EMERGENCY MEDICAL PLANNING AND INDUSTRIAL DISASTER

Electrical Injuries

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The continuing growth of the United States has led to an ever-increasing production of electrical energy. Yet it is interesting to note that despite the steady increase in the use of electrical power, the death rate from electrical shock has remained almost constant. This is graphically illustrated in Table 1.

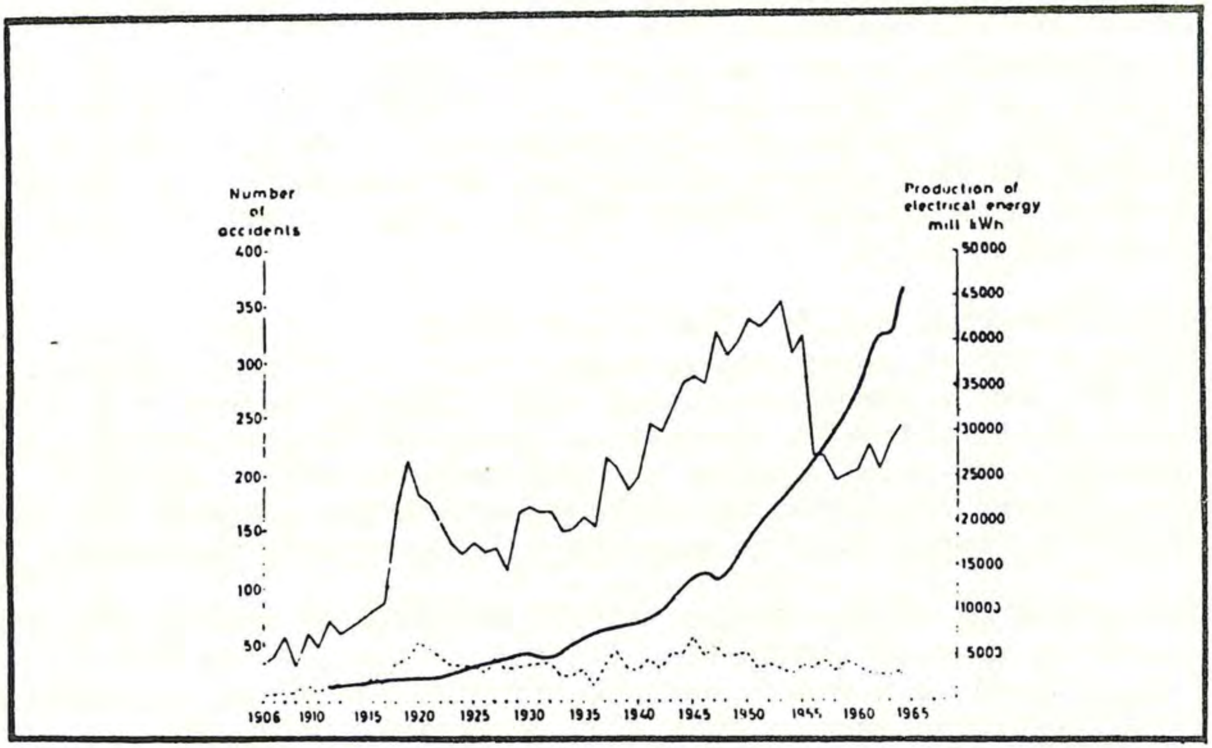
Accidental Deaths Due to Electric Current	1974	1973	1972	1971
Homewiring and appliances	1,157	1,149	1,008	1,065
Industrial wiring and appliances	203	232	206	216
Other electric current	636	564	604	534
Unspecified electric current	155	172	136	160

(Source: National Center for Health Statistics)

Comparable statistics from the works of Skoog (1) in Sweden show a sharp increase in production of electricity that parallels the injury rate, but the death rate remains almost the same. These data speak well for the home appliance industry, which is constantly working to eliminate hazards in its products.

Homes and industries in this country use 60 Hertz alternating current for electrical power. Since this is the type of power most commonly encountered, I shall address my remarks along that direction, disregarding those situations that involve high (radio and TV) frequencies or direct current. This particular frequency is, however, disturbing to the respiratory centers of the brain and the functioning of the heart. Other undesirable characteristics of alternating current include its tendency to cause tetanic contractions, which make it difficult to extricate one's self from contact with the power source.

Table 1
Electrical Injuries



The injuries produced can be divided into two groups: those due to low-tension current and those due to high-tension current. Low-tension current is usually associated with potential differences of less than 1,000 volts; with high-tension current the difference is greater than 1,000 volts (2). In Skoog's series, low-tension current victims were locked to the contacts; in high-tension injuries, on the other hand, the victims were thrown some distance from the contact by the tetanic contractions. High-tension injuries are further complicated by an accompanying electric arc. As a general rule, it can be estimated that a high-tension arc can jump an air gap of one inch for each 20,000 volts of potential difference. Once the arc is established, it can be drawn as far as about 10 feet without collapsing, all the while maintaining a conduction of current between the energy source and the point of lesser potential.

