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Forensic tools for the diagnosis of death due to electrocution: a comprehensive and multidisciplinary study

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Abstract

Deaths related to electricity are quite infrequent and generally categorised as accidental (usually related to occupational activities) or suicidal events. Homicides are very rare. The mechanism of death by electrocution usually results from the heart being traversed by a current, thus determining the onset of malignant arrhythmias and ventricular fibrillation with consequent cardiac arrest. The mechanism of tetany/paralysis of the respiratory muscles (intercostal muscles and diaphragm) is less frequent but may occur and is related to electricity passing through the thorax. When the electric current flows through the head, death may occur due to paralysis of the respiratory nervous centre, though this is far rarer. Finally, the electro-thermal mechanism is a possible cause of death when caused by a high-voltage electric current.

In the daily practice of the forensic pathologist, electrocution may represent a difficult diagnosis. As a matter of fact, death by action of electrical energy is a ‘‘functional’’ death-type, because fatality may occur as a result of disorders of the heart rhythm (such as ventricular fibrillation) or electrically induced contraction of the respiratory muscles: internal findings are frequently non-specific and may therefore substantially overlap with those of sudden death. The only specific sign of the passage of electricity is the electric burn mark: this skin lesion is caused by electro-thermal heating of the epidermis and dermis generated by the passage of the current. Electric marks generally have an irregularly rounded shape, although it is not uncommon to see other shapes. Sometimes, they can be hidden by folds of skin, hairy formations, hand calluses, or by the same skin burns such as those caused by an arch or related to clothing fire. When death due to electrocution is assumed, standard investigations are often not sufficient on their own to correctly assess the cause of the death.

Therefore, the study began with these assumptions and aims to fill these gaps in the forensic field on the diagnosis of electrocution death. The study was performed on the autopsies carried out in Berlin, Germany, over a 12-year period.

A total of 54 cases were found. Each case was studied with the analysis of the autopsy protocol (with external and internal examination) as well as the documentation provided by the police with analysis and photos of the scene, in addition to any other element that could aid the investigation. When present, post-mortem CT analysis and the results of toxicology and histology examinations have been also considered.

The results of the study showed the importance of a team approach, in which all the steps are crucial and must be taken with the utmost discipline and caution. The analysis of the

scene is fundamental and allows many elements of investigation to be obtained regarding the type of electricity (low / high), type of event (suicide / accidental / homicide) and points of possible contact between the victim and the current flow. The autopsy is the following crucial step: a complete autopsy with thorough external examination of the body and of the clothing in the search for subtle electrical marks is strictly required. Clothes may show burns corresponding to contact with metallic conductors and torn clothing with burned shoes may implicate lightning. Every particular element of the external examination must be adequately described and documented, with particular attention given not only to marks on the skin, but also to other elements that can provide indications, such as the presence of petechiae, associated with death by electrocution in a certain percentage of cases.

The internal examination of the cadaver for evidence of underlying natural diseases, such as cardiovascular conditions, is also important, as these may have predisposed the victim to coming in contact with live circuitry, or may have reduced the victim's capacity to survive an electric shock. All further investigations are also fundamental: post-mortem CT for recognition and characterization of lesions and pathological alterations, toxicological tests to evaluate possible causes or contributing causes of death as well as the abilities of the subject at the moment of contact with electricity.

The most important in this case is perhaps the histopathological investigation, with which the main characteristics of the electrical mark and its vitality can be identified and characterized, thus providing a fundamental contribution for understanding of the event, its effect on the individual's skin and body and on the vitality of the subject at the time of the electric discharge.

From all these elements, the multiple difficulties of the diagnosis and reconstruction of these cases are clear. The extensive study carried out as part of this research represents a valuable element of analysis and constructiveness for forensic pathology.

Forensic tools for the diagnosis of death due to electrocution: a comprehensive and multidisciplinary study

Summary

Introduction

Death by transmission of electrical or thermal power results from an overwhelming transmission of such energy to the human body. Although these types of cases are not frequently reported in the clinical and forensic field, a proper and comprehensive analysis strictly require a complete multidisciplinary approach to the study of the circumstances of the event and autopsy findings.

Only the thorough comprehension and study of such conditions can permit an in-depth analysis of the cases, the injurious/lethal mechanisms, and the causes and modalities of death. An exhaustive study and reconstruction of the scene is also of the utmost importance in obtaining a correct differential diagnosis of the causes of death and a modality (e.g. for the distinction between accidental event, suicide and homicide) correlation between the knowledge or activities of the victim and the use of electric current. The collection of the medical/familiar history is therefore also relevant. Electrocutions may thus be challenging cases to solve and usually require detailed investigations in order to ascertain why and how electrical stress was transmitted to the individual. In some cases, the assistance of professionals with specific knowledge in the electrical field might be desirable to provide help with the examination of the electrical system/device.

In order to fully understand how the current is transmitted to the body and its effects, a first introduction to the functioning of electrical circuits is important. Most people are familiar with the term “volts”. A “volt” is simply a measure of electromotive force in a system.

Another crucial concept is “Amperage”. Amperage, to indicate “the amount of current flow”, represents the main factor in electrocution. The value of Amperage may be obtained through a function: it is directly related to voltage and inversely related to resistance. *Voltage* represents the amount of electromotive force. The resistance to the conduction of electricity is measured in “Ohms”.

Such a function is expressed and synthetized in the following formula (A=Amperage, V=Volt, R=Resistance):

$$\mathbf{A = V/R}$$

What is the correlation between the amount of amperes and human symptoms or death?

The following approximations for 60-hertz alternating current in humans is generally accepted: the minimal perceptible amount of amperage to humans, felt as a “tingle”, is 1 mA (0.001 A). An ampere of 0.020 can cause muscular paralysis. An ampere of 0.100 can cause ventricular fibrillation and an ampere of 2.000 causes ventricular cessation. Electricity has two big effects on the human body: depolarization of nerves and muscles as well as heat production (when the time of exposure is prolonged).[1] Damages determined by electricity to the cells of nerves and muscles may provide changes in the membrane structure leading to the development of "pores" (electroporation) as defects of the membrane layers, as well as protein denaturation. With a temperature exceeding 60°C (140°F), tissue destruction may occur.[2] Moreover, such a huge thermal stress may lead to the denaturation of all tissues as a result of coagulation necrosis.[3] Different factors have a direct or indirect impact on these mechanisms and on the consequent features of electrical damage. These factors include the circuit type, time of contact, resistance of tissues, current voltage and amperage, the path of flow and the surface of contact points.

Death due to electrocution involve *low-voltage* (<600 V) as well as *high-voltage* (>600–750 V) electric currents. In the vast majority of the cases alternating currents are involved, since direct current is less used worldwide. Alternating current (AC) is an electric current which periodically reverses direction and changes its magnitude continuously with time, in contrast to direct current (DC), which flows only in one direction. Alternating current is the form for electric power to be delivered to businesses and residences. It is the form of electrical energy that consumers typically use when they plug kitchen appliances, televisions, fans and electric lamps into a wall socket.

Due to constitution and composition of human tissues, humans are four to six times as sensitive to alternating currents as to direct.

