Practice Guidelines for the Management of Electrical Injuries

Brett Arnoldo, MD,* Matthew Klein, MD† Nicole S. Gibran, MD

There has been increasing emphasis on the development of practice guidelines and validated measurements to evaluate surgical practice. Initiatives such as the National Surgical Quality Improvement Program (NSQIP) have demonstrated the importance of an outcome-based approach to improving surgical care. The development of guidelines and outcome-based benchmarks requires established standards of practice that should be based on level I data from well-designed prospective randomized trials.

Electrical burns are potentially devastating injuries with both short- and long-term sequelae. In 2001, the American Burn Association published a set of practice guidelines for various aspects of burn care in the Journal of Burn Care and Rehabilitation. However, guidelines for the management of electrical burns were not included. Two fundamental—and controversial—issues in the management of electrical burns are cardiac monitoring and evaluation and treatment of the injured upper extremity. We have reviewed and analyzed the available literature in an effort to develop practice guidelines for these two important issues.

SECTION I: CARDIAC MONITORING AFTER ELECTRICAL INJURIES

Recommendations

Standards. An electrocardiogram (ECG) should be performed on all patients who sustain electrical injuries (high and low voltage).

Guidelines
1. Children and adults who sustain low-voltage electrical injuries, have no ECG abnormalities, no history of loss of consciousness, and no other indications for admission (ie, soft-tissue injury), can be discharged from the emergency room.
2. All patients with history of loss of consciousness or documented dysrhythmia either before or after admission to the emergency room should be admitted for telemetry monitoring. Patients with ECG evidence of ischemia should be admitted and placed on cardiac monitors.
3. Creatine kinase enzyme levels, including MB fraction, are not reliable indicators of cardiac injury after electrical burns and should not be used in decisions regarding patient disposition. Insufficient data exists on troponin levels to formulate a guideline.

Options. Electrical injuries can result in potentially fatal cardiac dysrhythmias. The need for cardiac evaluation and subsequent cardiac monitoring are critical components in electrical burn management. Most patients who sustain electrical injuries undergo ECG evaluation, and patients with documented dysrhythmias, cardiac ischemia, or history of loss of consciousness will be admitted to the hospital for further evaluation and monitoring. However, the appropriate cardiac diagnostic tests and the indications for hospital admission, necessity of cardiac monitoring, and appropriate duration of cardiac monitoring have not been well established.

OVERVIEW

Purpose

The purpose of this guideline review is to review the current data on practices for diagnosing cardiac injury and indications for cardiac monitoring after electrical injury.

Users

These guidelines are designed to aid physicians in making decisions regarding patient disposition, diagnostic tests and management of patients following electrical injury.
Clinical Problem
The potential for development of cardiac dysrhythmia, cardiac arrest, and myocardial damage after electrical injury has been well documented. Cardiac dysrhythmias, cardiac standstill, and myocardial injury can occur after both low- (<1000 V) and high-voltage (>1000 V) injury. The potential for cardiac dysrhythmia and injury has prompted routine cardiac evaluation and low threshold for patient admission and of all patients who sustain electrical injury. Whereas obtaining an ECG is a well-established component of the early evaluation of patients after electrical injury, the indications for patient admission and appropriate duration of cardiac monitoring have been less clear. Traditionally, patients with low-voltage injuries who have normal ECGs and no history of loss of consciousness are discharged from the hospital. However, appropriate management of patients who sustain high-voltage injuries has not been well defined. Generally, patients who have a history of loss of consciousness, ECG abnormalities, or have injuries that would otherwise require admission are admitted to the hospital and are placed on telemetry monitors. There are several issues related to the cardiac evaluation and monitoring that need to be addressed: 1) Should all patients with high-voltage electrical injuries be admitted to the hospital, even if there is no evidence of cardiac abnormality? 2) What is the role of cardiac enzymes in the evaluation and management of electrical injuries? 3) How long should patients be monitored on telemetry?