More often than not, an electrical injury is a very complex, destructive force on the human body. Thus, the "true electrical injury" may be combined with an electrothermal burn and/or a flame burn, and also involve associated damage to the cardiorespiratory, urinary or skeletal systems in accompaniment with burn shock. Then too, delayed complications such as hemmorhage, gangrene, bacterial infection, renal failure, paralysis and cataracts may ensue.

The extent of tissue damage, except for delayed complications, is dependent upon the intensity of the current. In its simplest form, (based on a direct current circuit) Ohm's Law describes the relationship between current (I), potential difference (v) and resistance (R):

$$I \text{ (amperes)} = \frac{V \text{ (volts)}}{R \text{ (ohms)}}$$

Thus for a given voltage, the amount of current that passes through the tissue (and which determines the extent of damage) is inversely related to the resistance of the tissue. Putting it another way, for a given resistance, the amount of current flow and concomitant tissue damage will be increased by a corresponding increase in voltage.

The usual entry of an electrical current into the body is through the skin. The resistance of the skin varies with the thickness of the skin and the condition of the skin at site of contact (i.e., whether it is wet or dry). A well-calloused, dry hand, for example, has a resistance of 1 Meghohm (1 million ohms) while a moist hand may have a resistance of only 1,000 ohms. You can, therefore, comprehend the great difference between the effect of 110 volts on the calloused, dry hand as compared with the same voltage on a wet hand.

As the current enters the body, it will travel over the route of least resistance. We find that the electrical resistance of various tissues to the passage of current increases in the following order: nerves, blood vessels, muscle, skin, tendon, fat and bone (2). Thus, conduction proceeds most readily along nerves and blood vessels and least along the bone.

As mentioned earlier, low voltage alternating current causes tetanic contractions which lock the victim to the energy source. The longer the body is in contact with the electrical source, the greater is the damage as a result of heat that is generated within the tissue or body fluid. In the case of high voltage current the duration of exposure may be less, but since the voltage is higher, the current can also be higher, and there can be other injuries produced by violent expulsion of the body from the point of electrical contact.

True Electrical Injury

This is a unique burn injury that occurs when the body becomes the conduit for the electrical current. The extent of injury depends upon the voltage, the amperage, the surface area at the site of contact (or the resistance), the duration of the exposure and the pathway of the current through the body. High-tension injuries, those caused by 1,000 volts or more, are most likely to produce entrance and exit injury sites.

The particular pathway of the current through the body can dictate the type and extent of injury. For example, a 40-60 Hz alternating current of as little as 100 milliamperes that passes through the myocardium can cause a fatal dysrhythmia (2). Morley (4) feels that high-tension currents that pass through the myocardium cause a myocardial contraction, and these are usually fatal--only five cases of successful resuscitation have been reported in these instances.

Postmortem studies of electrical deaths in the United Kingdom showed the heart to be in complete systole. Skoog reported on one patient who had 6,000 volts of short duration enter the right hand and exit from the right leg; the victim was rendered unconscious but had a spontaneous recovery with no residual deficits (1). Unconsciousness can occur when the pathway is not through the central nervous system, and yet may be avoided when the current enters the scalp. Unconsciousness can also result from a tentnizing current across the chest wall that interrupts the muscles of respiration (4).

There were 36 employee fatalities reported to the Edison Electric Institute by the electrical utility industry in 1975. In all of these deaths, the current traversed the myocardium and/or the central nervous system.

Current Pathway	No. of Cases
From Hand to Hand	6
From Hand to Left Foot	11
From Both Hands to Both Feet	5
From Extremity to Chest or Abdomen	4
From One Hand to Both Feet	4
From Head to Legs	3
From Foot to Foot	1
From Both Hands to One Foot	1

For two fatalities, voltage was in excess of 15,000 volts; the rest were at less than 15,000 volts, and the lowest was at 300 volts (2).

Pathology of True Electrical Injury

Tissue damage is due either to the heat produced by the passage of current through the tissue or is a result of a specific action of the electricity on the tissues. The subsequent heating effect (H) may be expressed in terms of voltage (V) and Current (I) as:

$$H_{(watts)} = V_{(volts)} I^2_{(amperes)}$$

The area on the skin where the current enters appears dehydrated and depressed with a hyperemic border. The exit area shows considerably more damage with coagulation necrosis. Along the current path through the body the blood vessels show damage, and multiple thrombi are frequent. The peripheral nerves may not show much damage though there is evidence of paresis without anesthesia. (It is fairly typical for the route of conduction to follow the motor fibers in deference to the sensory fibers). There is usually good recovery from any resulting paralysis, unless the vascular supply to the nerves is impaired and cannot maintain the peripheral nerve (2). Muscles usually show extensive coagulation necrosis (2); also, there can be additional harm to the blood supply of the muscle and at sites distal to the muscle by the edema that accompanies the burn (5).

