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The Investigation of Electrical Deaths: A Report of 220 Fatalities

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ABSTRACT: We present the results of our investigation of 220 electrocutions. The ratio of high voltage to low voltage electrocution is found to be nearly 1:1. Further, in low voltage electrocution deaths electrical burns were absent in over 40% of the cases. Our approach to the investigation of possible electrocution, including equipment analysis, is discussed.

KEY WORDS: pathology and biology, death, electrocution

Accidental deaths by electrocution occur with a frequency of about 0.54 per 100 000 population per year in the United States [*1*]. The statistics of the Dade County Medical Examiner's Office reveal a rate of 0.78 accidental electrocutions per 100 000 population per year. This striking difference between the rate in Dade County and the rate in the United States prompted this study.

Material and Methods

The data are derived from the records of the Dade County Medical Examiner's Office covering the past two decades. Dade County's 5200 km^2 (2000 square miles) is the greater Miami area. The population during the study period rose from 0.75 million to 1.5 million people.

The medical examiner's office is charged under Florida law with the investigation of sudden unexpected and traumatic deaths [*2*]. Death certificates must be completed by medical examiners when the deaths are accidental, suicidal, or homicidal [*3*]. Authority for autopsy is delegated to the medical examiner, and autopsies are performed on almost every case that falls under statutory authority in Dade County. Autopsies were performed in all electrical death cases.

Initial scene investigation is usually delegated to police personnel who are trained in death investigation by the medical examiner's office. However, pathologists generally respond to undisturbed electrocution scenes.

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Results

There were 220 electrocutions during a 22-year period. Of these, 217 were classified as accidents, two were suicides, and one was a homicide. The intentional cases all involved 120 volts in the home. Lightning caused 16 deaths. Generated electricity accounted for 201 accidental deaths, 93 of these by voltages in excess of 1000 volts (high voltage) and 108 by voltages less than 1000 volts (low voltage).

Table 1 lists the ways by which the victims became energized in a high voltage circuit. Downed power lines played a role in only eight (9%) of the deaths. Twenty-nine individuals (31%) directly touched energized cables or other devices that were part of the high voltage conduction system. Fifty-eight percent of the high voltage victims contacted an overhead wire with a conductive device such as a crane or derrick. Eighty-six percent of the deaths from high voltage occurred on the job. Fifty-five percent of these individuals were employees of the power company or one of its subcontractors.

Table 2 lists the low voltage electrocutions. Only 45% of the deaths from low voltage were on-the-job accidents. Forty-three percent of the victims of low voltage electrocution had no perceptible electrical burns while only 4% of the victims of high voltage electrocution had none.

The month of occurrence for deaths from low and high voltages is shown in Figs. 1 and 2. During the months of June through October Dade County has a temperature pattern nearly identical to that of the bulk of the South, Mid-Atlantic, and Midwest areas of the United States. The period November through May averages nearly 16°C (30°F) warmer than St. Louis, Mo. [*4*]. Deaths from low voltage show a striking summer-month predominance: 74% of the low voltage electrocutions occur during June through October. Deaths from high voltage have little seasonal variation.

TABLE 1—*Data on high voltage electrocutions.*

	Deaths			
Source	Nonelectric Work	Electric Work	Not at Work	Total
Touched intact power line	9	16	4	29
Touched defective or downed line	0	0	8	8
Conductive device into power line	36	2	14	52
Motorized	26	0	1	27
Antenna	2	0	6	8
Kite	0	0	4	4
Pipe	3	1	0	4
Mast	1	0	3	4
Ladder	3	0	0	3
Other	1	1	0	2

TABLE 2—*Data on low voltage electrocutions.*

Source	Deaths, at Work	Deaths, Not at Work
Tool	27	13
Electrical equipment and wiring	16	13
Appliance	2	23
Energized item	4	10
Totals	49	59

