Investigation of Electrical Injuries and Deaths

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The proper investigation of the cause of injury and death from electrical current requires a multi-disciplinary approach into the circumstances surrounding the event. This means that police, forensically trained medical personnel, and forensically trained engineers must all come together and contribute to determining the how and why of the injury and death.

Of primary importance is that a high degree of suspicion must be maintained at all times concerning the role of electricity in producing the death or injury. This is extremely important in electrical events involving current with a voltage of 600 or less, so called low-voltage events. The reason these are so important is that in fatal electrical events (So called electrocutions) with low-voltage, the presence of any electrical marks is only found on about 50% of the bodies. Alternatively, electrical marks are absent in 50% of cases. The proper determination of the cause of death in such cases requires more than just a complete and thorough autopsy of the body (although this is required).

With high voltage electrical events, those involving voltages of greater than 600, electrical marks are almost always present. Generally, these marks are present on the energized side and the grounded side in the typical electrical event. However, marks may only be present on one side if the energized side or the grounded side is a large broad area. The grounded side of the circuit can be large and broad and may in a minority of cases not be associated with electrical marks.

Another aspect of electrical marks is that there are “entrance” and “exit” marks. Entrance and exit wounds are appropriate words to describe gunshot wounds, but are completely inappropriate for the vast majority of electrical events. The reason for this is that essentially all electrical events involve alternating current. Alternating current (AC) is the current that is delivered in almost all electrical events. Alternating current was introduced by George Westinghouse in the United States in the 1870’s. Alternating current has the advantage over direct current (DC) in that the voltage of the current may be altered easily by using transformers. This advantage allows current to be generated at relatively low voltages, then stepped up to very high voltages for transmission over fairly long distances using fairly small wires. The tall power lines seen crossing the countryside are transmission lines and the voltages often exceed 250,000 volts. The transmission lines in turn, connect to transformers where the voltage is stepped down to approximately 7,000 volts to be distributed to users of electricity. The common wires in every neighborhood are distribution lines. These distribution lines connect to transformers where the voltage is dropped a final time for domestic use.

The convenience and economy of being able to generate electrical power at modest voltages, to step the voltage up for transmission, to step it down for distribution and finally to step it down again for domestic use comes at a very high price in regards to safety. Alternating current is extremely dangerous at high voltages (transmission and distribution voltages) as even momentary contact with these high voltages results in extreme damage to the person in the path of the current.

A low voltage of alternating current is extremely dangerous as well, compared to direct current. Although the burning and poration seen with high voltages is not seen with low voltage, a more life threatening event occurs with low voltage alternating current. The current's alternating nature, if the pathway of the current flow is through the chest, results in the heart attempting to follow the current in place of the heart's pacemaker. This results in the heart trying to beat 2,500 times per minute in most of the world [1] The heart is incapable of beating 2,500 times per minute. Indeed it can depolarize only about 600 times per minute and this is what it does if the amount of current is sufficient to pace the heart. This is called ventricular fibrillation, and in humans this heart rhythm once initiated results in complete loss of blood pressure and a normal sinus rhythm will not start again.

This striking difference in safety led Alvah Edison to attempt to discredit alternating current by demonstrated lethality by exposing cows and horses to alternating current which caused the deaths of the animals. This approach was not met with a great deal of success, and Mr. Edison then coined the word "electrocution[2]" to describe the lethality of alternating current. He succeeded in getting the State of New York in the United States to switch to the "electric chair" a device which applies alternating current to the head and the leg of the condemned prisoner to produce death. Naturally Westinghouse equipment was used. This method of killing persons is only still done in the state of Nebraska, all others have gone to some form of lethal injection. However, the word electrocution remains today and has been expanded to include non-intentional deaths and even injuries as well as deaths.

Because alternating current goes through a complete cycle every 1/50th of a second, the flow of electrons goes away from a person in a circuit and thence toward a person 50 times a second (60 times in the Americas). This is why there is no difference in appearance between the energized and the grounded side of a circuit. They are intrinsically identical.