How is electric current transmitted to the human body and how does it flow?

When electrocution occurs due to low-voltage "household" current (110–120 V), there must be direct contact between the body and the electrical circuit. In such a case death is primarily caused by cardiac arrythmia, usually in form of ventricular fibrillation. In cases where high-voltage current is involved, a direct contact is not strictly necessary. As the body

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[1] *Wright, RK. Death or injury caused by electrocution. Clin. Lab. Med. 3:343–353, 1983.*
Kobernick, M. Electrical injuries: pathophysiology and emergency management. Ann Emerg Med 11:633–638, 1982.
DeBono, R. A histological analysis of a high voltage electric current injury to an upper limb. Burns 25:541–547, 1999.
Lee, RC. Injury by electrical forces: pathophysiology, manifestations, and therapy. Curr Probl Surg 34:677–764, 1997.

[2] *Sances, A., Jr., Larson, SJ., Myklebust, J., Cusick, JF. Electrical injuries. Surg Gynecol Obstet 149:97–108, 1979.*

[3] *DiVincenti, FC., Moncrief, JA., Pruitt, BA., Jr. Electrical injuries: a review of 65 cases. J Trauma 9:497–507, 1969.*

approaches high-voltage lines, an electric current (so-called "arc") may arise and literally "jump" from the line to the human body. A victim´s forearm near a 7500 kV power line can draw an arc with 3 to 4 mm distance.

The mechanism of injuries or death from high-voltage electrocution are therefore different. Death may usually occur due to two main different effects and their consequences:

- direct electrothermal injury, produced by the current itself (the temperature generated by an arc current can be as high as 40,000ºC), or
- respiratory arrest.

Table 16.1 The Distance An Electric Arc Can Jump*

Voltage	Distance Current Can Arc
1,000	few mm
5,000	1 cm
20,000	6 cm
40,000	13 cm
100,000	35 cm

* as given by Somogyi and Tedeschi[1]

Table from: Di Maio V. J. M, and Maio D. J. Di. Forensic Pathology. Boca Raton: CRC Press, 2001.

In urban areas, high-voltage current have usually 7000–8000 V. For instance, these lines may therefore lead to electrocution when they break and are touched after they fall to the ground, or when an undamaged line is touched by a metallic object with which a person is in contact.

As stated and explained in the A = V/R formula, another crucial parameter is the capability of the human body to resist to transmission of the electric flow ("resistance"). Resistance is the measure of difficulty electrons have in flowing through a particular object. It is similar to the friction an object experiences when moving or being moved across a surface.

The "good conductors" within the human body include blood, mucous membranes, muscle and nerves.[4] Mucous membranes show low resistance.[5] Tendons and fat provide more

[4] *Cooper, MA. Emergent care of lightning and electrical injuries. Semin Neurol 15: 268–278, 1995. Butler, ED., Gant, TD. Electrical injuries, with special reference to the upper extremities. A review of 182 cases. Am J Surg 134:95–101, 1977.*

[5] *Cooper, M. A. Electrical and lightning injuries. Emerg. Med. Clin. North Am. 2:489–501, 1984.*

resistance, while bone is the most resistant structure. In human bodies, the skin is involved in cases of electrocution. Skin shows a median resistance and is the primary resistor to current, thus resulting in more electrical energy being dissipated at the skin surface contact.[6]

Resistance is measured in *Ohms;* 1 ohm is equal to 1 volt of electrical difference per 1 ampere of current (1 volt/1 amp).

With low-current (e.g. 120 V), dry and calloused skin may have a resistance up to a million ohms, with dry skin the resistance is up to 100,000 ohms; moist skin has a resistance of 1,000 ohms or less while with moist and thin skin the resistance is as low as 100 ohms.[7]

When a high-voltage current is involved, there is no significant role in resistance played by the condition of the skin. In such cases voltage is therefore constant and amperage is the most important factor.

What is the dynamic of an electrical current flow running through the human body, from the point of origin to the point of exit?

When an electrical current enters within the body, it runs through it from the point of contact to the ground along the shortest path.

The "usual" path (most frequently observed) follows the path hand-hand or hand-foot. The necessary range of time for a current to lead to death directly depends on the amperage. As a matter of fact, electrocutions through very low-amperage current require a prolonged and continuous contact with the electrical current. As the current flows through the body, it overcomes the resistance of the tissues through less conductive areas. The body itself therefore becomes a conductor (with the exception of bones) and current flows through all tissues, thereby causing damage.[8]

When the electric current is related to household systems, where death usually occurs as the consequence of ventricular fibrillation, the time of contact necessary to produce a fatal outcome may be seconds or tenths of second, directly depending on the amperage. Again, the amount of Amperage is related to the resistance. To provide some clear examples:

Ditto, EW., III. Electrocution during sexual activity. Am. J. Forensic Med. Pathol. 2:271–272, 1981.
Cooke, CT., Cadden, GA., Margolius, KA. Autoerotic deaths: four cases. Pathology 26:276–280, 1994.

[6] *Morgan, ZV., Jr., Headley, RN., Alexander, EA., Sawyer, CG. Atrial fibrillation and epidural hematoma associated with lightning stroke; report of a case. N Engl J Med.259:956–959, 1958.*

[7] *Bruner JMR, Hazards of electrical apparatus. Anesthesiology 1967; 28: 396-425.*

[8] *Hunt, JL., Mason, AD., Jr., Masterson, TS., Pruitt, BA., Jr. The pathophysiology of acute electric injuries. J Trauma 16:335–340, 1976.*
ten Duis, HJ. Acute electrical burns. Semin Neurol 15:381–386, 1995.

- when the current is 120-V and skin resistance 1000 ohms, the amperage running though the body will be 120 mA. In this condition, ventricular fibrillation may be reached with a contact of 5 seconds;[9]
- when moist skin represents the point of contact between current and body, resistance may have a value less than 100 ohms. In those cases, the amperage of the transmitted current would be about 1200 mA: ventricular fibrillation should therefore occur in 0,1 seconds;
- when electrocution is due to high-voltage current, cardiac arrest is substantially immediate.

With ventricular fibrillation from low-voltage electrocution, a loss of consciousness may not instantly occur. Individuals getting a fatal electric shock might not immediately lose consciousness but still have time to speak and/or move before they collapse. This can be explained by the fact that the brain possesses approximately 10 seconds of oxygen reserve, in which a person may still be conscious. Accordingly, in low-voltage electrocution a quick resuscitation with defibrillation may prevent death. However, it has to be considered that when normal rhythm is restored, hypoxia from a respiratory arrest during asystole can lead to ventricular fibrillation and hypoxic–ischemic encephalopathy.[10]

With electrocution due to high-voltage current, the consequently electrothermal damage is frequently irreversible. In such cases, the heart may start again spontaneously; conversely, respiration may not restart because of direct injury (due to hyperthermic effects) and paralysis of the respiratory centre. The effects of hyperthermia may be detected in judicial execution: a study by Werner demonstrated a brain temperature of 63°C following execution.[11]

The flow of current through the human body may also lead to fractures. This is due to a mechanism of generalized and violent muscular contraction that may occur both with low- or high-voltage current. According to the current state of knowledge, these fractures usually affect long bones, especially where the amount of muscle mass is higher.[12] In the study of

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[9] *Ferris LP, et al., Effect of electroshock and health. AIEE Trans 1936; 55:498.*

[10] *Wright, RK., Davis, JH. The investigation of electrical deaths: a report of 220 fatalities. J Forensic Sci 25:514–521, 1980.*
Kleinschmidt-DeMasters, BK. Neuropathology of lightning-strike injuries. Semin Neurol 15:323–328, 1995.
O'Keefe, GM., Zane, RD. Lightning injuries. Emerg Med Clin N Am 22:369–403, 2004.
Kleiner, JP., Wilkin, JH. Cardiac effects of lightning stroke. JAMA 240:2757–2759, 1978.

