

An ABC Technical Algorithm to Treat the Mangled Upper Extremity: Systematic Surgical Approach

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Mangled upper extremity, as a result of trauma, is a life-altering event requiring a multidisciplinary approach for a successful outcome. All attempts are made to salvage the extremity and preserve function, which may require multiple complex procedures. This paper discusses the importance of a systematic reconstructive sequence and provides a review of commonly utilized techniques, supported with illustrative cases. (*J Hand Surg Am.* 2017;■(■):1.e1-e10. Copyright © 2017 by the American Society for Surgery of the Hand. All rights reserved.)

Key words Complication, mangled, upper extremity, surgical approach.



COMPARED WITH THE LOWER EXTREMITY, the functional outcome of upper limb amputation is drastically inferior.^{1–4} Occasionally, amputation may be the only option. As such, all efforts should be made at limb salvage and function, even if this requires major local or ectopic replantation.⁵ The care of the upper extremity with devastating injuries can be intimidating because it may require multiple complex procedures.

Following a systematic reconstructive sequence can provide structure and lead to the best possible outcome. The purpose of this article is to suggest a sequential approach for the treatment of the mangled upper extremity. An “ABCDE” algorithm that we have found useful facilitates the decision-making process in the management of these difficult cases, along with a discussion of the most common surgical techniques, is presented.

A—ASSESSMENT

Early management of the mangled upper extremity begins upon patient presentation to the emergency department. Antibiotic therapy should be initiated urgently upon arrival based on established guidelines of open fracture treatment.⁶ Examination of the limb, with particular attention to neurovascular status and motor function, should be performed and documented. The patient should be evaluated for potential compartment syndrome with a clinical evaluation and compartment pressure measurement, if indicated.

The first important issue in the treatment algorithm hinges on the vascular status of the limb. Distinction should be made between a devascularized limb and an extremity with overall adequate perfusion. If the extremity is deemed avascular, the time since the injury is considered warm ischemia and early revascularization is critical to stop ongoing necrosis and toxin release and potentially prevent reperfusion syndrome.^{7,8}

While having a single treatment team makes plans for debridement, repair, and reperfusion easier, this may not be practical at many tertiary-care institutions with multiple specialties involved in care. As such, coordinated teamwork and leadership are crucial when different specialties are working concomitantly. Miscommunication can lead to disastrous results and

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need for additional, unnecessary surgery. For example, in a scenario involving a patient with an avascular, mangled upper extremity, the decision on whether to address the vascular injury or bony stabilization first can be cloudy. Furthermore, if proper attention to all of these injuries is not undertaken, one may preclude the other team's ability to effectively treat the patient. An easy compromise to this is with the use of a vascular shunt. An initial excisional debridement of the wound is quickly done under tourniquet, with identification of the main structures to be repaired. At this point, fasciotomy can also be performed if deemed necessary, especially in the case of extended ischemia time.^{9,10} A vascular shunt is applied on a large-caliber artery (Fig. 1).¹¹ The tourniquet is then released, with care to prevent any significant bleeding from the venous outflow (a small amount of bleeding is desired to "wash out" the toxins). This vital step provides the orthopedic surgeon much needed time to perform all the other procedures in the reconstructive sequence. It is much easier and safer to perform vessel and nerve anastomosis with improved skeletal stability. Furthermore, considering possible need for bone shortening during skeletal fixation, there is an added potential benefit of being able to avoid vein/nerve grafting.

In a scenario in which the limb is not devascularized, the order of the surgical approach can be slightly different. More time can be spent on proper identification of injured structures and thorough debridement of the devitalized and contaminated tissues. Here, a potential risk exists of devascularizing the limb owing to overzealous debridement close to neurovascular bundles. This can be avoided by having a surgeon who is familiar with the reconstructive strategies and local anatomy performing the debridement.

Regardless of vascular status, the first step in a successful outcome relies on an initial debridement. Whether the debridement is done under tourniquet or not will depend on the status of the wound and the limb. Having tourniquet control provides enhanced visualization for easier structure identification and improved ability to perform a more adequate removal of contaminants, as well as minimizes the risk of iatrogenic injury.¹² Furthermore, the tourniquet affords reduced blood loss not only by its direct compressive effect but also owing to improved ease of dissection and ligation of injured vessels. One of the few disadvantages of debridement under tourniquet control is that the parameter of "circulation" is lost when evaluating tissue viability with the 4 "Cs" of tissue viability: color, consistency, contractility,

and circulation.¹³ It is, therefore, advisable to perform final assessment of tissue viability with the tourniquet deflated.^{14,15}

Commonly, more than 1 debridement is required to decrease the rate of infection.¹⁶ The use of negative-pressure wound therapy (NPWT) is beneficial when several debridements are required or until the wound is ready for definitive soft tissue coverage. It allows for reduction in swelling, decrease of inflammatory mediators, and improved infection control by keeping the wound sealed.¹⁷ In addition, NPWT may be used to mold the position of injured fingers into the safe position as well as "stabilizing" fractures much as would an air cast.

B—BONE

The bone work is of crucial importance to provide a stable wound. Proper skeletal stabilization will help decrease swelling and inflammation and improve the overall condition of the patient. Depending on the severity of the wound and clinical condition of the patient, one technique will be chosen over another. Rigid fixation enables early active motion when possible.

In the situation in which damage control orthopedics is required, an external fixator can be applied expeditiously to provide some stability. Pins are placed outside the zone of injury in such a way as not to interfere with future wound exploration/preparation. The biggest disadvantage of the external fixator is the need for a second surgery for definitive fixation. With modern implants, however, definitive bone fixation can be done quickly without significant delay that could compromise a systemically unstable patient. This is especially important if the mangled extremity requires critical revascularization. Whereas the order of fracture fixation versus vascular repair remains controversial and should be evaluated on a case-by-case basis, we believe the best timing for internal fixation is immediately prior to the vascular repair.¹⁸ At this point, injured structures are out of the field, allowing for easiest bony exposure and thus minimizing the risk of injury. More importantly, there is an additional benefit of providing improved stability for the vascular work to be done.

Another technique in the armamentarium of an orthopedic surgeon is bone shortening. This strategy offers several advantages. First, the removal of the contaminated and devitalized bone will create a better contact surface of healthy tissues, with easier reduction of the fracture and the possibility of improved

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