The Contemporary Management of Electrical Injuries
Resuscitation, Reconstruction, Rehabilitation

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Purpose: Due to advances in resuscitation of patients with electrical injuries, new challenges in reconstruction and rehabilitation have emerged. This study is a comprehensive institutional review of a prospectively gathered database of patients with electrical injuries, from initial resuscitation through final impairment ratings.

Methods: A trauma registry was used to identify patients with electrical injuries. Procedures needed, their timing, final impairment ratings, and return to work were recorded.

Results: From 2000 through 2005, we managed 115 patients with electrical injuries. Mean follow-up was 352 days. The average patient age was 34.9 years. Eighty-five (73.9%) of these injuries were work-related. There were 2 mortalities (1.7%). Although average burn size was only 8%, patients suffered many complications acutely and chronically. Numerous surgical interventions were required during the resuscitative (within 48 hours), an early reconstructive and resurfacing (within 30 days), and a late reconstructive and rehabilitative phase. Mean final impairment rating was 11%. Average time to return to work was 101 days.

Conclusions: Electrical injuries can produce significant morbidity despite relatively small burn sizes. Patients require early operative procedures for prevention of further injury. Timely reconstructive surgery may improve final function and return to productivity. Finally, continued reconstruction may ensure improved late outcomes. The plastic surgeon is essential to patients with electrical injuries through all phases of their care.

Key Words: electrical burn, burn resuscitation, burn reconstruction, burn rehabilitation, burn treatment, burn plastic surgery, contemporary burn management

(*Ann Plast Surg* 2007;58: 273–278)

Received and accepted for publication September 19, 2006.
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This study was supported by the University of North Carolina–Chapel Hill Department of Surgery and the North Carolina Jaycee Burn Center.
Presented at the Annual Meeting of the Southeastern Society of Plastic and Reconstructive Surgeons, The Cloisters, Sea Island, GA, June 3–7, 2006.
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ISSN: 0148-7043/07/5803-0273
DOI: 10.1097/01.sap.0000250837.18740.d9

Electrical injuries represent approximately 5% of burn admissions.[1,2] In 1999, the impact of electrical injuries was estimated to be in excess of $1 billion annually. Electrical injury is a leading cause of work-related injury,[1] and these injuries contributed to 380 deaths and 5467 persons missing work per year in the 1990s.[2] Nearly all cases of electrical injury eventually involve litigation for negligence, product liability, or worker compensation.[3] Addressing the injuries successfully will translate into great personal benefit to the patient and economic benefit to society in terms of regained productivity on the part of these young patients.

Our hypothesis is that the early and continued involvement by the plastic surgeon in the care of patients with electrical injuries will lead to improved outcomes and greater return to productivity. We present 2 patients and discuss the approach to the care of these patients.

Questions that remain to be answered include timing of and indications for reconstructive and prophylactic interventions. Surgical management versus splinting is a point of discussion with oral commissure burns. The use of free flaps, synthetic or modified human materials, and transplants remain a controversial option.

Background

Many authors have addressed specific needs of the patient with electrical burns.

Resuscitation

Rouse and Dimick[4] clearly defined differences between electrical and burn injury. In addressing the early needs of the patient with electrical burns, they reiterated the need for high-volume resuscitation, aggressive fasciotomy, and surgical debridement. Koumbourlis[5] described the care of these patients in the intensive care unit (ICU). Luce[6] and Celik et al[7] described the scope of injuries suffered. Engrav et al[8] discussed the treatment and outcomes of patients with immediate median and ulnar nerve palsies.

Reconstruction

Canady et al,[9] al-Qattan et al,[10] and Barone et al[11] looked at oral commissure burn treatment. Konigova,[12] McCauley,[13] MacKinnon et al,[14] and Orgill and Pripaz[15] examined multiple aspects of reconstruction of electrical injuries, while Kumar and Varma,[16] Zhu et al,[17] Yunchuane et al,[18] and Chai[20] examined emergent reconstruction.

Rehabilitation

Smith et al[19] identified long-term neuropsychiatric issues: tetraplegia, gait disturbance, personality changes, seizures, and

nerve compression. Lee, et al[21] explored the multidisciplinary approach to prevention and rehabilitation with a strong focus on the basic sciences. Esselman et al[2] provided an excellent comprehensive review of contemporary rehabilitation.

Purpose

The purpose of this investigation is to evaluate the epidemiology, inpatient and outpatient course, and long-term outcome of contemporary patients with electrical burn injury. We wish to redefine the role of the plastic surgeon through all phases of treatment.