[11] *Werner AH, Death by electricity, NY Med J 1923; 118:498-500.*

[12] *Tarquinio T, Weinstein, ME and Virgilio, RW, Bilateral scapular fractures from accidental electric shock. J. Trauma 1979; 19(2): 132-133.*

Wright et al. it was feasible to figure out the reactions and the movements of the body from electrically induced contraction of muscle:[13] the neck and the back tended to stretch backward, the arms to revolve inward, the elbows to flex, the fingers to form fists. Moreover, knees unbended straight and the feet stretched. Such contractions, when intense enough, may even move a human body metres away from the original position.

For what concerns the evidence provided by an autopsy, the first element that may be detected is the presence of an "electrical burn" or "electrical mark" on the body. However, this is not always present, especially in cases of low-voltage electrocution and with particular electrocutions, such as when transmission of electricity occurs through water (for example, in a bathtub). The direct consequence is that the current will enter over a broad surface, although with a very low resistance. Even when death occurs in a bathtub, the features of an electric mark might be present, when part of the body is out of the water and in contact with metallic objects.[14] Even quite uncommon events have been reported, for example of people drinking from a fountain while touching a cable through which an electric current was flowing, or cases of people urinating on rail lines with active electrical current.[15]

According to the literature, the majority of cases with high-voltage electrocution show some sort of electrical burn, but such a feature may be detected in 50-80% of the cases of low-voltage electrocutions. Apart from the typical case of electric shock in the bathtub, burns may be absent when the contact with the current occurs over a small area.

Where is it usually possible to observe electrical burns?

These may be detected at the place of entrance of the current within the body and at the point of exit (or both).

According to the knowledge gained from previous studies, electrical marks as entry sites are likely to be found on the hands (usually palms) and fingertips. The most usual exit site of

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Dumas JL and Walker N, Bilateral scapular fractures secondary to electrical shock. Arch Orthopaed & Trauma Surg, 1992; 111(5):287-8.
Stueland DT, et al., Bilateral humeral fractures from electrically induced muscular spasm. J of Emerg. Med . 1989; 7(5):457-9.
Shaheen MA and Sabet NA, Bilateral simultaneous fracture of the femoral neck following electrical shock. Injury 1984; 16(1): 13-14.

[13] *Wright RK, Broisz HG, and Shuman M, The investigation of electrical injuries and deaths. Presented at the meeting of the American Academy of Forensic Science, Reno, NV, February 2000.*

[14] *Lawrence, RD., Spitz, WU., Taff, ML. Suicidal electrocution in a bathtub. Am J Forensic Med. Pathol. 6:276–278, 1985.*

[15] *Moar, JJ., Hunt, JB. Death from electrical arc flash burns. A report of 2 cases. S Afr Med J. 71:181–182, 1987.*

grounding is the foot sole. Even different entries and exits may be observed when current flows through various arcs and different body areas.[16] According to previous casuistries, electrical burns are present in 57-83% of cases, depending on different factors, such as time of exposure, current flow and type of voltage.

Characteristic skin lesions due to electric current may be generally observed in low-voltage injuries. The dimension and shape of the entrance site may resemble the form and size of the conductor.

Their appearance may show features of an erythematous area with blisters or as an irregular abraded area, sometimes with lifted margins and a paler central area. As a result of the heat, some discolorations of the mark itself and the surrounding skin may also be observed,. The first consequence of a contact between the electricity flow and the skin is heating and vaporization with formation of blisters. When the current itself (or the transmission of electric current to the body) stops, blisters will collapse and the epidermis may split. The typical features of the electrical burn include a small lesion, usually well defined, with crater-like margins, a greyish-yellowish-blackish centre with a surrounding pale zone caused by arteriolar spasm and coagulative necrosis. Sometimes a surrounding area of hyperaemia with blisters may be detected. A so-called “spark burn” may be observed with high-voltage current if the contact is less firm, creating an arch of current. It occurs because of small flames being released from a burning object, by rubbing two hard things together, or a flash of light made by electricity. With prolonged touch and transmission of electrical flow, severe burns may be caused by heat.

It is worth specifying that a macroscopic distinction between pre- and post-mortem electrical marks may not be possible. Given the possibility for such lesions to be produced post-mortem, even a microscopic histopathological analysis may not be conclusive if death occurs rapidly before a tissue inflammatory response has occurred.

If low-voltages are able to determine, in a certain percentage of cases, macro- and microscopically recognizable electrical marks on the skin, high-voltage current may cause extremely severe damage with possible charring of the body.

If transmission of electricity occurs from proximity to or the touching of a high-voltage current, this may lead to severe third-degree burns. Without a direct contact, but when the

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[16] *Lee, RC. Injury by electrical forces: pathophysiology, manifestations, and therapy. Curr Probl Surg 34:677–764, 1997.*
Solem, L., Fischer, RP., Strate, RG. The natural history of electrical injury. J Trauma 17:487–492, 1977.
Chandrasiri, N. Electrocution by dielectric breakdown (arcing) from overhead high-tension cables. Med Sci Law 28:237–240, 1988.

current is flowing through intermediary objects, burns are usually asymmetrical and vast, frequently whitish in colour, and in many cases with lifted margins and a middle hollow along with yellowish to black discolorations of the burned skin and the immediate surrounding area due to direct heat.

When the voltage is very high, massive destruction of tissues may occur, even with loss of extremities and breach of organs. Moreover, it is not rare that some tissues of the victim may be detected adhering at the contact area with the current source (e.g., metallic objects). Victims may even present a dark-blackish metallic coating on the skin because of metallic vaporization. Entries and exits may vary in dimensions and even be missed, since they can go unrecognized in extensive heat injuries. Typical lesions show a median charred area encompassed by a greyish zone of necrosis with a peripheral red zone. A temperature over 90°C (194°F) has charring consequences - about 30 seconds of skin contact with a low-voltage current is required for this to happen. With 54°C (130°F) for 40 seconds, the onset of epidermal necrosis is observed.[17] Multiple arcs of electricity may also occur, producing an aspect of so-called "crocodile skin''.

A thorough investigation of the scene is of utmost importance in cases of electrocution. An examination of the supposed source of electrical flow is essential, both for the safety of the scene (allowing operators to intervene without risks) and for the comprehension and reconstruction of the causes and manner of death. In some cases, the direct inspection of the device rather than examination of the corpse may provide crucial information for the cause of death when electrical burns/marks are not detectable.