There is often a difference between the energized and grounded sides of the circuit. The reason for this is that electrical burning in contact electrical burns occurs as a mirror image to the conducting material touching the skin. Presume a situation where a copper wire is stripped of insulation and bent to make the letter "O". Another piece of copper wire is stripped of its insulation and bent to make the letter "K". The wire is attached to the chest of a person using tape and then connected to an electrical plug which is inserted into an electric outlet. The mirror image of "O" and "K" will be left on the skin. There will be no difference in the appearance of the electrical burns other than their shape. These burns are typically

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[1] George Westinghouse in the United States introduced 60 Hz or 60 cycles per second for alternating current, in Europe, the Middle East, India and China the standard became 50 Hz or 50 cycles per second. 60 Hz changes voltage 60 times 60 or 3,600 times per minute. 50 Hz changes voltage 50 times 50 or 2,500 times per minute.

[2] Electrocution is a contraction of Electros from the Greek word for amber, the rubbing of which by cloth or skin results in a static electrical charge, and Execution for the killing of a person by the government.

called electrical branding marks. The extent of the burning will be a direct function of the length of the circuit and the voltage of the circuit. If the burns are examined, the burning will only extend out a millimeter or so beyond the margins of the wire. The reason for this is that the high water content of skin and subcutaneous tissue results in a huge calorie load being required to produce burning. The current density drops exponentially as the distance from the wire increases, and one is thus left with a brand of the conductive item.

A further word about the microscopic appearance of electrical burns is in order. Hematoxylin and eosin stained burned skin is often examined to document whether a burn is electrical or thermal. In reality, all electrical burns are thermal, as the burning is produced by the heating caused by the flow of electrons through the skin and subcutaneous tissue the friction of which causes heat. Thus, a thermal burn and an electrical burn are not distinguishable on the basis of microscopic appearance. The only difference in so called thermal as opposed to electrical burns is that with electrical burns the skin appendages, sweat glands and hair follicles are affected much more greatly at a depth with electrical as opposed to so-called thermal burns. Also, the thermal effects at the depth is greater relatively with electrical as opposed to so-called thermal burns. These differences are not pathognumonic. Many writers have suggested that "streaming nuclei" are diagnostic of electrical burns. They are not. Many electrical burns lack "streaming nuclei" and "streaming nuclei" can be seen as a pressure effect as a post mortem artifact.

Finally, almost always in low voltage electrical events which result in death, the presence of electrical burns is a post mortem phenomenon. Therefore, any so-called vital reaction in low voltage electrical burns is a miss-construed artifact. To explain this, let me go back to my illustration with the bared electrical wires attached to the chest. If the wires are attached to the mid-back at about C6 and the mid-sternum as the same level, the heart will be in the direct path of the current. If the voltage is 240, the heart will nearly instantly go into ventricular fibrillation.[3] With VF, blood pressure goes to zero and circulation stops. Therefore any vital reaction, the presence of bleeding into the wound, either preceded the electrical event or was artifactually produced due to resuscitation efforts.

To examine the electrical event further will require looking at specific voltages, as there is as much difference between high voltage and low voltage electrical events as there is between gunshot wounds and stab wounds. In addition, it will be necessary to examine, hopefully briefly, the physics of electrical circuits, at least as far as understanding the nomenclature of these circuits. Finally, a look at electrical equipment is necessary to understand how electrical events occur.

[3] Fibrillation will start during the EKG period between S and the start of the next P. It appears to require several cycles of alternating current to initiate ventricular fibrillation. Assuming a heart rate of 72 beats per minute for the subject of this experiment, the time between S and P is approximately 0.8 seconds. During 0.8 seconds the 50 Hz current will go through 40 cycles.

Ohm's law and its progeny.

Ohms law states that the Amount of Current in amperes is the result of dividing the voltage by the resistance to the passage of electricity in Ohms. I-E/R is the usual way this is expressed. This formula means that if we have any two of the items in the equation (Current flow in Amps, Voltage in Volts or Resistance in Ohms) we can calculate the third.

