with a clinical psychologist may help in the rehabilitation process. The help of compassionate family members and supportive friends should also be enlisted.

The patient may become concerned about the external appearance of the appendage, to the detriment of its function. A cosmetic prosthesis may help in maintaining the function of an aesthetically unattractive appendage until its appearance can be improved by further surgery.

Summary

Mangling hand and forearm injuries challenge the whole management team. Assessment of the pathophysiologic condition, careful inventory of the injured structures, and early aggressive wound excision and reconstruction should be followed by expertly directed rehabilitation. Using this sequence, optimal hand function may return to the mutilated hand. Priorities in reconstruction are vascular restoration, stable skeletal fixation, and provision of adequate skin cover.

A surgeon who aims to undertake this line of work should train in aspects of plastic, orthopaedic, and microvascular surgery and thoroughly understand the rehabilitation process. To provide patients the best possible chance to obtain optimal results after such devastating injuries, training programs should be modified to reflect this approach.

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