METHODS

An IRB-approved search of a prospectively maintained trauma database from 2000–2005 was undertaken at the North Carolina Jaycee Burn Center of the University of North Carolina at Chapel Hill. The facility is an ABA-accredited unit with 20 ICU beds. Data from initial resuscitation through final ratings[26] were then culled. Results were sorted into the resuscitative phase (first 48 hours), the resurfacing and early reconstructive phase (48 hours through 30 days), and the late reconstructive and rehabilitative stage (greater than 30 days).

RESULTS

Demographics

Of 2548 patients treated at the burn center during this time period, electrical burns comprised 115 patients (Fig. 1). Of the 115 patients with electrical injury, 85 (73.9%) were work-related. Average patient age was 34.9 years. One hundred ten of the patients were men, and 5 were women. Average total body surface area burn was 8%. Two patients (1.7%) died. Etiology of the electrical injury was high voltage in 60 patients, low voltage in 25, arc in 29, and lightning in 1 (Fig. 2). Eighty-five of the injuries (74%) were work-related. Eighty patients had workman's compensation coverage. Final ratings were conducted in 32 patients (40%). The mean final impairment rating was 11% of the total body. Mean time to return to work was 101 days. Ten patients (12.5%) were lost to follow-up. Mean follow-up was 352 days.

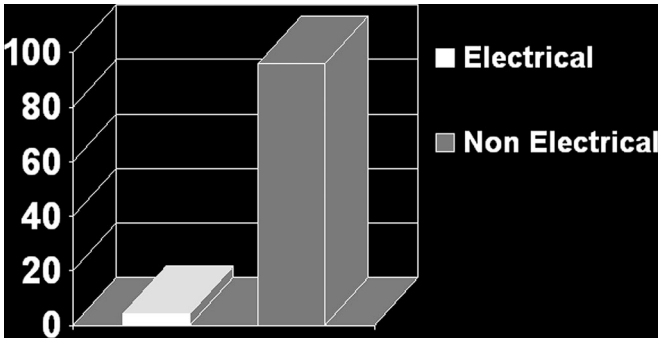

FIGURE 1. Mechanism of injury.

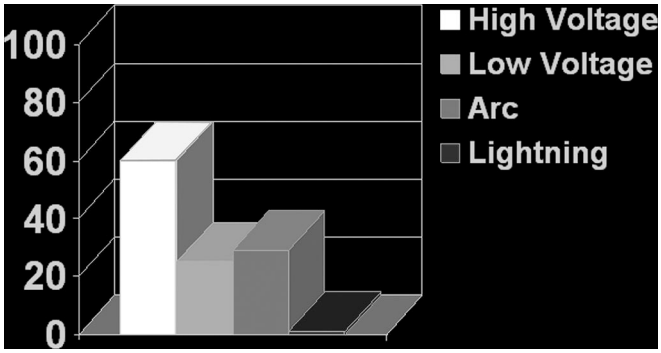

FIGURE 2. Etiology of electrical injury.

Resuscitation Phase

In the first 48 hours, fasciotomies were performed on 19 patients (16.5%). Thirteen patients (11.3%) required nerve decompression (carpal tunnel release, Guyon canal release, or cubital tunnel release). Early excision was necessary in 9 patients (7.8%), and 2 patients (1.7%) were treated for renal failure. The mean length of ICU stay was 6.5 days

Resurfacing and Early Reconstruction Phase

Thirty-eight patients required reconstruction during the early phase. Thirty-seven (32.3%) required staged excision,

FIGURE 3. High-voltage injury to abdomen, chest, bilateral thighs, and upper extremity.

FIGURE 4. Early excision.

FIGURE 5. Initial central Dexon mesh and lateral skin grafting.

FIGURE 6. Return to OR with necrotic bowel.

FIGURE 7. Abdominal wall hernia.

FIGURE 8. After excision, and skin grafting.

and 34 patients (29.6%) were grafted. Materials used were split-thickness skin grafts, full-thickness skin grafts, homograft, and Integra. Orthopedic procedures (amputations or joint procedures) were performed on 15 patients (13%). Four patients (3.5%) required flap coverage. Types of flaps used were fillet flap, first dorsal metatarsal artery flap, groin flap, and radial forearm flap.