Process
A Medline search was conducted of all available literature from 1966 to 2004 using the key words electrical, burns, cardiac, monitoring. In addition, several articles were not identified in the Medline search but were referenced in the articles reviewed and were found to be relevant: a total of 27 articles were reviewed and found to be relevant.

References were classified as Class I evidence (prospective, randomized, controlled trials); Class II evidence (prospective or retrospective studies based on clearly reliable data); Class III evidence (evidence provided by clinical series, comparative studies, case reviews or reports); or as a technology assessment (a study that examined the utility/reliability of a particular technology).

Scientific Foundation
Cardiac Abnormalities. All studies reviewed confirmed that cardiac abnormalities—including dysrhythmias and myocardial damage—occur after both low-voltage and high-voltage injuries, reinforcing the need for ECG evaluation of all patients. Nonspecific ST-T changes were the most common ECG abnormality, and atrial fibrillation was the most common dysrhythmia.

Criteria for Admission
Admission and cardiac monitoring for patients with history of loss of consciousness, ECG abnormalities, or with other indications for admission (ie, TBSA burned, need for extremity monitoring) are standard practices in all series of electrical injuries reviewed. In addition, the majority of patients with low-voltage injuries and normal ECG are discharged home from the emergency room without complication. The safety of this practice also was confirmed in two series of pediatric patients. The possible exceptions include patients with other injuries that require hospitalization or children with an oral burn that would require monitoring for labial artery bleeding.

Virtually all patients with high-voltage injuries are admitted for cardiac monitoring; however, it is unclear whether this step is necessary. With increasing emphasis on cost-effectiveness, the routine admission of all patients with high-voltage injury must be questioned. Hunt, Bailey et al, and Arrowsmith et al reported that all cardiac irregularities were evident either on admission to the emergency room or within several hours of hospitalization and in 1986, Purdue and Hunt reported that no serious arrhythmias occurred in any patient who a normal ECG on admission. Taken together, these studies suggest that a negative initial evaluation could obviate the need for hospital admission solely for cardiac monitoring. However, these were observations based on retrospective data and are inadequate to form the basis of a practice guideline. On the basis of their findings, Purdue and Hunt generated the following set of admission criteria for electrically injured patients: 1) loss of consciousness or cardiac arrest in the field; 2) documented cardiac arrhythmia in the field; 3) abnormal ECG; or 4) a separate indication for admission. They applied these criteria prospectively to 10 consecutive patients and reported no complications. This study is the first to investigate not routinely monitoring patients who sustained high-voltage injuries. However, this series is too small to affect practice.

One study suggested that presentation of cardiac abnormalities could be delayed. Jensen et al reported three patients with a delay in the onset of symptoms after low-voltage (two patients) and high-voltage (one patient) injuries. All presented to the emergency room only after they developed chest pain.
and palpitations. However, none of the patients had ECGs or any sort of evaluation at the time of injury and, therefore, this study does not provide substantive evidence of truly late dysrhythmia presentation.

**Duration of Monitoring**

No published studies have directly studied the appropriate duration of telemetry monitoring after injury. Several series reported monitoring for 24 hours after admission if there were no ECG abnormalities on admission or monitoring for 24 hours after resolution of dysrhythmias. Arrowsmith et al reported that all patients with dysrhythmias resolved within 48 hours of admission either spontaneously or with pharmacologic intervention. However, there are no data available to formulate appropriate management guidelines for this issue.

**Utility of Creatine Kinase**

Creatine kinase levels frequently are obtained after electrical injury. CK has long been used as an indicator of muscle injury and can help in determining the extent of extremity muscle injury. The MB subunit has been reported to be more specific for myocardium and, therefore, has been used to evaluate cardiac injury after electrical injury. Only one study reported a reliable correlation between serum CK-MB levels and cardiac injury. Chandra et al reported that the time course of the MB fraction increase and decrease was a reliable indicator of cardiac ischemia. However, this study does not correlate the elevated enzyme levels with any other study of cardiac injury. Conversely, the evidence of poor or questionable correlation was quite strong. Several studies demonstrated that CK-MB levels poorly predict cardiac injury and that the elevated enzyme levels likely result from noncardiac muscle injury. Housinger et al suggested that positive MB fractions in the absence of ECG findings should be interpreted with caution because they may not signify cardiac injury. Given the paucity of evidence supporting the utility of CK-MB levels, this laboratory value should not be used as a diagnostic criterion for cardiac injury after electrical injury.