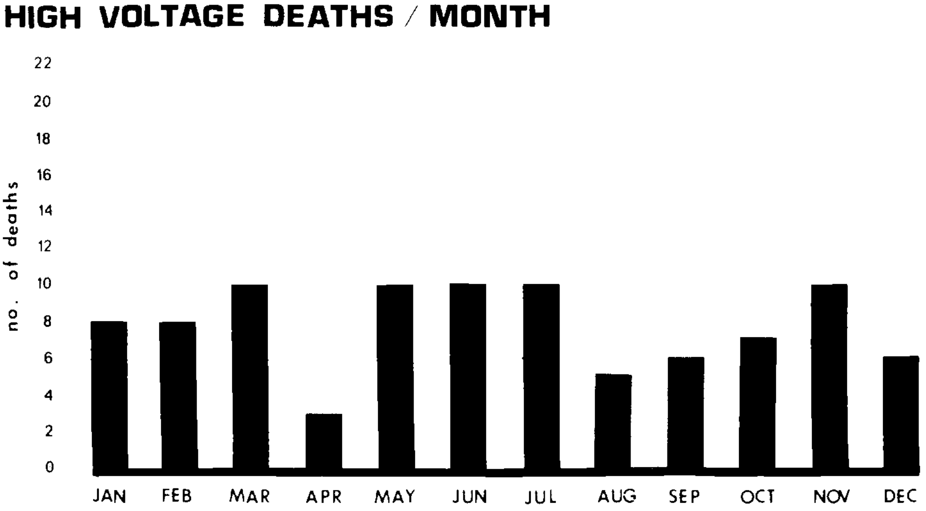

FIG. 1—*Month of occurrence for high voltage deaths.*

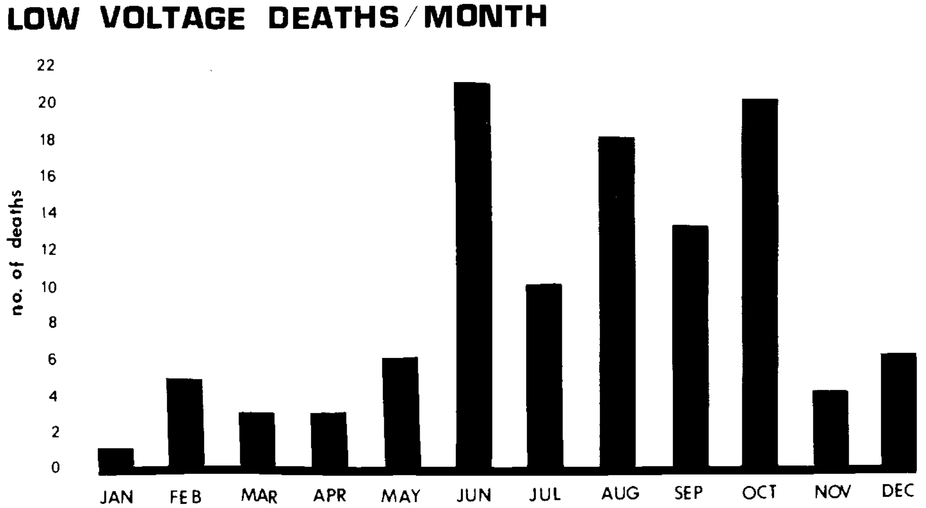

FIG. 2—*Month of occurrence for low voltage deaths.*

Discussion

Investigation of electrocution deaths requires some basic knowledge of electrical physics and pathophysiology.

Electricity is commonly measured in volts, amperes, and ohms. These elements are interrelated by Ohm's law:

$$\text{amperes} = \text{volts}/\text{ohms}$$
$$\text{volts} = \text{amperes} \times \text{ohms}$$
$$\text{ohms} = \text{volts}/\text{amperes}$$

Voltage is the measure of electromotive force in the system. Amperage is the measure of current flow per unit time. An ohm is the unit used to measure resistance to the conduction of electricity. In other words, one unit of flow (amperes) occurs with one unit of force (volts) divided by one unit of resistance (ohms).

The amount of current flow, or amperes, is the most important single factor in human electrocution. By direct measurement and extrapolation from animal studies the following approximations as to various effects of current flow in humans for 60 hertz alternating currents are generally accepted [*5-8*]:

0.001 ampere—barely perceptible tingle
0.016 ampere—"let go" current
0.020 ampere—muscular paralysis
0.100 ampere—ventricular fibrillation
2.000 amperes—ventricular standstill
20.000 amperes—common household fuse blows

Because of the interrelations of ohms, volts, and amperes, predictions of the effects of electricity can be made. The human body has a minimum internal resistance of less than 500 ohms. Hands and feet have minimal values of 1000 ohms. Dry skin easily reaches resistances of 100 000 ohms [*8*].