Late Reconstruction and Rehabilitation Phase

Fifteen patients required operation during the late reconstruction and rehabilitation phase. Five patients (4.3%) required flaps, which included radial forearm adipofascial turnover flap, latissimus flap, gastrocnemius flap, posterior interosseous flap, and cervicofacial fasciocutaneous flap. Nerve decompression, neurolysis, nerve graft (median and peroneal), and neuroma excision composed the 12 (10.4%) nerve procedures. Six patients (5.2%) had tendon reconstruction performed. This included tendon repair, staged tendon graft, tendon transfers (opponensplasty and FPL), tenodesis, and tenolysis. Ten patients (8.7%) required treatment of contractures. Procedures performed included ATR, full-thickness skin grafts, and steroid injections. Web space reconstruction was required in 5 patients (4.3%). Two patients (1.7%) had their ears reconstructed with a cartilage graft and TP fascial flap. Ectropion release was performed in 1 patient and mouth construction in 1 patient (Abbe flap).

Case 1

A 34-year-old man presented with a 45% TBSA injury to trunk and extremities, from a high-voltage transformer (Figs. 3–9). The patient sustained burns to his abdomen, lower chest, bilateral thighs, and upper extremity.

During the resuscitative phase, the patient required upper-extremity fasciotomies and a chest escharotomy. Following initial resuscitation, he was taken to the OR for excision of his burns, abdominal exploration, and grafting. At the time of this operation, the patient's intraabdominal organs appeared viable. The excision of the abdominal wall burn was

FIGURE 9. Hypertrophic scar at palm and necrosis at forearm graft site.

taken to the level of the fascia, and the patient's abdomen was closed using Dexon mesh.

Several days later, the patient's course worsened, and he was taken to the OR for reexploration of his abdomen and any necessary further excisions. Necrotic small bowel and abdominal fascia were encountered. Both were excised, and the small bowel was anastomosed primarily. During this early reconstruction phase, initial placement of Biobrane was followed by a skin graft over the small bowel. The patient required a tracheostomy tube placement and a bilateral orchiectomy during this time, as well.

During the late reconstruction phase, the patient had bilateral carpal tunnel releases and the release of an antecubital fossa flexion contracture. Currently, the patient has a large abdominal wall hernia that is fairly well contained by an abdominal binder. He has had several episodes of skin breakdown and intertriginous cellulitis. The patient reports limited activity as any bending aggravates the irritation caused by the abdominal binder. Care of this patient is ongoing.

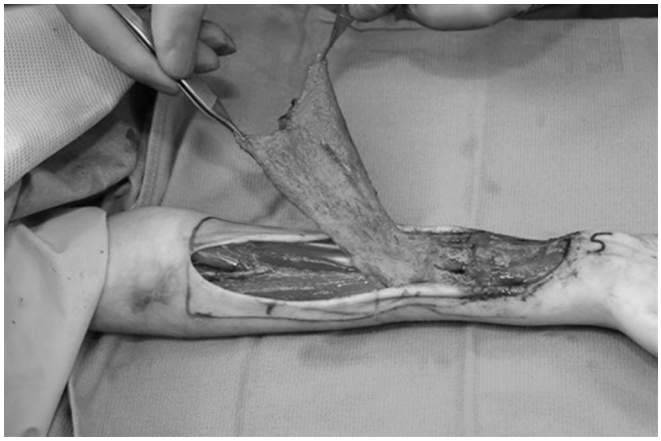

FIGURE 10. Reverse radial forearm flap.

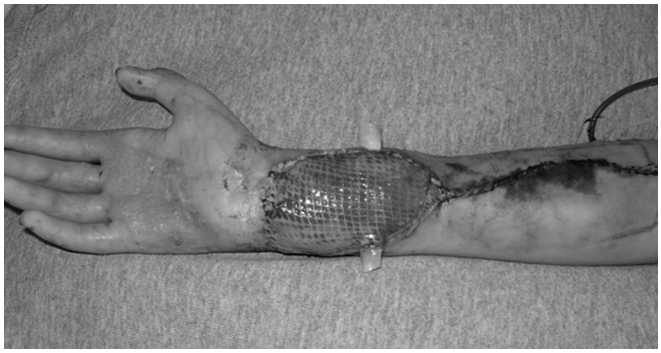

FIGURE 11. Graft over reverse radial forearm flap.