**SUMMARY**

The current practices of admitting patients with history of loss of consciousness, documented dysrhythmia in the field, or ECG abnormalities are well supported in the literature. Similarly, discharging patients from the emergency room with low-voltage injuries and normal ECGs is well established. However, few data are available to support establishment of guidelines for the management of patients with high-voltage injuries and normal ECGs. The two studies that addressed this question have population sizes that are too small to support changes in practice. Future prospective and randomized studies (as described herein) are needed to effectively establish practice guidelines. In addition, there is inadequate evidence to formulate guidelines for the duration of monitoring for patients with ECG abnormalities.

Sufficient data are available to conclude that CK-MB is an unreliable diagnostic test for cardiac injury after electrical injury. The presence of skeletal muscle injury in these patients confounds the results of this laboratory test. No studies identified in this review examined the specificity and utility of troponin levels in determining cardiac injury.

**Key Issues for Further Evaluation**

1. Utility of troponin: CK and CK-MB not specific for cardiac muscle. Insufficient data exists evaluating the utility of troponin in assessing cardiac injury.
2. Duration of monitoring: insufficient data exists to determine the optimal duration of telemetry monitoring after electrical injury for patients who have abnormal ECGs or history of loss of consciousness. There have been no studies that directly examined this specific question.
3. Admission for high-voltage injuries: insufficient data exists to establish guidelines for whether to admit patients who sustain high-voltage injuries but have normal ECG’s and no history of loss of consciousness. The available data suggest that these patients could be discharged but further, prospective evaluation is required.

**Evidentiary Table**

Studies on the practices of cardiac evaluation and monitoring are summarized in Table 1.

**II. EVALUATION AND MANAGEMENT OF THE UPPER EXTREMITY**

**Recommendations**

**Standards.** Insufficient data exist to support a treatment standard for this topic.

**Guidelines**

1. Patients with high-voltage electrical injury to the upper extremity should be referred to specialized burn centers experienced with these injuries as per American Burn Association referral criteria.
2. Indications for surgical decompression include progressive neurologic dysfunction, vascular
## Table 1. Evidence table