Manner of Death

Deaths caused by electrocution may be accidental in manner, especially for a high-voltage current. As a matter of fact, they occur because of involuntary contact with a high-voltage line, for example while handling a large metallic device (e.g. metallic ladder). Electrocution is often caused by defective tools or electrical appliances. Some rare cases are sexually related accidents with electrodes in the anus or clipped to the penis.

[17] *Jumbelic, MI. Forensic perspectives of electrical and lightning injuries. Semin. Neurol. 15:342–350, 1995.*
Wright, RK., Davis, J. H. The investigation of electrical deaths: a report of 220 fatalities. J Forensic Sci 25:514–521, 1980.
Danielsen, L., Gniadecka, M., Thomsen, HK., et al. Skin changes following defibrillation. The effect of high voltage direct current. Forensic Sci Int 134:134–141, 2003.

At the state of the art, several studies on accidental electrocution demonstrated that most of the cases are due to low-voltage current, most frequently household voltage.[18] Following American statistics, every year about 1000 deaths related to electrical injury occur in the United States, while 3 to 6.5% of all admissions to American Hospitals in specific "Burn Units" are due to electrical injuries.[19]

Around 75% of accidental deaths involve people between 15 and 40 years of age, the studies showing a predominance of male victims.[20] Failure or damage to ground tools as well as using devices next to wet surfaces are risk factors. People experiencing electrocution during job activities are on average younger than other victims of work-related fatalities. The most common period for such events is the summer, owing to more frequent outdoor activity and, the decreased use of heavy insulation and sweating.[21]

According to previous studies, about 20% of all electrical accidental falls involve children.[22] As a matter of fact, children may be inclined to electric injury because of their tendency to chew on objects (e.g., electric cords) (and to be directly (i.e., through the mouth or fingers) or indirectly (e.g., through metal object, such as a fork) struck by an electrical flow.[23]

According to the literature, suicides occur less frequently. Suicides are related to the construction of particular devices, often by people who have knowledge of electricity and electrical engineering. Some cases show the use of a timer; cables are usually fixed from the electrical source directly onto the skin of the victim. Homicides are very uncommon. The most frequent method of committing such a homicide with electricity is to drop an active

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[18] *Wright, RK., Davis, JH. The investigation of electrical deaths: a report of 220 fatalities. J Forensic Sci 25:514–521, 1980.*
Bailey, B., Forget, S., Gaudreault, P. Prevalence of potential risk factors in victims of electrocution. Forensic Sci Int 123:58–62, 2001.

[19] *Cooper, MA. Emergent care of lightning and electrical injuries. Semin Neurol 15: 268–278, 1995.*
Martinez, JA., Nguyen, T. Electrical injuries. South Med J. 93:1165–1168, 2000.
Bernstein, T. Effects of electricity and lightning on man and animals. J. Forensic Sci. 18:3–11, 1973.

[20] *O'Keefe, GM., Zane, RD. Lightning injuries. Emerg. Med. Clin. N. Am. 22:369–403, 2004.*

[21] *Fatovich, DM. Electrocution in Western Australia, 1976–1990. Med J Aust. 157: 762–764, 1992.*
Zhang, P., Cai, S. Study on electrocution death by low-voltage. Forensic Sci Int 76: 115–119, 1995.

[22] *Fontanarosa, PB. Electrical shock and lightning strike. Ann Emerg Med 22:378–387, 1993.*

[23] *Rai, J., Jeschke, MG., Barrow, RE., Herndon, DN. Electrical injuries: a 30-year review. J Trauma 46:933–936, 1999.*
Nguyen, BH., MacKay, M., Bailey, B., Klassen, TP. Epidemiology of electrical and lightning related deaths and injuries among Canadian children and youth. Inj Prev 10:122–124, 2004.

electrical device into water while a person is having a bath. The so-called "Bathtub electrocutions", are becoming rarer over time due to the common utilization of low-voltage Ground-Fault Current Interrupters (GFCI), which can control and regulate the current flow.[24]

Another possible mechanism leading to death due to the transmission of electricity is lightning. Lightning is effectively an electric current. Within a thundercloud many small bits of ice (frozen raindrops) bump into each other as they move around in the air. These collisions create an electric charge and after a while, the whole cloud fills up with electrical charges. The positive charges or protons form at the top of the cloud and the negative charges or electrons form at the bottom of the cloud. Since opposites attract, this causes a positive charge to build up on the ground beneath the cloud. The grounds electrical charge concentrates around anything that sticks up, such as mountains, people, or single trees. The charge coming up from these points eventually connects with a charge reaching down from the clouds and this leads to the lightning strike. Since the under-surface of the thundercloud is usually negatively charged, discharges are also negative. The most common situation in which lightning strikes occur is that of a thunderstorm; other types of storms and volcanic eruptions might also lead to lightning strikes.

Lightning bolts may harm or kill a person with a direct strike, a side flash, or conduction through another object. A typical example would be a lightning bolt hitting a metal structure with electricity flowing down the metallic parts of the object and striking an individual who is touching it.

When a side-flash occurs, the lightning hits a target (e.g. a tree) and then ricochets off it, hitting the individual. If someone has one foot closer than the other to the strike point, electricity may flow through legs and body due to the potential difference between the legs. When the lightning bolt strikes the body directly, or when a really close object is hit, the flow can develop over the surface of the body and/or get through it. In such events, typical features include burnt and torn clothing, seared hair, burns on the surface of the skin due to metallic objects (e.g. pieces of the clothing) as well as burns caused by the flow of current through the body (features of entry and exit).[25] A direct strike to the head can penetrate skull orifices

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[24] *Marc B, Baudry F, Douceron H, Ghaith A, Wepierre JL, Garnier M. Suicide by electrocution with low-voltage current. J Forensic Sci. 2000 Jan;45(1):216-22.*
Dokov W. Forensic characteristics of suicide by electrocution in Bulgaria. J Forensic Sci. 2009 May;54(3):669-71.
al-Alousi LM. Homicide by electrocution. Med Sci Law. 1990 Jul;30(3):239-46.
Pfeiffer, H., Karger, B. Attempted homicide by electrocution. Int J Leg Med 111, 331–333 (1998).
[25] *Wetli CV, Keraunopathology: An analysis of 45 fatalities, Am J Forens Med Path 1996; 17 (2): 89-98.*

(eyes, ears, and mouth) and cause immediate death.[26] When a person is inside a vehicle hit by lightning, the likelihood of being harmed is extraordinarily low. What occurs in lightning strikes is a direct or indirect transmission to the body of a high-voltage flow of current. Therefore, the features of the injuries on the corpse are effectively the same as the previously described with high-voltage lines.

In case of a direct strike, death is due to cardiopulmonary arrest, electrothermal injuries or both. Moreover, the respiratory centre of the brain plays an important role in determining a fatal outcome; if electrocution occurs as a consequence of a close strike point, people affected may survive.