The resistance of human skin usually protects man from electrocution, as does the high resistance of the structures in which humans are ordinarily found. In any electrocution there must always be a source of electrons under sufficient force to overcome the resistance of the body and a low-resistance pathway to ground.

Applying the dry skin resistance for hand-to-hand contact with 120 volts (common household current) gives the equation:

$$\text{amperes} = 120 \text{ volts}/100\,000 \text{ ohms} = 0.001 \text{ (tingle sensation)}$$

However, for water- or sweat-soaked skin the resistance often drops to 1000 ohms:

$$\text{amperes} = 120 \text{ volts}/1000 \text{ ohms} = 0.120 \text{ (ventricular fibrillation)}$$

Electrical current is generated by large electromagnetic devices and transmitted over many kilometres at tension often exceeding 100 000 volts. By use of transformers this voltage is usually stepped down to 7620 volts, which is the usual voltage in residential and industrial high voltage distribution lines. This current is generally phased so that wire-to-wire voltage is approximately 15 000 volts. However, electrocutions of humans usually (with rare exception) are line-to-ground events (half of the voltage of a phased line-to-line circuit). Finally, the voltage is stepped down for domestic use. Most residential service today is 120 volts from line to ground, and from wire to wire it is 240 volts. Human electrocution is usually line to ground, or 120 volts. It is important to query power company officials or others concerned as to the specific voltage involved in the fatal pathway because the voltage may be expressed in the line-to-line mode.

Electrical Burns

An electrical burn occurs only if the temperature of the skin is sufficiently raised for long enough to produce structural damage. Therefore, whether or not burns will be produced depends on several factors: (1) the amount of current flow per unit time, (2) the voltage, (3) the area (actually the volume) of contact with the energized source and the ground, and (4) the length of time of exposure. If the flow is small, the area large, or the time short, no burns will be produced.

All of the electrical and time variables are dealt with by one expression—electrical power—usually expressed as kilowatt-hours or watt-seconds. A watt is one volt times one ampere. Thus, expressed in watt-seconds, the minimum power required to fibrillate at 60 hertz, 120 volts is 0.1 ampere times 120 volts times 0.1 seconds, or 1.2 watt-seconds [*9*]. A watt produces 0.24 calories of heat. Thus the minimum power required to fibrillate produces 0.29 calories (1.2 watt-seconds times 0.24 calories/watt-second). Assuming two 1-cm^2 contact points—one energized, the other grounded—and further assuming the heating to be completely concentrated in the skin of the contact points for a depth of 1 cm, the skin temperature would rise only 0.145°C [(0.29 calories ÷ 2 cm^3 water)1°C/calorie]. This is clearly less than sufficient to produce burns. Indeed, just to produce first-degree burns requires exposure of the skin to 50°C for 20 s, in our model requiring at least 26 calories [*10*].

If one examines the deaths from low voltage in this series, the victim always made contact, creating an electrical circuit through himself from an energized source to ground. This was either momentary or prolonged. It was momentary if electrically induced tetanic muscle contractions moved the victim in such a way as to break the circuit. It was prolonged if the involuntary contractions did not break the circuit. Those with momentary contact had no burns. Those with prolonged contact had burns.

A low voltage electrical burn as commonly observed (central pallor with charring surrounded by erythema) is not necessarily a "vital" reaction. Indeed, in the usual low voltage situation, fibrillation is initiated within the first 0.1 s of exposure and blood pressure precipitously plummets. Again based on the previous model, and on increasing resistance of the contact skin as it is heat-denatured, we can see that as an absolute (and impossible to attain) minimum 9 s of contact is required to produce a skin temperature of 50°C and just first-degree burns. Assuming that at least 90°C is required to produce charring of the skin, 37 s is the absolute theoretical minimum time to produce a characteristic electrical burn. The blood pressure and circulation have long since disappeared in the usual low voltage incident by the time burning occurs. Thus electrical burns are "postmortem," in the sense of not requiring blood circulation for their expression.