<table>
<thead>
<tr>
<th>Reference</th>
<th>Study Description</th>
<th>Data Class</th>
<th>Conclusions/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahrenholz et al, 1988&lt;sup&gt;13&lt;/sup&gt;</td>
<td>Retrospective study of 125 patients admitted with electrical injuries</td>
<td>II</td>
<td>Demonstrated that there is a poor correlation between elevated CK-MB levels and cardiac injury</td>
</tr>
<tr>
<td>Arrowsmith et al, 1997&lt;sup&gt;10&lt;/sup&gt;</td>
<td>Retrospective study of 145 patients admitted with electrical injuries to determine incidence of cardiac complications</td>
<td>II</td>
<td>All patients with cardiac complications had them at the time of admission. Patients with normal ECG and no loss of consciousness do not require admission for cardiac monitoring</td>
</tr>
<tr>
<td>Bailey et al, 1995&lt;sup&gt;43&lt;/sup&gt;</td>
<td>Retrospective review of 141 children admitted to the emergency department with household electrical injuries</td>
<td>II</td>
<td>Children with normal ECG and low voltage injuries do not require cardiac monitoring. Authors also suggested that ECG is not indicated for children with low-voltage injuries, no loss of consciousness, no tetany, no water contact, and no current crossing the heart region</td>
</tr>
<tr>
<td>Bailey et al, 2000&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Prospective evaluation of a set of admission guidelines after electrical injury. Guidelines were applied to a total of 224 patients</td>
<td>II</td>
<td>Guidelines for admission were used in the majority of cases. According to the guidelines, all patients with high-voltage injuries were admitted, as were patients with low-voltage injuries with ECG abnormalities, past cardiac history, water contact, and tetany</td>
</tr>
<tr>
<td>Chandra et al, 1990&lt;sup&gt;6&lt;/sup&gt;</td>
<td>Prospective evaluation of 34 patients admitted with high-voltage electrical injuries to determine predictors of myocardial damage</td>
<td>II</td>
<td>Time course of CK-MB elevation in patients with electrical injuries suggests that it is cardiac in etiology. ECG may not be reliable for diagnosing myocardial damage</td>
</tr>
<tr>
<td>Cunningham, 1991&lt;sup&gt;44&lt;/sup&gt;</td>
<td>Retrospective study of 70 patients admitted with electrical injury</td>
<td>II</td>
<td>Discharged all patients with low-voltage injuries who are asymptomatic and had normal ECG without complication</td>
</tr>
<tr>
<td>Guinard et al, 1987&lt;sup&gt;15&lt;/sup&gt;</td>
<td>Prospective evaluation of 10 patients admitted with electrical injuries</td>
<td>III</td>
<td>Demonstrated poor reliability of CK-MB to identify cardiac injuries</td>
</tr>
<tr>
<td>Housinger et al, 1985&lt;sup&gt;7&lt;/sup&gt;</td>
<td>Prospective study of 16 patients to determine incidence of possible myocardial damage following electrical burn</td>
<td>III</td>
<td>Demonstrated poor correlation between elevation of CK-MB levels and ECG abnormalities. Pyrophosphate scans were used as diagnostic standard for cardiac injury</td>
</tr>
<tr>
<td>Hunt et al, 1980&lt;sup&gt;9&lt;/sup&gt;</td>
<td>Retrospective review of 102 patients with high-voltage injuries</td>
<td>II</td>
<td>All cardiac abnormalities were evident either on admission of within several hours of hospitalization</td>
</tr>
<tr>
<td>Jensen et al, 1987&lt;sup&gt;11&lt;/sup&gt;</td>
<td>Three case reports of late presentation of cardiac abnormalities after electrical injury</td>
<td>III</td>
<td>Three patients with late presentation of cardiac abnormalities. However, none of the patients were evaluated immediately after injury</td>
</tr>
<tr>
<td>Lewin et al, 1983&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Case report of 19-year old patient with myocardial injury after electrical injury</td>
<td>III</td>
<td>Demonstrated correlation of CK-MB levels with ECG abnormalities and myocardial injury</td>
</tr>
<tr>
<td>Purdue and Hunt, 1986&lt;sup&gt;5&lt;/sup&gt;</td>
<td>Retrospective study of 48 patients admitted with high-voltage injuries. On the basis of these findings, a prospective study of 10 patients applying guidelines for admission</td>
<td>II</td>
<td>Designed a protocol for determining which patients should be admitted following high voltage injury. No complications following discharge of patients with high voltage injuries and no other indications for admission. Comment: First study to demonstrate safety of discharging patients with high-voltage injuries and normal ECGs. However, small group of patients studied</td>
</tr>
<tr>
<td>Wallace et al, 1995&lt;sup&gt;8&lt;/sup&gt;</td>
<td>Retrospective study of 35 pediatric patients with both low and high voltage injuries</td>
<td>II</td>
<td>Children with low-voltage injuries and normal ECGs can be discharged. However, all patients with high-voltage injuries were admitted and monitored</td>
</tr>
<tr>
<td>Zubair et al, 1997&lt;sup&gt;12&lt;/sup&gt;</td>
<td>Retrospective study of 127 pediatric patients with low- and high-voltage injuries</td>
<td>II</td>
<td>Recommend 4 hours of monitoring for all patients before discharge and admission of all patients with high-voltage injuries, loss of consciousness, or ECG abnormalities</td>
</tr>
</tbody>
</table>

Comment: First study to demonstrate safety of discharging patients with high-voltage injuries and normal ECGs. However, small group of patients studied.
compromise, increased compartment pressure, and systemic clinical deterioration from suspected ongoing myonecrosis. Decompression includes forearm fasciotomy and assessment of muscle compartments. The decision to include a carpal tunnel release should be made on a case-by-case basis.