Typical features of lightning strike injuries are the so-called “Lichtenberg figures”,[27] a branching electric discharge that sometimes appears on the surface or in the interior of insulating materials. In some cases, they can be detected on the human body. Lichtenberg figures are not burns. They do not resemble vessel or nerve distribution. They tend to occur on the arms, back, neck, chest, or shoulders of lightning strike victims. They are usually described as reddish fern-leaf patterns, sometimes referred to as "lightning flowers" or "lightning trees.". The casuistry about lightning victims shows that males are more frequently hit by lightning since they more often perform manual work outdoors .[28]

<u>Internal Injuries in cases of Electrocution</u>

People surviving electrocution show frequently clinical and organic features of arrhythmias and myocardial ischemia.[29] Nevertheless, some studies show that the heart can be normal at autopsy. The myocardium may show little haemorrhages in the form of petechiae; larger haemorrhages have been detected in the pericardium and endocardium. According to previous literature, petechiae may develop on the eyelids, conjunctiva, pleura and epicardium. When present, they represent a sign of vitality. Petechiae are not related to

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[26] *Chao, TC., Pakiam, JE., Chia, J. A study of lightning deaths in Singapore. Singapore Med. J. 22:150–157, 1981.*
Cherington, M. Neurologic manifestations of lightning strikes. Neurology 60:182–185, 2003.

[27] *ten Duis HJ, Klasen H1, Nijsten MWN, et al., Superfi cial lightning injuries — Their “ fractal” shape and origin. Burns 1987; 13:141-146.*

[28] *Whitcomb, D., Martinez, J. A., Daberkow, D. Lightning injuries. South. Med. J. 95:1331– 1334, 2002.*
Centers for Disease Control and Prevention. Lightning-associated deaths—United States, 1980–1995. MMWR Morb Mortal Wkly Rep 47:391–394, 1998.
[29] *Leibovici, D., Shemer, J., Shapira, SC. Electrical injuries: current concepts. Injury 26: 623–627, 1995.*

voltage or current flow within the body, but may only be the effect of the combination of elevated blood pressure along with venous congestion.[30]

In the heart, microscopically small or larger areas of focal necrosis with haemorrhage and acute contraction bands in the myocardium as well as in the conduction system have been detected. Such changes may explain ongoing delayed arrhythmias. Some cases of myocardial infarction have been postulated. In this case, infarction is directly related to coronary spasm and occurs even without coronary atherosclerosis.[31]

Table 3
Lightning Injuries

Cutaneous burns *(139,143,152,153,165,167,174,205)*
Absent (discrete entry and exit rare)
Superficial
• Linear (corresponding to accumulation of sweat or water)
• Erythematous burns owing to flashover
• Punctate
Thermal (clothing ignition, melting belt buckles and zippers *[214]*)
Singed hair *(205,215)*
Lichtenberg figures (ferning, feathering, arborescent "burns," keraunographic markings *[143,153,174,216]*)
Ruptured eardrum (secondary to direct burn, shock waves, basal skull fracture *[143,152,153,165,167,174,217–219]*)
Pulmonary contusion (blunt injury, blast effect *[152,153,174,220]*)
Myocardial infarct (rare); myocardial contraction bands *(143,153,165–167,174,175,178,221–223)*
Muscle necrosis, myoglobinuria, renal failure (rare compared with high-voltage AC electrocution *[143,153,165,180,224]*)
Spinal cord damage (direct, secondary to fracture *[167]*)
Direct brain injury (associated with cranial burns *[143,164,166,174]*)
• Coagulation of parenchyma
• Epidural and subdural hemorrhage (? blunt trauma *[155,166,174,224]*)
• Peri- and intraventricular hemorrhage *(155,174)*
• Subarachnoid hemorrhage (? blunt trauma *[166,224]*)
• Basal ganglia hemorrhage (direct or thermal); brainstem hemorrhages *(166,224,225)*
• Skull fracture (blunt trauma *[155]*)
Facial fracture (blast effect *[226]*)
Postcardiac arrest hypoxic–ischemic encephalopathy *(224)*
• Associated cerebral infarction

Table from: Shkrum M.J., and Ramsay D.A. Forensic Pathology of Trauma: Common Problems for the Pathologist. Totowa, N.J.: Humana Press, 2007.

[30] *Fatovich, DM. Electrocution in Western Australia, 1976–1990. Med. J. Aust. 157: 762–764, 1992.*
Karger, B., Suggeler, O., Brinkmann, B. Electrocution—autopsy study with emphasis on "electrical petechiae." Forensic Sci Int 126:210–213, 2002.

[31] *James, TN., Riddick, L., Embry, JH. Cardiac abnormalities demonstrated postmortem in four cases of accidental electrocution and their potential significance relative to nonfatal electrical injuries of the heart. Am Heart J. 120:143–157, 1990.*
Xenopoulos, N., Movahed, A., Hudson, P., Reeves, W. C. Myocardial injury in electrocution. Am Heart J. 122:1481–1484, 1991.
Walton, AS., Harper, RW., Coggins, GL. Myocardial infarction after electrocution. Med J Aust 148:365–367, 1988.
Colonna, M., Caruso, G., Nardulli, F., Altamura, B. Myocardial haemorrhagic necrosis in delayed death from electrocution. Acta Med Leg Soc (Liege) 39:145–147, 1989.

The power of the electric flow along vessels may cause damages to the intima and media layers, thus leading to immediate or delayed thrombosis with resulting ischemia. Bigger arteries (e.g. in lower extremities) show a better resistance to the current due to a greater blood flow, but smaller arteries (e.g. intramuscular arteries) may be injured and/or occluded by the electrical stress. The formation of an aneurysm may also occur as well as the tear of pre-existing brain aneurysms. Electric shock may cause nerve and muscle injuries, especially with high-voltage current, leading to muscle necrosis.

Other significant consequences have been reported in several studies: compartment syndromes, myoglobinuria causing renal failure, hyperkalaemia. The feature of blunt pulmonary trauma due to contusion is more frequently observed. Some may develop ARDS as delayed consequence.[32] The ischemic consequences to skeletal muscles may also be delayed and show necrosis after a certain period. At the beginning the muscle may show normal features, although thermal denaturation changes already occurred. When the muscle damage is massive, amputation could be necessary. A direct damage to the lungs is unlikely in electrocutions. The rupture of abdominal organs (e.g., stomach, intestine, gallbladder, oesophagus) from "blast" effects have been also described. Ischemic damage to the bowel may be caused by the coagulation necrosis of small vessels. Even cases of paralytic ileus have been observed.

When lighting strike occurs, the extremely high temperatures may cause blasting effects. This leads to the occurrence of heat-induced injuries as well as blunt injuries (e.g. bone fractures related to falls). Muscle spasm leads to cervical spine and long bone fractures and dislocations.[33]

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[32] Lee, RC. Injury by electrical forces: pathophysiology, manifestations, and therapy. Curr. Probl. Surg. 34:677–764, 1997.
Cooper, MA. Emergent care of lightning and electrical injuries. Semin. Neurol. 15: 268–278, 1995.
Fieguth, A., Schumann, G., Troger, HD., Kleemann, WJ. The effect of lethal electrical shock on postmortem serum myoglobin concentrations. Forensic Sci Int. 105:75–82, 1999.
Puschel, K., Lockemann, U., Bartel, J. Postmortem investigation of serum myoglobin levels with special reference to electrical fatalities. Forensic Sci Int 72:171–177, 1995.
Leibovici, D., Shemer, J., Shapira, S. C. Electrical injuries: current concepts. Injury 26: 623–627, 1995.