Generally, but not always, we can determine the voltage of a circuit that someone is in. In domestic use 240 volts is commonly encountered. In industrial settings, the voltage is usually 480[4] In high voltage situations the voltage is whatever phase to ground is. Generally, the power company will quote the phase to phase voltage which is nearly double the phase to ground. Always ask for the phase to ground figure, assuming the event is phase to ground.

We can also estimate the resistance of the person. Dry calloused skin, say of a laborer, can exceed 250,000Ω. The current that a person with 250,000Ω resistance holding an energized tool at 240 volts would be 240 v/250,000Ω or 0.0096 amps. In examining the table below, it can be seen that the person holding the tool with an energized case would not be able (if he were a male) to feel the passage of current.

Figure 1
Electrical affects various current flows

Amperage	Effect
0.0005 female 0.0015 male	Perceptible Tingle
0.012 female 0.017 male	No "Let Go"
0.050	Cross Chest Asphyxiation (approximate)
0.100	Minimum (approximate) fibrillation threshold Cross chest
1.000	Lower defibrillatory threshold

Assume that the person does not have calloused hands and that the hands are moist with good circulation, under this circumstance the resistance of the hands could go to 1000 Ω with 240 volts the circuit would result in 0.240 amps. This is above "let go" and well within the fibrillatory range.

[4] Electricity is generated using a machine with three ______ in a circle which are separated by 120°s. These generate 3 electrical phases each 120° out of phase with each other. Single phase service is generally used in homes, in industrial operations all three phases are employed. Electrical events almost always are from a single phase to ground with the person in the circuit

Effects of Current Flow

As was discussed above, the same voltage can result in amazingly different affects upon people, depending upon what their resistance to the flow of electricity is. This can vary at low voltages from not being able to even feel a tingle all the way to being dead of ventricular fibrillation.

The effect of current through tissue is to depolarize the cells in the pathway. Ordinarily, in mammals the resting potential is -0.090 v or -90 millivolts. When a nerve or muscle cell is not doing anything, if one measures the voltage on the inside of the cell compared to the outside it will measure -0.090 volts. There is an abundance of electrons on the inside of the cells maintained that way by the K+ pump. To make a nerve carry a signal or a muscle contract requires that the resting potential go to zero or perhaps slightly positive. This is ordinarily done by chemical means utilizing acetylcholine being released from the ends of nerve fibers. This makes the nerve or muscle depolarize or lose the resting potential. Loss of resting potential also occurs when an electrical circuit travels near a muscle cell or nerve. The streaming electrons decrease the resting potential. Ordinarily there is an over abundance of electrons in the cell, when there is an increase in the electrons on the outside the resting potential goes to zero or even positive. This results in the muscle contracting, after a period of about 0.2 seconds, the latency period from depolarization to contraction of actin-myosin.

Professor Dalziel in the United States during WWII did a series of experiments on volunteers. He had them hold 1" diameter copper pipes in their right and left hands and he increased the voltage until they could feel the tingle of the passage of electricity. All the while he measured the amount of current flow. He found that women can generally feel 0.0005 amps or 0.5 milliamps. Men could feel about 0.0015 amps or 1.5 milliamps. As he increased the voltage (and thus the current), eventually the volunteers could not open their hands anymore. This he called the "no-let go" threshold. In general, this averages 0.017 amps or 17 milliamps of current for men and 0.012 for women.[5]

The explanation of this "no let-go" threshold is that as the current is increased, more and more of the muscle (and nerve) fibers are depolarized. The strength of the muscles moving each joint is stereotypic in normal humans. For current traveling from hand to hand, the flexors of the fingers and thumb are stronger than the extensors, the flexors of the elbow are stronger than the extensors, the flexors of the shoulder are stronger than the extensor. Thus, the hand closes around the pipe and moves it toward the chin as "no let-go" is approached and met. The voluntary effort to release the pipe cannot be done, and this figure in amps is a narrow range and reproducible from person to person.