**Options.** There are several methods to evaluate the injured extremity. Compartment pressures may be measured as an adjunct to clinical examination. Pressures greater than 30 mm Hg, or tissue pressure reaching within 10 to 20 mm Hg of diastolic pressure, may be used as evidence of increased compartment pressure and potential deep-tissue injury, indicating the need for surgical decompression in the appropriate clinical setting. Technetium-99m pyrophosphate scan may be used as an adjunct to clinical examination at centers experienced with this technology. Doppler flow meter can be used as an adjunct to assess extremity perfusion. It should not be relied on as the sole indicator of deep-tissue viability and adequate perfusion.

**OVERVIEW**

**Purpose**
The purpose of this guideline is to review the principles of monitoring and treatment of high-voltage electrical burn injury to the upper extremity. The upper extremity is commonly injured after high-voltage electrical and carries with it a high rate of morbidity.

**Clinical Problem**
Burns resulting from high-voltage electric current (>1000 V) often are associated with a greater degree of deep-tissue injury than is initially appreciated. As a result these rather infrequent injuries, which make up only 3% to 12% of burn center admissions, are associated with high amputation rates and greater use of resources than comparable %TBSA cutaneous burns. Unnecessary exploration can increase morbidity, length of stay, and the use of scarce resources. Delayed exploration and decompression in the compromised extremity, however, may result in increased amputation rates along with increased organ failure and mortality.

**Process**
A Medline search from 1966 to the present was used to evaluate monitoring and the need for early exploration and fasciotomy in electrical injury to the extremity. A search for the key words, “electrical injury,” “fasciotomy,” “compartment syndrome,” “compartment pressure,” “Doppler flow meter,” “technetium 99m pyrophosphate,” “infrared photoplethysmography,” and “burn injury” was performed, and relevant articles were reviewed. Studies of patients with lower-extremity injuries were included because of the scarcity of data involving exclusively the upper extremity. An attempt was made however to analyze the data involving the upper extremity exclusively where possible.

**Scientific Foundation**
Electrical injuries, including lightning strikes, should be referred to a specialized burn center as per American Burn Association criteria. Many surgeons advocate immediate surgical exploration (usually within the first 24 hours), and decompression of patients with high-voltage electrical injuries. Early exploration, fasciotomy, and débridement are followed by serial débridement of necrotic tissue and subsequent closure. These studies are somewhat difficult to interpret; however, because of the differences in the degree of injury no prospective, randomized, controlled trials evaluating immediate exploration have been performed. The rational for this aggressive approach relates to thermal mechanics. Joule’s law defining the amount of power (heat) delivered to an object:

\[
\text{Power (J-Joule)} = I^2 \times R \\text{ (Current times R Resistance).}
\]

Accordingly, deep muscle necrosis can occur in the muscle adjacent to bone, which has a high resistance. Failure to perform adequate fasciotomy and to evaluate all muscle compartments may lead to misdiagnosis of deep thermal injury. This approach however, commits the patient to several operations and may prolong hospital stay and morbidity.

In the d’Amato series, six patients underwent emergency exploratory surgery and amputation for obvious necrotic extremities, followed by serial débridement. No patient required an amputation for misdiagnosed deep muscle necrosis. However, missed injury was present in two patients, who required further surgical intervention, although neither required amputation because of the missed injury. Parshley’s series evaluated 41 patients with 27 extremities explored. Amputation rate was 40% with 10 extremities salvaged, which the authors attribute to early aggressive operative intervention. Haberal’s series of 94 patients had an amputation rate of 43%. The authors attributed this high amputation rate in part because of a delay in surgical exploration as a result of patients being transferred from nonspecialized facilities. Achauer et al reported a series of 22 patients with an amputation rate of 40%. They recommend “extensive débridement of all damaged tissue and ex-
### Table 2. Evidentiary table: high-voltage electric injury to upper extremity