In the high voltage situation even momentary contact is associated with burning. Returning to the formula and using 7620 volts (the usual transmission voltage), 1000-ohm resistance, and 0.1-s exposure gives watt-second = (volts/ohms) × volts × seconds:

$$\text{watt-second} = \frac{7620}{1000} \times 7620 \times 0.1$$

$$\text{watt-second} = 5806$$

$$\text{calories} = \text{watt-second} \times 0.24$$

$$\text{calories} = 1393$$

While not exactly a burn, the arborizing pattern seen in lightning deserves mention. In this series it was seen six times out of 16 deaths. The mechanism of production appears to be heat denaturation of erythrocytes with consequent hemolysis and marked acceleration of "fixed" lividity. This pattern was also seen in a death caused by 155 000-volt electrocution.

Mechanisms of Death

There are basically three mechanisms whereby electricity kills. At the lowest current flow, somewhere over "let-go" current and below the fibrillation threshold (that is, 0.02 to 0.1 amperes), prolonged electrical current flows—probably greater than 1 min—are required to kill because hypoxia with subsequent brain and heart incapacitation must occur. Hypoxia will be accelerated as tetanization of muscle increases oxygen demand.

In the range from less than 0.1 to 2 amperes alternating current produces ventricular fibrillation. In this condition the heart contractions are greater than 300/min instead of the normal 70 to 100. Once this rhythm is initiated, unconsciousness occurs in approximately 10 to 15 s and the victim cannot be resuscitated after 5 to 10 min. With rare exceptions, humans do not spontaneously revert from ventricular fibrillation to normal sinus rhythm. Ventricular fibrillation is most commonly observed in people dying of heart attacks and is usually present in low voltage electrocutions.

Direct experimentation in humans has not been permitted in the fibrillation range of currents applied to the skin. Extensive work has been performed on humans with direct electrode contact to the heart, but this is not helpful in studying the usual electrocution [*9*]. Experiments on dogs have shown that during common abnormal physiologic conditions there is a striking tendency to lower the current required to produce ventricular fibrillation [*11,12*]. These include adrenergic stimulation ("flight or fight" reaction) and acidosis. Both of these conditions commonly occur in the low voltage electrocution situation where the victim is performing physical exertion yielding acidosis and where there may be perception of the current flow in the form of intense discomfort yielding adrenergic stimulation. In real-life situations it is conceivable that current flows of less than 0.1 ampere skin-to-skin may produce ventricular fibrillation and death.

The third mechanism of death occurs with current flows of more than 2 amperes. These current flows happen with currents from high voltage applications:

$$\text{amperes} = 2000\ \text{volts}/1000\ \text{ohms} = 2 = \text{heart standstill}$$

In cases with such massive current flows the heart is completely stopped, and when the circuit is broken it may commence beating normally again [*7*]. Although the heart may restart, breathing often does not, and cardiac death occurs from 10 to 20 min after electrocution [*8*]. With such high current flows, a massive amount of heat is generated, which leads to irreversible brain death in less than a minute of continuous contact with 7620-volt currents or, with shorter exposures, to delayed deaths from the complications of electrical burns [*13*].

Investigation of Electrical Deaths

Diagnosing high voltage electrical deaths is normally possible from the autopsy. Electrical burns are almost always present and usually indicate the points of contact with the energized source and with ground unless severe arcing or burns secondary to electrically caused fires obscure the contact points. The burns of any clothing should be studied during a careful autopsy. Photography is particularly important in documenting the scene and autopsy.

In nearly half of the low voltage electrocutions the autopsy will not reveal electrical burns. Autopsy may show findings consistent with sudden loss of cardiac function from ventricular fibrillation or, alternatively, findings of asphyxia and nothing else. The investigation of deaths from low voltage must include a careful study of the circumstances of death. Any case that indicates a potentially grounded person was near a potential source of low voltage current must be considered a possible electrocution [*4*]. In addition, anyone who is heard to scream, swear, or shout and then is observed to die after a few seconds must be considered a possible victim of electrocution [*13*]. This behavior occurs quite frequently in low voltage electrocutions and is almost unheard of in other causes of death. Any body with inexplicably early rigor development, or with regional rigor development such as in one arm and one leg, should also be considered as a case of electrocution. The tetany from electrical current accelerates the development of rigor.

The investigation of a possible low voltage electrocution requires an "autopsy" of the environment. In each case such an investigation must be performed by or under the direction of the pathologist. This examination must be performed by someone familiar with electrical engineering and electrical pathophysiology who has direct interest in determining the true cause of death.