Obviously there can be extensive destruction deep in the tissues after a "true electrical injury". This deep injury is not apparent on the first examination after the incident. Skin burns are apparent, but this burn is unusual in that it is more like a crush injury.

Electrothermal Burns

This type of injury is caused by the heat generated when there is arcing, which is usually associated with high-tension current. The arc is created when body contact is made with a charged conductor. The temperature of the arc can range from 1,000^{o}C to 4,000^{o}C, which is sufficient to melt the body tissues (1). The injury produced is dependent on the voltage of the conductor, the part of the body in contact with the arc, and how and where the body is grounded. The higher the voltage, the higher the temperature of the arc and the greater its ability to leap through space (3). After the arc strikes the body, the current travels through the body producing a "true electrical injury" as well. Pathology of pure electrothermal burns shows severe coagulation necrosis and carbonization of tissue.

Flame Burns

Heat produced by an arc can be great enough to ignite clothing or other flammable articles at the injury site. The flame burn from electricity is the typical 1^{o},2^{o}, or 3^{o} burn. If the clothing is burned, there are frequently 3^{o} burns.

It is not unusual for an individual with electrical burns to exhibit the flame burn, the electrothermal burn and the "true electrical injury". However, flame burns may be so severe that one may fail to recognize the occult areas that are due to the "true electrical injury".

Contact with a high-tension wire while erecting a radio antenna is a common type of electrical accident. In one such case, there was injury to both arms, the chest, abdomen, scalp, and right buttock and both feet. Despite the extent of his injuries, especially to the scalp, the patient did not lose consciousness. He was in shock and his urine showed hemoglobinuria; fasciotomies were required emergency treatment, as well as extensive debridement. After 48 hours, the patient's right arm was amputated at the shoulder, and he lost some of the digits of the left hand and a full thickness of skin of the abdominal and chest walls. Later, the full thickness of his parietal bone was debrided to expose an intact dura. Nevertheless, he recovered with no central nervous system dysfunction.

This case illustrates the severity of an electrical injury. Far more care and treatment is required than for the usual severe burn patient who has enough skin remaining to survive. Skin losses were full thickness tissue down to and including the underlying bone. The exact depth of the injury can rarely be ascertained immediately after the accident, and frequently 42-72 hours is necessary before the depth of the tissue necrosis is apparent. Severe electrical injuries frequently involve functional parts of the body i.e., the hands and/or the feet.

Associated Injuries

When "true electrical injuries" occur, there may be unconsciousness and respiratory arrest even though the current does not pass directly through the respiratory centers and the brain stem. In DiVincenti's series, 29 out of 65 patients had CNS complications, but only six had entrance wounds over the scalp. Transmyocardial currents may produce dysrhythmia and cardiac arrest; 8 out of 65 showed ECG changes (2). A United Kingdom study of 7,724 electrical accidents showed 496 of the victims were rendered unconscious. Careful evaluation of the accident reports revealed that two out of three had only respiratory arrest, while one out of three had an absent pulse and cardiac arrest.

Severe damage to body tissue by electrical injury causes the release of myoglobin into the circulation and genitourinary system from damaged muscles. The injury also causes a loss of body fluids into the damaged area. This combination of body fluid loss and high concentration of abnormal protein from the muscle creates a renal complication similar to that seen with crush injuries (3). Hemochromogens may appear in the urine. However, the vast majority of the pigment can be identified as myoglobin (6). The longer the pigment persists in the urine, the greater the amount of muscle damage.

The severe tetanic contractions characteristic of alternating current can also cause fractures and dislocations of the skeletal system. These fractures may occur as a direct result of the violent muscle contractions or indirectly from the falls that are frequent from high-tension lines. In DiVincenti's group 7 out of 65 had fractures (2).

Severe electrical injuries also produce shock similar to that seen with other burns. The shock is due to the leakage of plasma from the circulation through the heat-damaged capillaries. In addition, there may be an increase in the permeability of the endothelium of capillaries distant from the injury as the result of toxins released from the injured tissues. Fluid loss begins immediately after the injury and progresses rapidly during the next 8-10 hours. This loss is usually stabilized within 48-72 hours. There may be a continued fluid loss in the areas where there is a skin loss, which will persist as long as the wound remains unhealed. The exudate is primarily plasma and protein substance; red cell depletion is usually less than 10%.