[33] DiVincenti, FC., Moncrief, JA., Pruitt, BA., Jr. Electrical injuries: a review of 65 cases. J Trauma 9:497–507, 1969.
Williams, DB., Karl, RC. Intestinal injury associated with low-voltage electrocution. J Trauma 21:246–250, 1981.
James, TN., Riddick, L., Embry, JH. Cardiac abnormalities demonstrated postmortem in four cases of accidental electrocution and their potential significance relative to nonfatal electrical injuries of the heart. Am Heart J. 120:143–157, 1990.
Fieguth, A., Schumann, G., Troger, H. D., Kleemann, W. J. The effect of lethal electrical shock on postmortem serum myoglobin concentrations. Forensic Sci Int 105:75–82, 1999.

In the daily practice of the forensic pathologist, electrocution may represent a tough challenge. As a matter of fact, death by action of the electrical energy is a ‘‘functional’’ death-type, because fatality may happen as a result of disorders of the heart rhythm (such as ventricular fibrillation) or electrically induced contraction of the respiratory muscles: internal findings are frequently non-specific and therefore substantially overlap with those of sudden death.

The only specific sign of the passage of electricity may be the electric burn mark.

The present study started from these assumptions. At the state of the art, an extensive and detailed study on a large number of deaths due to electrocution is crucial to increase and refine the diagnostic tools of forensic pathology. Therefore, there is a great necessity for further research on new methods suitable for this purpose which can allow the pathologist to identify the cause of the death in an electrocution with reasonable certainty.

Puschel, K., Lockemann, U., Bartel, J. Postmortem investigation of serum myoglobin levels with special reference to electrical fatalities. Forensic Sci Int 72:171–177, 1995.
Carvajal, H. F., Feinstein, R., Traber, D. L, et al. An objective method for early diagnosis of gram-negative septicemia in burned children. J Trauma 21:221–227, 1981.

Materials and methods

The study was conducted on the autopsies performed in the city of Berlin, Germany, over a 12-year period.

The Institute of Forensic Medicine of the Charitè University of Berlin (*Institut für Rechtsmedizin der Charité Berlin*) along with the State Institute for Forensic and Social Medicine of Berlin *(Landesinstitut für gerichtliche und soziale Medizin)* perform all judicial autopsies on behalf of the Berlin judicial authority, with a total amount of about 2500 autopsies per year.

Following the usual procedure, for each autopsy a protocol is drawn up with all the macroscopic findings of the external and internal examination of the body which are collected together with the discussion on the causes and manner of death, in order to be given to the judicial authority for investigation purposes. The protocol contains a detailed description of all the findings of the external and internal examination of the organs accompanied by photos of the corpse and of the most significant injuries. Furthermore, in many cases (depending on the type of case, the cause of death as well as the requests of the judicial authority) the study of the case is enriched by other types of investigations:

- post-mortem CT-scan performed prior to autopsy, with 3D reconstruction of the body;
- toxicological analysis on biological fluids and organ fragments sampled from the cadaver during the autopsy, as well as material sampled from the scene when necessary;
- microscopic histopathological analysis on biological tissues sampled from the cadaver during the autopsy.

With the aim of evaluating all the possible aspects that can help a medico-legal diagnosis of death by electrocution, a retrospective study has been carried out on the electrocution cases performed at the Institute of Forensic Medicine of the Charitè University and at the State Institute for Forensic and Social Medicine *(Landesinstitut für gerichtliche und soziale Medizin)* in Berlin.

Firstly, a search was performed in the electronic database, which covers the time period 2007-2020 (up to the moment of the ultimation of the present study) in order to detect all cases of death due to electrocution. The database, as well as all protocols and data analysed, are reported in German language.

A search was performed in the database according to keywords such as *"Strom"* (current) *"Stromtod"* (death by electrocution), *"Elektrokution"* (electrocution) *"Stromschlag"* (current strike) *"Verdacht auf Stromtod"* (suspected death by electrocution). A long survival time after the electric shock was considered an exclusion criterion: a case of long survival was detected in the database (about a month and a half after an episode of low voltage electrocution), the cause of death was however directly linked to consequences of prolonged hospitalization after the event (pneumonia and pulmonary embolism) without specific elements related to the previous electrocution.

A total of 54 cases in the time range 2007 - 2020 was found. Each case was then studied with the analysis of all the available data: autopsy protocol (with external and internal examination) as well as the documentation provided by the police with analysis and photos of the scene, in addition to any other element of help for the investigation (e.g. reconstruction of the circumstances of the event, possible source of the current, clues for the distinction between accidental event, suicide and homicide). When present, post-mortem CT analysis and the results of toxicology and histology examinations have been also considered.

The cases were classified and analysed according to different parameters:

- parameters related to the victim: age, gender, known pathologies, known assumption of medicines/drugs;
- parameters related to the scene: place of death/discovery of the corpse, position of the corpse;
- type of electrocution: low-voltage or high-voltage;
- type of device/instrument/source of electricity;
- external findings at the autopsy: presence/absence of electrical/burn marks, place and characteristics of the electrical/burn marks when present, occurrence of petechiae, any other peculiar finding at the external examination with relation to the electric flow;
- macroscopic internal findings at the autopsy: general conditions of the inner organs, characteristics of blood, occurrence of petechiae, organic injuries, fractures, any other peculiar finding at the internal examination;
- cause of death and possible differential diagnosis;
- manner of death: accident, suicide (with presence/absence of farewell messages), homicide;
- in case of suicide, possible influence of the victim's knowledge/skills in relation to the use of electricity (so-called "occupation-related suicide");

