# A 3-Phase Approach for the Management of Upper Extremity Electrical Injuries

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**KEYWORDS**

• Electrical burn • Burn • Electrical injury • Microsurgery • Nerve grafting • Tendon reconstruction
• Amputation

**KEY POINTS**

- Because of the pathophysiologic mechanism of the electric field, the magnitude and depth of electrical injuries can be far greater than what is superficially visible and can produce additional injury independent from traditional thermal damage.
- In accordance with Ohm's law, electricity will flow through the body simultaneously through different tissue planes according to individual tissue resistance. Resistance increases by tissue type as follows: nerve, vessels, muscle, skin, tendon, fat, and then bone.
- The treatment of electrical injuries of the upper extremity remains firmly grounded on fundamental trauma-relevant principles.
- All patients with high-voltage electrical injuries to the upper extremity warrant early, if not immediate, operative exploration for debridement and compartment releases.
- Reconstruction of the electrical injury demands a systematic approach to restoring sensory and motor function using basic reconstructive principles, including stable soft tissue coverage followed by tendon and nerve transfers and grafting.

**Video content accompanies this article at www.hand.theclinics.com.**

## INTRODUCTION

Electrical burn injuries constitute a minority of presentations to major burn centers (approximately 4% in the most recent national burn repository[1]). However, they are often described as being "the most devastating of all thermal injuries on a size-for-size-basis,"[2] with high-voltage injuries having been shown to exhibit increased inpatient length of stay, more operations required per patient, and increased mortality when compared with other burns of similar size.[3]

Electrical injuries constitute a unique point along the spectrum of burn disease because of the pathophysiologic mechanism of the electric field, which can produce additional injury independent from traditional thermal damage. These electric field effects are frequency dependent and can

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injure biological tissues in completely nonthermal fashions.[4] At a basic conceptual level, the electric flow (or current) between 2 points is a function of the electric potential difference (voltage) and resistance to flow between those points. This concept is quantified as Ohm's law ($I = V/R$, where *I* is electric flow, *V* is voltage, and *R* is resistance to flow). The clinically relevant message is that electricity will flow through the body simultaneously through different tissue planes according to individual tissue resistance. More flow will occur in tissues of lesser resistance and less flow in those of higher resistance. Resistance increases by tissue type as follows: nerve, vessels, muscle, skin, tendon, fat, and then bone. Skin acts initially as a protective barrier; but once its resistance is overcome, current flows freely through underlying deeper tissues.

Electric flow generates increased tissue temperature, which is a key contributor to the magnitude of tissue damage,[5] with most of the heat produced at skeletal muscle because of volume considerations.[6] In addition, nonthermal causes of injury include microvascular and macrovascular thrombotic insult, protein denaturation, and direct cell necrosis due to electroporation.[6–8] Moreover, electric flow can also directly induce cardiac arrhythmia and respiratory muscle spasm.[4] Severity of injury itself is a function of voltage, current, current type (alternating vs direct), and contact time. *In essence, the magnitude and depth of injury can be far greater than what is superficially visible. Therefore, suspicion for concurrent and potentially hidden deeper tissue injury must remain high with any electrical injury of the upper extremity.*

Sources of electrical injury are categorized into high voltage (>1000 V) or low voltage (<1000 V). Most electrical injuries seen at burn centers result from contact with high-voltage power lines. Greater than 90% occur in young men at work-related settings and originate in the upper extremities.[3] The most common location of an electrical injury entry wound is the right hand, followed by the left hand, with the exit wounds most commonly at the left foot.[9]

Low-voltage injuries result almost exclusively from indoor contact with domestic electrical sockets or wires. These injuries typically produce relatively minor superficial skin burns or transient peripheral neurologic symptoms, but complex injuries due to prolonged contact time or oral contact have also been reported. Other less common sources are lightning strikes, with a reported mortality of up to 30%,[4] and arc injuries whereby current induces flash-type thermal injury by passing through air without directly conducting through patients.

Despite these unique and complex considerations, the treatment of electrical injuries of the upper extremity remains firmly grounded on fundamental trauma-relevant principles. Treatment is conceptually divided into 3 phases: initial management consistent with Advanced Trauma Life Support (ATLS) and Advanced Burn Life Support (ABLS) protocols, maintenance therapy to preserve tissue equilibrium, and delayed reconstruction (≥3 months after injury) to restore upper extremity sensory and motor function.

## INITIAL MANAGEMENT

### *Life over Limb*

All patients who present with electrical injuries should be initially assessed as trauma patients consistent with ATLS protocols. This critical first phase focuses on recognition of other life-threatening injuries, stabilization of patients, and multisystem resuscitation. These protocols have been described extensively elsewhere,[10] but unique considerations in this patient population are described in detail here.

The importance of managing life over limb at initial assessment of any upper extremity electrical injury cannot be overemphasized because of the chance of other concurrent and potentially life-threatening injuries, which has been estimated to be as high as 15%.[2] Mortality rates from these injuries range from 3% to 14%.[11] In one series, concurrent injuries included myoglobinuria (44%), metabolic acidosis (31%), oliguria (19%), electrocardiogram changes (12.5%), and acute renal failure (4.5%),[12] whereas another study listed loss of consciousness (52%), traumatic brain injury (5%), chest injury (5%), abdominal injury (2%), soft tissue injury (11%), and fractures (11%) in high-voltage patients.[3] Fractures often result from tetanic muscle contractions induced by electrical flow.[2] The index of suspicion for concurrent injury must remain high, especially with high-voltage mechanisms.

A unique consideration in this patient population is the likelihood of current-induced cardiac arrhythmias. Therefore, these patients should receive an initial electrocardiogram (ECG), followed by subsequent 24- to 48-hour cardiac monitoring for any ECG abnormalities, cardiac dysrhythmias, cardiac arrest, or loss of consciousness.[13]

### *The Secondary Survey*

The secondary survey follows the primary survey.[10] Importantly, once adequately stabilized and resuscitated, all patients with electrical burns should be transferred to specialized burn centers, consistent with the American Burn Association's referral