Case 2

A 9-year-old boy presented with 6% TBSA injury to extremities from a low-voltage barn outlet. He sustained burns to his bilateral hands and forearms, as well as his feet and legs bilaterally. During the immediate resuscitation, the patient underwent fasciotomies and carpal tunnel release of the right hand. One day later, the patient had further fascioto-

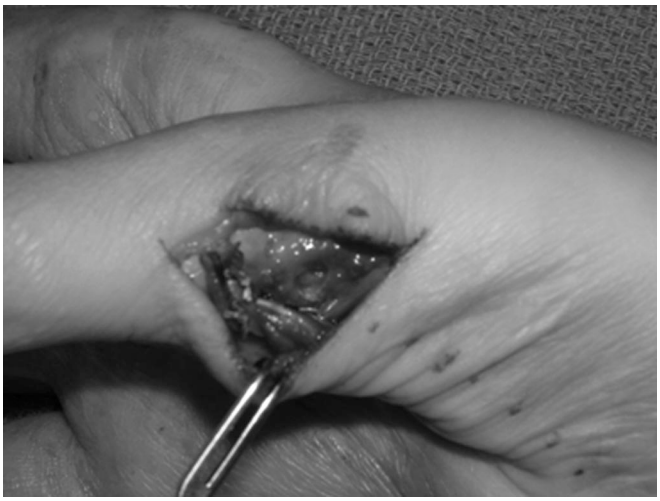

FIGURE 12. Opponensplasty.

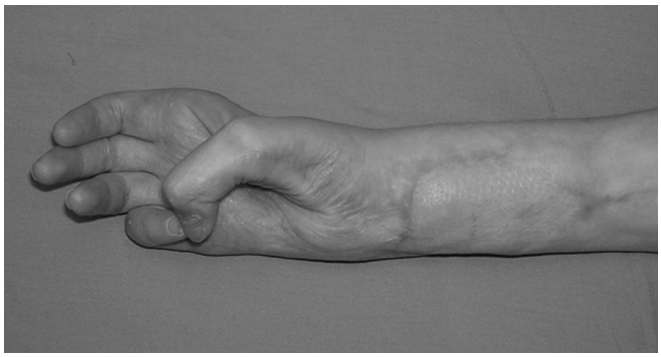

FIGURE 13. Recovered opposition.

mies performed on the right arm and a carpal tunnel release, and all of his burns were excised.

During the early reconstructive period, the patient had left toes 3–5 and right toes 2–5 amputated. Within the next few days all burns were first homografted, then autografted. The graft to the right forearm did not survive. Multiple tendons and the median nerve were exposed. This area was treated with wound care until a turnover adipofascial flap was used for definitive coverage. A split-thickness skin graft was placed over the flap (Figs. 10 and 11).

During the late reconstructive period, an opponensplasty was performed to allow for opposition (Figs. 12 and 13). Care of this patient is ongoing.

Summary

Both high- and low-voltage electrical injuries can produce significant morbidity despite a relatively small burn size, as illustrated by the 2 cases presented. Patients require early and ongoing operative procedures for prevention of further injury, for initial resurfacing, and for reconstruction. During the resuscitative period, efforts were focused on limiting further tissue damage. Fasciotomies, escharotomies, and excisions were performed, with or without nerve tunnel releases.

The early reconstructive period was marked by grafting, reexplorations, and nerve tunnel releases, as well as amputations or joint procedures.

During the late reconstructive and rehabilitative period, efforts were directed at restoring form and function. Once primary reconstruction and aggressive physical and occupational therapy yielded maximal results, further procedures to improve late function were undertaken. Nerve procedures, contracture releases, flaps, and mouth or ear reconstruction were typical during this phase.

DISCUSSION

Electricity is the flow of electrons through a conductor.[5] Mechanisms of electrical injury include Joule heating and dielectric heating. This Joule heating results in thermally driven permeabilization of the cell membrane and protein denaturation. In addition, direct electropermeabilization of cell membranes causes tissue damage.[1]

According to Ohm's Law, current is proportional to the voltage divided by the resistance. Recently, the historic belief that nerves and blood vessels preferentially conducted electric current was proven to be incorrect. Bones, fat, and tendons have the highest resistance, creating the most heat. Nerves, blood, and mucous membranes have a lesser resistance.[22] In vivo, however, conduction of current is related to the composite resistance of all body tissue components and to the cross-sectional diameter of the body part.[6]