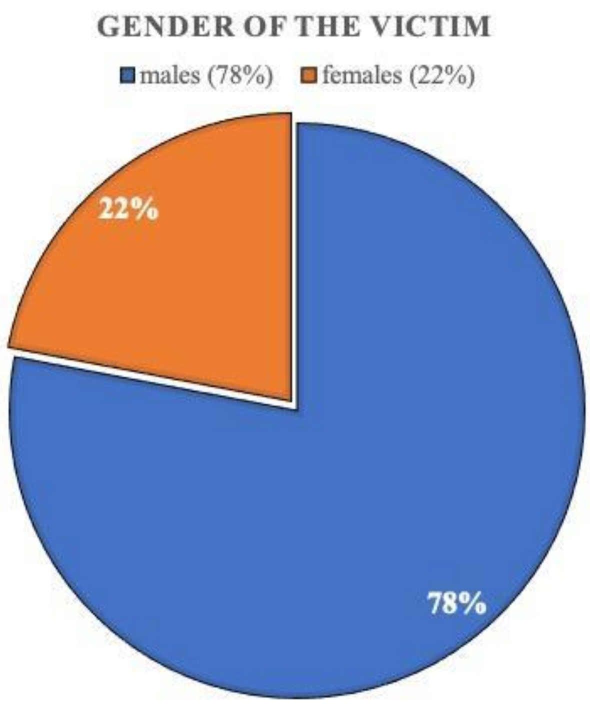
- study of the post-mortem CT-scan: evidence of any internal/external injury to tissues and bones;
- study of the toxicological investigations: evidence of drugs/medication assumption, possible influence on the cause and manner of death. Blood, urine and stomach content sampled during the autopsy were processed according to known regulations and extracted in a fractionated manner. The extracts obtained were checked for opiates, cannabinoids, cocaine, amphetamines, barbiturates, barbitural-free sleeping pills, analgesics, benzodiazepines and other psychotropic drugs, cardiovascular drugs and drugs of other modes of action as well as other toxic substances using high-performance liquid chromatography (HPLC), gas chromatography with a mass-selective detector (GC / MS) and enzyme immunoassay (EMIT);
- study of the histological investigations: microscopic features of the electrical burn, microscopic features of internal organs. Only the findings with a direct correlation with the cause and mechanisms of death, or in any case with the transmission of electrical energy, were considered. Other histopathological findings (e.g. incidental findings or pre-existing pathologies of the individual, not related to electric death) were not considered. The histological analyses included thus brain, lungs, liver, spleen, kidneys and skin (specifical site of electrical mark or burns). The tissue fragments were sampled directly during the autopsy and stored in buffered formalin, then subjected to reduction and preparation on a thin slide for microscopic analysis. For the skin, a sample of the suspect area was taken with epidermis, dermis and subcutaneous tissue (adipose tissue) also including a surrounding area of tissue apparently without lesions.

On the basis of the combined analysis of all this information, the objective of the study was to provide information that may be of help for the forensic pathologist in the diagnosis and reconstruction of electrocution deaths, providing additional scientific criteria that may be added to the macroscopic diagnosis and the direct inspection of the scene.

Results

Age and gender of the victims

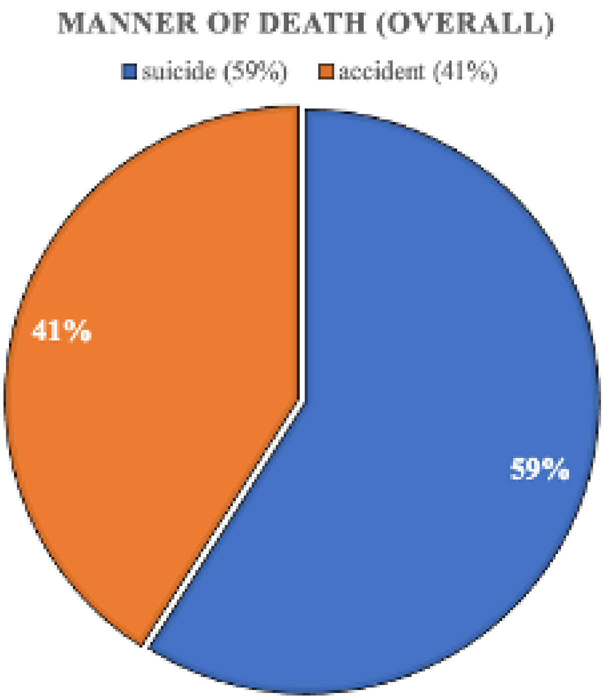
The age range of the victims varied between 15 and 94 years (in both cases –youngest and oldest victim-, the individual committed suicide by introducing a hair dryer, connected to the source of current via an extension cable, into a bathtub full of water). The median age of the victims was 48.15 years. In the cases analysed within the present study, a clear male prevalence of the victims was detected: only 22% of the victims were females (12 cases) while the remaining 78% were males (42 cases).



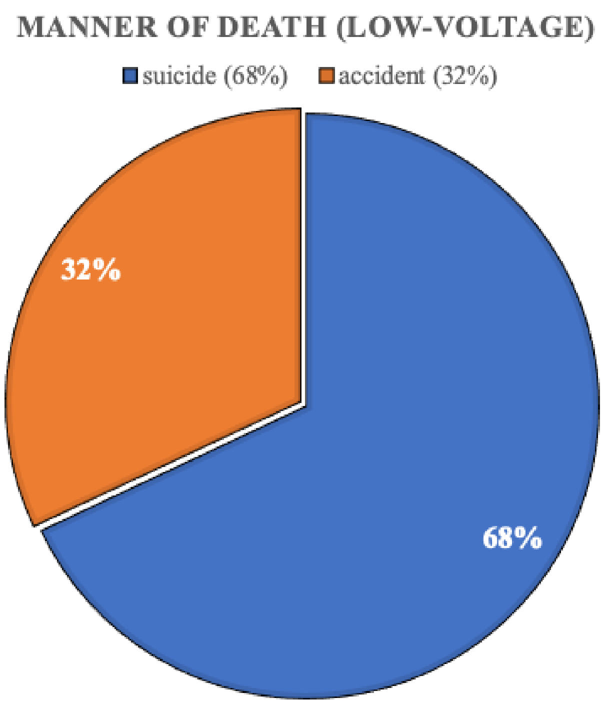
Manner of death

For what concerns the distinction between the different modalities of death, in the time range a prevalence of suicides (32 cases, 59%) was detected.

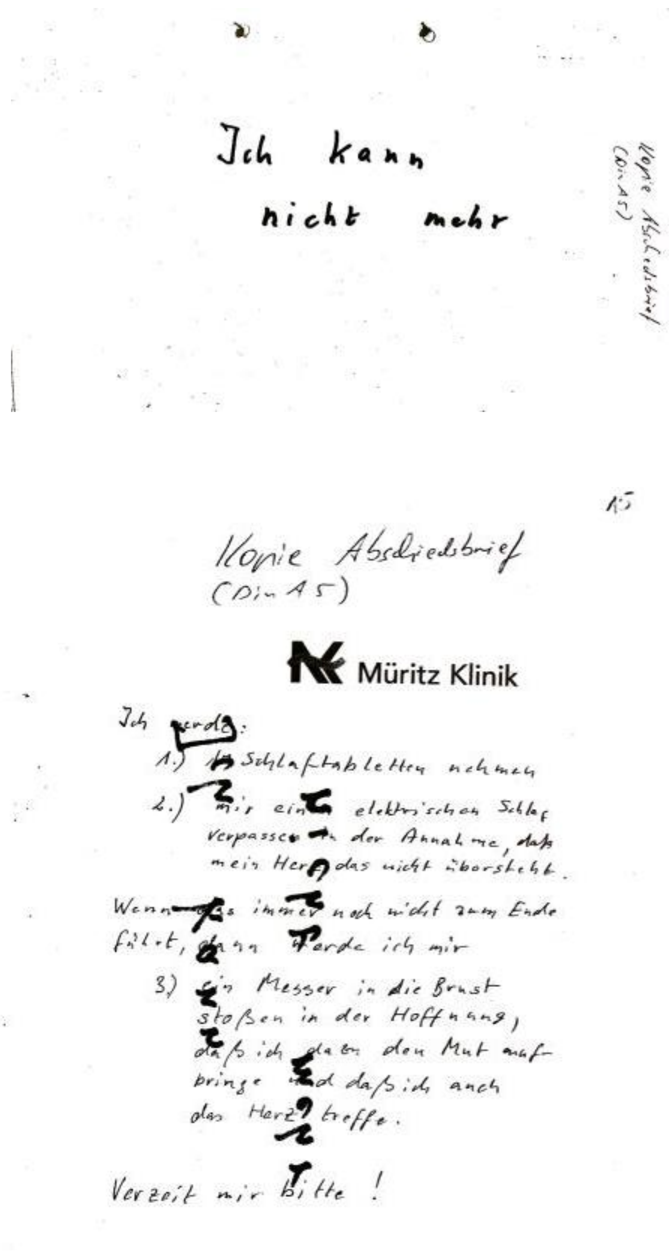
Accidental events have been registered in the remaining 41% (22 cases). In the analysed range of time no homicide cases have been registered.