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
<th>Data Class</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinby et al, 1978&lt;sup&gt;25&lt;/sup&gt;</td>
<td>Retrospective review of 44 patients divided into 22 with electric arc and 22 with flow of current</td>
<td>II</td>
<td>In conductive burns with entrance site in hand, incision was carried from hand to interconnect the arc burns at wrist, elbow, and shoulder. Fasciotomies done if muscle discolored, or tense, transverse carpal ligament release done. Amputation rate 68%</td>
</tr>
<tr>
<td>Luce et al, 1984&lt;sup&gt;26&lt;/sup&gt;</td>
<td>Retrospective review of 31 patients</td>
<td>II</td>
<td>Fasciotomy and wound exploration and debridement within 24 hours of admission Amputation rate 35.5%</td>
</tr>
<tr>
<td>Parsley et al, 1985&lt;sup&gt;22&lt;/sup&gt;</td>
<td>Retrospective review 41 patients with passage of current</td>
<td>II</td>
<td>Early fasciotomy in patients with passage of current Amputation rate 40%</td>
</tr>
<tr>
<td>Achauer et al, 1994&lt;sup&gt;21&lt;/sup&gt;</td>
<td>Retrospective analysis of electric injury of the hand in 22 patients</td>
<td>II</td>
<td>Extensive debridement and compartment release almost always done on day of injury. Amputation rate 40%</td>
</tr>
<tr>
<td>Mann et al, 1996&lt;sup&gt;31&lt;/sup&gt;</td>
<td>Retrospective review 62 patients with high voltage upper extremity injury</td>
<td>II</td>
<td>Fasciotomy indications: severe pain and loss of arterial Doppler signal, neurologic deterioration, systemic clinical deterioration from suspected ongoing myonecrosis. Carpal tunnel release performed along with fasciotomy. 16 of 62 patients (25.8%) required emergent decompression within first 24 hours. Amputation rate in these patients 45%. Overall amputation rate 10%</td>
</tr>
<tr>
<td>Yowler et al, 1998&lt;sup&gt;32&lt;/sup&gt;</td>
<td>Retrospective chart review 51 patients with high voltage injuries to the upper and lower extremity</td>
<td>III</td>
<td>Indications for fasciotomy: Elevated muscle compartment pressure greater than 30 mmHg. Neurologic dysfunction, vascular compromise, extensive deep burn. 11 patients under went 18 major amputations</td>
</tr>
<tr>
<td>DiVincenti et al, 1969&lt;sup&gt;24&lt;/sup&gt;</td>
<td>Retrospective review of 65 electrical injuries over 17 years, upper and lower extremities included, high and low voltage injuries included</td>
<td>III</td>
<td>Early fasciotomy indicated for cyanosis of distal uninjured skin, impaired capillary refill, progressive neurologic change, brawny edema and muscle compartment tightness. Amputation rate 32.5%</td>
</tr>
<tr>
<td>Butler et al, 1977&lt;sup&gt;23&lt;/sup&gt;</td>
<td>Retrospective review of 182 cases over twenty years. Includes high voltage and low voltage injuries</td>
<td>III</td>
<td>40 patients underwent an average of 5 operations. Marked swelling of the wrist and hand, the volar carpal ligament is divided at time of extremity fasciotomy. Amputation rate 65%</td>
</tr>
<tr>
<td>Mann et al, 1975&lt;sup&gt;27&lt;/sup&gt;</td>
<td>Series of 8 patients with high voltage injury. Includes upper and lower extremities</td>
<td>III</td>
<td>Early decompression fasciotomy and debridement. Amputations done on at least one extremity in all patients</td>
</tr>
<tr>
<td>D’Amato et al, 1994&lt;sup&gt;20&lt;/sup&gt;</td>
<td>Series of 6 patients with high voltage upper extremity injury</td>
<td>III</td>
<td>Mandatory exploration of forearm and hand compartments following initial resuscitation. All patients required amputation</td>
</tr>
<tr>
<td>Hussmann et al, 1995&lt;sup&gt;45&lt;/sup&gt;</td>
<td>Retrospective evaluation of 38 high voltage injuries. Included upper and lower extremity</td>
<td>III</td>
<td>Early serial debridement of obviously necrotic tissue, fasciotomy including carpal tunnel release for “compartment syndrome” 39 amputations performed in 38 patients</td>
</tr>
<tr>
<td>Saffle et al, 1980&lt;sup&gt;35&lt;/sup&gt;</td>
<td>Evaluation of wick catheter to measure intramuscular compartment pressures (IMP) in 31 extremities in 18 patients, compared with clinical and Doppler findings</td>
<td>II</td>
<td>Recommended routine measurement of IMP as a more sensitive than Doppler pulses, and use of a threshold value of 30 mmHg for performance of escharotomy</td>
</tr>
<tr>
<td>Moylan et al, 1971&lt;sup&gt;36&lt;/sup&gt;</td>
<td>Prospective evaluation of ultrasonic flowmeter to assess circulatory changes in 60 limbs in 24 patients with circumferential burns</td>
<td>II</td>
<td>Escharotomy is indicated when Doppler flow is absent in distal arteries or arches. Note: This paper documents that Doppler pulses can be present in the face of clinical evidence of tissue compression and ischemia</td>
</tr>
<tr>
<td>Salisbury et al, 1974&lt;sup&gt;47&lt;/sup&gt;</td>
<td>Evaluated post-mortem intrinsic muscle biopsies following extremity burns. Presence of necrosis was similar in patients with (72.2%) and without (66%) escharotomies</td>
<td>II/III</td>
<td>Muscle ischemia or necrosis can occur with intact pulses and even following escharotomy. Note: since this was a post-mortem study, tissue necrosis may have been a non specific finding</td>
</tr>
</tbody>
</table>