Although not reported by Dalziel, the effect of current on the rest of body is well known. As humans are bipedal, the lower extremities and back have the reverse dominant muscle groups. The extensors of the toes, ankle, knee and hip are stronger than the flexors. The extensors of the back and neck are stronger than the flexors.

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[5] Professor Dalziel attempted to determine what the values were for infants and children, but he said they just cried.

Therefore, if there is a circuit through a person from a hand to the feet, the person will tighten the grip on what is in the hand and bring the hand to the chin, the feet, ankles, legs and back will extend. If the circuit stays intact, the person will fall over backward. If the energized item is still in the hand, there will be a new area of grounding, the back.

These effects on people are seen if the let-go threshold is met or exceeded. This can be seen with both high voltage and low voltage circuits. High voltage are ordinarily always above let-go, low voltages generally are above let-go.

The effect of current flow can be impressive. If the person in the circuit is grounded at the knee or foot and the current is in the hand, chest or back, he or she will shoot backward, often doing a somersault, ending up facing 180° from where he or she started. An upward change in elevation of up to 30 feet has been seen by the author, with a young healthy person.

The involuntary contraction accompanying the flow of electrons through a person results a striking increase in the values of Creatine Kinase. This is the enzyme which catalyses the production of ATP (Adenosine Tri-Phosphate) from CP (Creatine Phosphate). These high energy phosphates supply the energy for muscle contraction. The sudden massive contraction associated with an electrical circuit through a person, even one which lasts only 0.20 seconds, causes a rise in the CK. The upper limit of normal for sedentary adults is about 200 IU. Values of 1,000 are commonly seen in persons subjected to a brief electrical circuit. Values of 10,000 are encountered with prolonged high voltage circuit.

The peak values are seen about 8 hours after the electrical event. This means that the person must survive for a period to see the increase in CK.

Troponin also is commonly increased in persons subjected to electrical circuits. The increase is more modest than CK and an increased Troponin does not appear to indicate heart damage.

Another effect of the involuntary contraction is that rigor mortis in the muscles traversed by the current will come on much more quickly, indeed perhaps as instant rigor mortis. This can be seen with current flows as little as 400 joules (watt seconds or amps * volts seconds) commonly used in defibrillators. Therefore another sign of death from an electrical event, if looked for quickly after death, is the presence of unequal distribution of rigor mortis.

In cross chest current flow, hand to hand or hand to foot or feet, there is the forceful contraction of the intercostals and the diaphragm. This results in a noise varying from a load grunt to a scream. In investigating any death, if the deceased has uttered a scream or grunt and then appears to have died, the death should be considered an electrocution until you can prove that it was not.

The absence of low voltage electrical burns does not prove that a death was not from electricity. With low voltage (120 volts 60 Hs in the USA) it has been reported that approximately 50% of persons dying will not have electrical marks. That percentage is probably about the same for 240 volts and 50 Hz.

The explanation for this is simple. With low voltage the deaths are due to ventricular fibrillation. If the involuntary contraction caused by the depolarization of the muscles breaks the circuit, either the energized side or the ground side or both are pulled away from, the person in the circuit may well go into ventricular fibrillation. If the circuit only lasted 0.2 seconds, the heating effect will not be sufficient to leave a current mark. Thus in investigating such cases, the only positive signs are early rigor mortis, the history of a grunt or scream, and eyewitness testimony of involuntary rapid movement.

Again, a high index of suspicion concerning an electrical event must be maintained. As the autopsy has limited usefulness, except to show whatever disease process existed before the electrical event, then someone must determine whether the events immediately prior to death could have created a circuit through the deceased.