If this plan is not followed serious errors occur, as exemplified by a case in this series. A 36-year-old fishing boat captain about to disembark from his boat was carrying bait fish on stainless steel leaders. He was crouched barefoot on the gunwale. He suddenly screamed, stood up, jumped onto the dock, took a few steps, and collapsed. Attempts at resuscitation from documented ventricular fibrillation were unsuccessful and the victim was subsequently pronounced dead at a hospital. The police suspected electrocution because of the scream and notified the power company and the medical examiner, a forensic pathologist. By the time the medical examiner arrived the power company investigator had come and gone, telling the police investigator that he found no electrical defect. The police investigator interpreted this to mean that the death was not due to electrocution.

The medical examiner found the wiring to the dock to be two-wire Romex® protected by a poly(vinyl chloride) conduit. Junction boxes were of the standard galvanized steel variety. The junction box on the dock next to where the captain had been holding the wire leaders had a short circuit from the energized side to the metal. It measured 120 volts from box to ground. The gunwale of the boat had a protective metal rim over the fiberglass, which was grounded and thus had grounded the captain. The circuit was completed when his bait fish leaders touched the energized junction box and his feet the metal ground of the gunwale.

The medical examiner discovered all this but the power company investigator did not. The power company investigator is primarily interested in his employer's interest. The power company's responsibility stops at the electric meter. There was no defect from the generator to the meter.

Most low voltage elelctrocutions involve portable equipment. In every sudden death that may be an electrocution all associated portable equipment and the power cords should be transported with the body to be examined by or under the direction of the pathologist.

The procedure to be followed is as follows.

1. The electrical outlet must be checked to see that it is properly wired. Improper wiring with reversal of the energized side of the circuit with the ground is occasionally seen. Inexpensive commerical testing devices can be plugged into the outlet to check this. These give a coded light reading. Alternatively, a volt-ohm-milliammeter (VOM) may be used. The voltage readings should be correct: 120 volts from energized side to neutral and ground and zero voltage from neutral to ground. The suspected ground should be verified as being truly grounded. Photographs should document these procedures, and the written report must be specific.
2. All wiring to the equipment device should be visually and electrically examined. Adjust the VOM to ohms at the lowest setting and then test the continuity of the individual wires. Each wire should reveal zero ohms end to end and infinity ohms from one wire to another. Examine each plug and receptacle on each extension cord to be certain that the energized wire is to the dark brass prong of the male plug and to the smallest slot of the female receptacle. The neutral wire should attach to the light prong and the larger slot of the receptacle. The ground circuit should likewise be identified as to proper polarization. With twist-lock connectors visual inspection will indicate the proper polarity.
3. The continuity of the tool or appliance should be tested both when the switch is on and when it is off. The ground should read zero ohms to the case. Neutral and energized wires should read infinity ohms to all exposed parts of the tool. If apparently intact, the tool should be run and the case to ground checked for dangerous voltages. A few volts

with the ground circuit defeated during the operating test is usually of little consequence. Variations on this scheme occur when the device is double-insulated, that is, having no redundant ground circuit. Clearly, in this case the ground circuit cannot be tested.

4. Should there be reasonable suspicion that the death was due to electrocution and all the circuitry tests are normal, the tool should be carefully disassembled, and any condition consistent with an intermittent short circuit should be carefully noted. Usually this cannot be harmful if the tool case was properly grounded back through all extensions, properly polarized, to the original energy source, properly grounded and polarized. The usual electrocution circumstance occurs when it is evident that the ground wire of the tool plug has not been used or the grounding prong has been removed. Under these circumstances the presumption should be maintained that there was a short circuit until two conditions are fulfilled: (1) the tool is proven beyond any doubt to be electrically safe and (2) completely logical and unequivocal cause of death other than electrocution has been demonstrated after thorough autopsy and correlation of the circumstances.

Conclusion

For 22 years it has been the policy of the Dade County Medical Examiner's Office to aggressively investigate possible electrical deaths. This investigation has included an "autopsy" of the circumstances and equipment in every possible electrocution. The 50% higher rate of electrocution deaths in Dade County suggests that deaths from electrocution may be underreported in the rest of the United States.

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