(Continued)
tensive compartment release done as an emergency (almost always on the day of injury).” Luce reported a series of 31 patients with an extremity amputation rate of 35.5% who “were taken to the operating room within 24 hours of admission.” In the DiVincenti et al24 series of 65 patients, there was an amputation rate of 32.5%. There are no studies that specifically evaluated the impact of timing on treatment outcome. Some recent literature has supported a more selective approach to management may reduce the number of operative interventions and subsequently the morbidity of high voltage electrical injury.31,32 Mann et al31 followed a selective management algorithm for upper-extremity high-voltage electrical injury. Indications for surgical decompression included extremities that exhibited progressive peripheral nerve dysfunction, clinical manifestations of compartment syndrome, or injury sufficient to cause difficulty in resuscitating the patient. Sixty-two patients had a total of 100 upper-extremity injuries. Early (within 24 hours of admission), surgical decompression was required in 22% of injured upper extremities. An amputation was ultimately required in 10% of the extremities. Extremities that were not decompressed immediately did not require amputation. The amputation rate for those patients requiring immediate surgical decompression was 45%. This amputation rate is similar to previous studies, which appear to include patients with lesser degree of injury. In the series from the Army Institute of Surgical research,32 51 patients with high-voltage injury were managed selectively. Indications for operative intervention were evidence of neurologic dysfunction, vascular compromise, extensive deep burn, or increased muscle compartment pressures (repeated measurements >30 mm Hg). A total of 11 patients (21.6%) underwent 18 major extremity amputations.