We followed 2 patients through their treatment courses. During resuscitation, patient 1 required excision of nonviable tissue. An adequate, but not excessive resuscitation is essential for balancing potential morbidity related to hypovolemia versus unnecessary compartment syndromes. Elevation can further decrease the risk of compartment syndromes in minimally involved extremities. Patients are monitored for myoglobinuria. Cardiac monitoring is advised during this period for low-voltage injury. Prevention of nerve injury and preservation of muscle and tendon function mandate early involvement of the plastic surgeon as patients with commercial frequency electrical burns commonly have mononeuropathies.[23] They are most likely to burn the upper limb.[24] (Patients with lightning injuries occasionally suffer from progressive myelopathies, which are not treatable.[2]) Another factor that contributes to greater tissue injury is small circumference of a body part. All of the above illustrates the vulnerability of the extremities, particularly the upper. Although early fasciotomy and nerve tunnel release may not alter the course of direct nerve injury, they may prevent further injury due to extrinsic pressure on the nerves. The plastic surgeon in these cases was involved in early fasciotomies, nerve tunnel release, and evaluation of options for immediate resurfacing for both patients. Kamar and Varma,[16] Zhu et al,[17] Yunchuan et al,[18] and Chai[19] all reported reconstruction during this time period. Methods used by them included multiple pedicled and local flaps, including one harvested from an extremity that needed amputation. Good outcomes compared with previous patients were reported by Zhu et al.[17] However, improvements in critical care during this time period may have contributed to better outcomes. Ultimately, the treatment approach during resuscitation is aimed at stabilizing the patient and preventing further injury. More study is needed to determine the best timing of major reconstruction and if early reconstruction prevents progression of injury.

During the early reconstructive and resurfacing phase, more definitive graft and flap coverage by the plastic surgeon for both patients was essential to protect vital structures (nerve, muscle and tendon, and bowel). The major challenges for coverage in our patients were the forearm of patient 2 and the abdomen of patient 1. The forearm was covered using a turnover adipofascial flap and skin graft without difficulty. Coverage of the massive abdominal defect in patient 1 proved more difficult. The patient was closed with mesh and then a skin graft. However, he currently suffers the complications of a large abdominal hernia. Methods of definitive abdominal coverage previously described include but are not limited to flaps based on anterior midline or intercostal perforators, superficial inferior, or superior epigastric vessels. These flaps include thoracic myocutaneous and external oblique flaps for the upper abdomen, tensor fasciae latae flaps for infraumbilical defects, extended latissimus dorsi flaps, and rectus abdo-

minus flaps.[25] Patient 1 did not have sufficient tissue to perform any of these flaps safely. Future options for coverage of massive electrical abdominal wounds may be dermal matrix or abdominal wall transplant. However, the patient and surgeons at this time do not believe that the risks of these procedures outweigh the benefits currently possible. Scalp injuries can prove very challenging to definitively cover, as well. Many types of flaps have been reported, and dermal matrix or substitute may be a viable option. The plastic surgeon may need to address injuries such as oral commissure burns during this time. Canady et al[9] advocate early surgery, whereas Al-Qattan et al[10] and Barone et al[11] had satisfactory results with splinting after primary healing. Surgeons performed amputations on patient 2 during this time. Physical and occupational therapy were started to minimize complications such as contracture, decreased range of motion and eventual joint fusion, pressure sores, and generalized deconditioning.

Finally, when preventive procedures and therapy fail to fully restore function, the plastic surgeon revisits the patient. Particularly, tendon and nerve procedures may restore some lost function during the late reconstructive phase, as seen with carpal tunnel releases and opponensplasty on our patients. Ultimately, these interventions may decrease final impairment and facilitate return to work and society. The patient with electrical injury is a young, employed person who can potentially return to a productive working life. Successfully achieving this goal would save society a great loss of human potential and benefit the patient greatly.

We would like this objective record of final impairment ratings and days to return to work to serve as a control for us to compare future treatment strategies, such that relative outcome data may be generated. More study is needed to determine precise indications for and timing of prophylactic procedures, whether comprehensive reconstruction during the resuscitative phase benefits patients, if and when free flap coverage is a safe option, and whether dermal matrices or substitutes improve functional outcomes. Although we lack controlled data on outcomes, it is evident that the plastic surgeon is actively involved in all phases of the pursuit of maximal recovery of the patient with electrical injury.

CONCLUSION

While physicians and practitioners of many specialties play integral roles during specific phases of the care of patients with electrical injuries, the plastic surgeon is essential to all phases of the treatment of these patients. Their involvement spans from performing prophylactic procedures early through maximizing functional outcomes after primary reconstruction and maximal occupational and physical therapy.

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