There are two things required for a circuit. A source of current and a ground are both required simultaneously. Generally, with low voltage, the grounding is most absent. To be grounded requires touching the ground, concrete, metal contacting either ground or concrete, a grounded tool or appliance. If the person has on shoes, then grounding to ground or concrete via the feet cannot happen. However, a three prong electrical plug on an appliance will generally supply a source of grounding, as the third prong is a ground. The first thing to do is determine the possible source of grounding.

The second is to find the source of current. The possibilities are endless. Defective appliances make up the bulk of the cases. If one examines electrical plugs, the least number of prongs which will make the appliance work is two. One side is energized. One side is neutral or grounded. The electricity is supplied on the energized side and the circuit is completed on the neutral side. If there is a leakage of current from the energized side into the case of the appliance then the potential exists for a lethal current through a person.

If a situation exists where a grunt or shout is heard, where there is early rigor mortis, where there is involuntary movement before death, where the autopsy examination shows minimal lethal disease, then an effort must be made to rule out electrical circuit. Someone with knowledge of electrical injury and death must investigate the circumstances and the scene. Unfortunately many electrical engineers and electricians do not understand electrical injury and death. Unfortunately neither do most death investigators.

There is one other important point to note. Ventricular fibrillation is followed by 12 to 17 seconds of normal brain activity. If the circuit is broken by the involuntary contraction and the person is in ventricular fibrillation then he or she has 12 to 17 seconds to alter the scene. Often, after a curse, the person disconnects the source of electricity. This can be most disconcerting to the person investigating the death. No electrical burn and no source of electricity does not get the investigation off to a good start.

High voltage electrical injury and death

At least with high voltage the points of electrical contact are almost always clear. They are almost always delineated by electrical burns. These burns will be present whether the person breaks the circuit by involuntary contraction or not. If the circuit continues, then burning will be extensive.

The only exception of electrical burns is if one side of the circuit is large and flat. This will make the contact area so large that no burns appear. Generally this is the ground side.

The odd thing about high voltage is that death is that deaths are the exception not the rule. In general with current flows exceeding 1 amp, the current through the chest is defibrillating. The current density is so high with skin to skin above 1 amp that the heart just contracts. When the circuit is broken, the heart is self starting. It will start again, generally in sinus rhythm. There are exceptions to this, but in general high voltage does not produce ventricular fibrillation. If high voltage produces death, it is from literally burning up if the circuit is prolonged or as the result of the involuntary contraction producing fatal falls.

High voltage typically produces extremely severe electrical burns resulting in loss of extremities which were in the circuit. These burns result from simple heating, as all electrical burns do, and also from poration. Poration is a phenomenon where the cell walls of vessel s, nerves, muscle and connective tissue have holes punched into them by the high voltage electrical current. This is most commonly seen in areas where the cross-sectional diameter of the extremity is smaller; wrists, knees, elbows, ankles. Treatment consists of attempting to maintain adequate hydration while doing incisions to reduce the pressure resulting in the leakage of fluid from the tissue with poration.

The Electric Chair

Is not a very efficient way to produce death. Although abandoned by every state but Nebraska in the United States and never adopted by other countries, it is worth talking about. The current is delivered from the head to the ankle. This provides a current pathway through the brain. This is certainly humane, as electricity flows at nearly the speed of light or nearly 300,000,000 meters per second. Pain fibers transmit at about 100 meters per second. The pain caused by the passage of electricity gets to the thalamus much slower than the depolarization of the thalamus. With depolarization of the thalamus there is no pain. With high voltage the resistance of humans drops to around 200Ω. Thus with the typical electric chair of 4,000 v the current flow is 4000/200 or 20 amps. Twenty amps is in the defibrillatory range. When the current is turned off, the heart starts again spontaneously. As the common way to pronounce death is the absence of heart beat, commonly in persons electrocuted in the electric chair, the heart continues to beat. Indeed, this can continue for many minutes after the current is turned off. This is one of the reasons that the electric chair was abandoned by all but Nebraska. The actual mechanism of death with the electric chair is almost always heat denaturation of the brain. Temperatures of 43° are encountered if the measurements are made soon after the electrocution