Hemmorhage is common after an electrical injury. The blood vessels are injured by the current passing along them; the larger blood vessels may bleed profusely from the damage. The thrombi that are formed and the damage to the vessels may produce stasis at first. Later, the thrombi may disappear, followed by very severe hemmorhage.

The initial injury to the blood vessels and tissues may be sufficient to compromise the circulation of the digits and extremities and result in gangrene. The thrombi cause ischemia and the vascular supply to the extremities is further impaired by the leaking of fluid into the injured tissue. Fasciotomies are needed early to lessen the loss.

The injured and devitalized tissue readily becomes an excellent medium for the growth of bacteria leading to severe infection. Clostridia is a common organism. The devitalized tissue must be removed and rarely is it accomplished in one debridement.

There are heavy demands on the kidney from the moment of injury. The "burn shock" decreases the circulating volume and the excretory load is increased by the by-products of injured muscle. This combination can cause a shutdown of kidney function and require renal dialysis.

The resultant paralysis may be temporary or even permanent if the blood supply and nerves are sufficiently damaged. Physio-therapy can be utilized once the general condition of the patient improves.

The occurence of cataracts is a late complication and may occur months after the original injury. Origin of this disorder can be traced to the thermal radiation from the high temperature arc.

Emergency Care

The injured person must be removed from the energy source prior to initial care. Special equipment and personnel may be necessary in order to extricate the victim and to avoid additional injuries to the victim or his rescuers.

The ABC's of Cardiopulmonary Resuscitation (CPR) must be the first consideration. Check the airway and breathing. Referring again to Morley, he found that 2/3 of the individuals who were apneic after the accident were found to have effective heartbeat and needed only respiratory resuscitation. Morley also analyzed the various methods of respiratory resuscitation. Inasmuch as the apnea may be due in part to the severe tetanic contractions of the muscles of respiration, it is reasonable to believe that the simple movement of the victim can be an important factor in breaking up the muscle spasms. Absence of heartbeat will suggest the presence of ventricular fibrilation; thus, external cardiac compression should be started immediately. The cardiopulmonary resuscitation should be continued until the person is transferred to an advanced life-support system.

Method	% Recovery
Schafers or Holger Nielson (Manual Method)	50
Mouth-To-Mouth (13-64)	20
Positive Pressure Breathing Machine (10-44)	22
Untrained Witnesses (Just moved arms and legs of victims (7-7)	100

Don't use the "rule of nines" to calculate the fluid needs of electrical injury patients. This type of injury is very deceptive at the onset and must be treated as if it were a crush injury. The fluid loss must be anticipated and its replacement must be sufficient to accommodate the "burn shock" fluid loss in addition to a urine output of 30-40 ml/hr. Hence, catheterization is essential in combination with the intravenous fluids. Monitoring of the urine flow is mandatory to prevent renal damage.

General Assessment of the Patient

After the life-threatening traumas have been assessed and treated, a more thorough examination of the victim should take place to detect damage other than that arising directly from the burn. Take an ECG to look for myocardial involvement along with baseline laboratory studies on the blood gases, electrolytes, hemoglobin, blood type and crossmatch. The presence of acidosis should be anticipated and treated accordingly.

Estimate and record the percentage of body surface area affected. You may cover the thermal burns of the skin with a clean, dry dressing; sterile sheets are adequate.

The superimposed "true electrical injury" may be masked by the thermal injury to the skin; therefore, look for entrance and exit wounds which will indicate that the current has passed through the body. The entrance wound is typically a depressed area while the exit is marked by an expulsive appearance--as if the skin were actually thrown out. Paralysis of an extremity with preservation of the sensory system in that extremity is indicative of a "true electrical injury". Persons who fall after an electrical shock may have injuries of the chest, abdomen or even the kidneys. These injuries should be treated by appropriate emergency procedures. Likewise, skeletal injuries should be identified, splinted and stablized. As soon as the victim's condition has been stabilized, he should be transferred to a burn care center.

REFERENCES

1. Skoog, T. 1970. Electrical Injuries. J. Trauma. 10:816.
2. DiVincenti, F. C., M. A. Moncrief and B. A. Pruitt. 1969. Electrical injuries: a review of 65 cases. J. Trauma. 9:497-507.
3. Artz, C. P. 1974. Changing concepts of electrical injury. Amer. J. Surg. 128 (5):600-2.
4. Morley, R. 1973. Resuscitation after electric shock. Lancet. p. 1059.
5. Quinby,W. C., and J. F. Burke. 1974. Treatment of Burns. Trauma Management Year Book. Medical Publishers. 50:1137-38.
6. Baxter, C. R. 1970. Present concepts in management of major electric injury. Surgery Clinic of North America. 50:1401.

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