Table 2. (Continued)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
<th>Data Class</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith et al,</td>
<td>Prospective evaluation of infrared photoplethysmography (PPG) to evaluate vascular status in burned extremities and compared with IMP, Doppler, and muscle blood flow (MBF). PPG correlated well with IMP and MBF, but poorly with Doppler with changes noted with IMP &gt;30 mm Hg</td>
<td>III</td>
<td>Advocated use of PPG as a noninvasive method of assessing vascular compromise. This study supports an IMP ≥30 mm Hg as an appropriate threshold for escharotomy in burned extremities</td>
</tr>
<tr>
<td>198438</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chen et al,</td>
<td>High resolution color and pulse Doppler ultrasonography used to determine burn wound area in 12 patients with deep electrical injury</td>
<td>III</td>
<td>Different tissue found to have differing degree of injury. Concluded that ultrasound could demonstrate morphologic changes in subcutaneous tissue, muscle, and blood vessels after deep electric injury</td>
</tr>
<tr>
<td>200339</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hunt et al,</td>
<td>Technetium-99 m pyrophosphate scans performed in 14 patients with high voltage electrical injury. Scans were performed between first and fifth day post injury</td>
<td>II</td>
<td>Location and extent of muscle injury was correctly ascertained preoperatively in all patients</td>
</tr>
<tr>
<td>197940</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affleck et al,</td>
<td>Retrospective review of computerized registry identified 11 patients who underwent Pyrophosphate (PyP) scan. Eight patients had high voltage electrical injury, one had frostbite, and two had soft-tissue infection</td>
<td>III</td>
<td>Revealed a sensitivity of 94% and specificity of 100% showing demarcation between viable and nonviable tissue, confirmed at operation</td>
</tr>
<tr>
<td>200141</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hammond et al,</td>
<td>Early scanning (within 3 days of injury) with PyP in 19 limbs in 15 patients with electrical injury. Sensitivity of 75% and specificity of 100%</td>
<td>II</td>
<td>Compared to control group of 17 patients treated without PyP scan, the scan was not associated with reduced length of stay, or with decreased number of surgical procedures</td>
</tr>
<tr>
<td>199442</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Copyright © American Burn Association. Unauthorized reproduction of this article is prohibited.
A wick-catheter technique was used to measure intramuscular pressures. A threshold of 30 mm Hg was an indication for escharotomy (based on vascular compartment syndrome literature). Whether or not this can be extrapolated to include electric injury is unclear. In addition, Moylan et al.\(^36\) showed that ultrasonic (Doppler flow meter) signal from the distal arteries and palmar arch was a more sensitive indicator of perfusion than clinical palpation. Salisbury\(^37\) demonstrated, however, that this objective measure of perfusion could not be relied on as the sole indicator of deep tissue viability and need for escharotomy in circumferential burns. Therefore, more sensitive indicators of perfusion have been investigated.

Small studies have evaluated the use of infrared photoplethysmography (PPG) to assess vascular compromise in injured extremities, including direct vascular injury, crushing forces, and severe burns.\(^38\) PPG correlated well with muscle blood flow, and intramuscular pressure, but not with Doppler measurements.

Recently, high-resolution color and pulse Doppler ultrasound has been used to evaluate wound area in electrical injuries.\(^39\) In this study, 12 patients with deep electric injury were evaluated. It was found that degree of injury differed between tissue types. Changes in course, and blood flow speed also were noted in injured tissue. Findings were all confirmed at subsequent operation.

Some authors recommend the use of nuclear medicine scans in an attempt to identify areas of muscle necrosis.\(^40,41\) Other studies have questioned the utility of nuclear scans in this setting. They have fallen out of favor in routine cases, although some centers reported use of this modality selectively.

**SUMMARY**

No definitive data exist to show that immediate surgical decompression reduces the need for amputation in any series. The management of these patients has traditionally included immediate (within the first 24 hours), surgical exploration and decompression. A more selective approach based on clinical findings may be used at specialized centers.

**Key Issues for Further Evaluation**

**Evaluation of the Upper Extremity.** Studies to evaluate the utility of measuring compartment pressures in the presence of electrical injury need to be performed. It is unclear whether data from the orthopedic and vascular literature can be extrapolated to burn care. In addition, studies evaluating more non-invasive technologies, such as infrared PPG and high-resolution ultrasound, may add much-needed clarity to this clinical problem.

**Surgical Management.** Prospective randomized studies that evaluate immediate vs expectant débridement using well-defined criteria would be useful in defining guidelines for surgical management of the injured extremity.

**Evidentiary Table.** Table 2 summarizes research on the monitoring and treatment of high-voltage upper-extremity injury.

**REFERENCES**

gressive approach to the extremity damaged by electric curr-