However, if only the cases of death due to low-voltage transmission was considered, a suicide rate of 68% was recorded. In 71% of suicide cases, a medical history of depression was present.. In 14% of cases there was a positive history for other psychiatric pathologies (schizophrenia, bipolar disorder, psychosis, adaptation disorder).



It is worth underlining that in 54% of the cases of suicide, farewell letters or messages were found. This indicates an important and clear component of "planning" and "study" of the act of suicide.



Ich kann
nicht mehr

Kopie Abschiedsbrief
(DinA5)

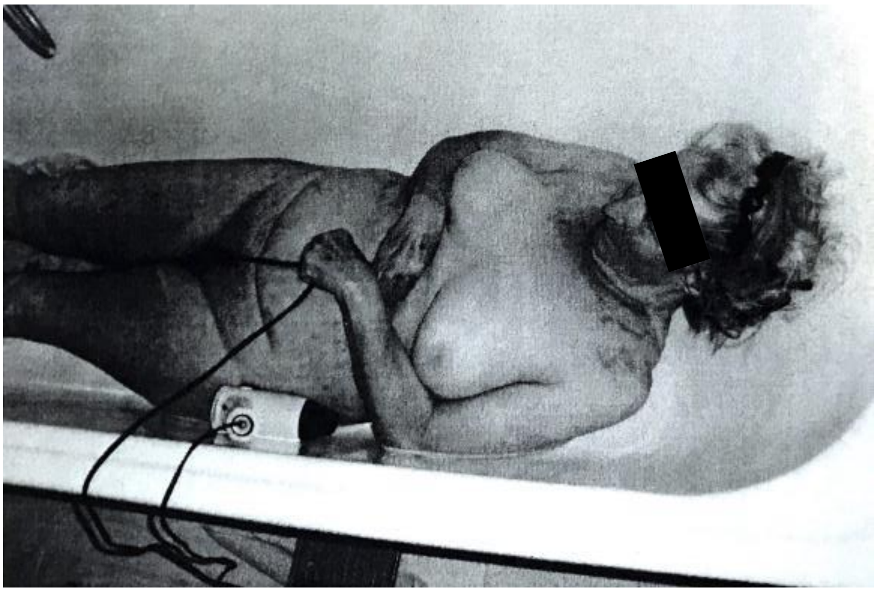
Kopie Abschiedsbrief
(DinA5)

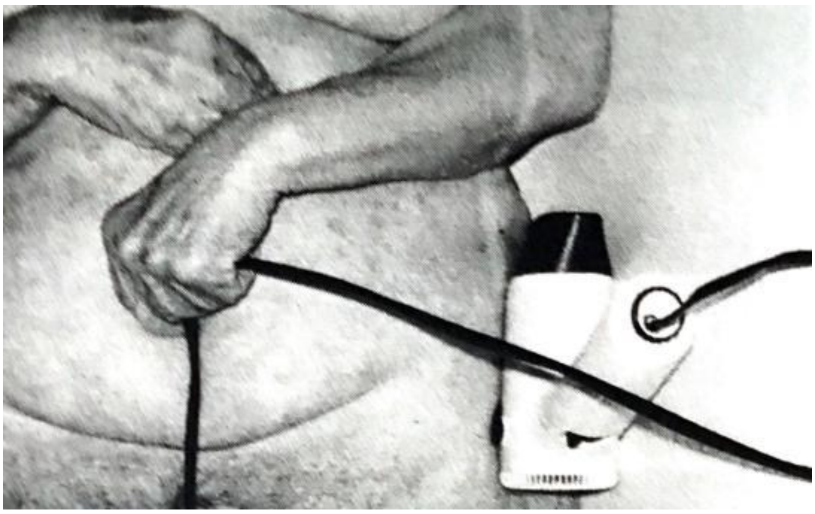
Müritz Klinik

Ich [redacted]erd[redacted]:
1.) [redacted] Schlaftabletten nehmen
2.) [redacted]ir ein[redacted] elektrischen Schlag verpasse[redacted] [redacted] der Annahme, daß mein Her[redacted] das nicht übersteht.
Wenn[redacted]s imme[redacted] noch nicht zum Ende führt, [redacted]ann [redacted]erde ich mir
3.) [redacted]in Messer in die Brust stoßen in der Hoffnung, [redacted]aß ich dabei den Mut aufbringe [redacted]d daß ich auch das Herz[redacted] treffe.
[redacted]
Verzeiht mir [redacted]itte!

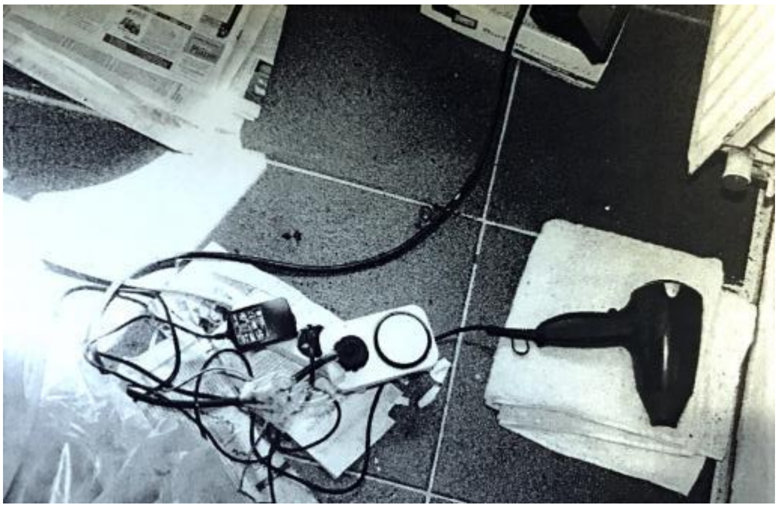
Two parts of a farewell letter in a suicide case: - (above) "I can't take it anymore"
– (under) "I will:
1) take sleeping pills
2) give myself an electric shock hoping my heart won't overcome it.
If that still doesn't work, then I will
3) stuck a knife in my chest in the hope I'll have the courage and hit the heart.
Please forgive me!"

Furthermore, the analysis of the scene in suicides has often found clear signs of a detailed organization, with precise construction of the electrical circuit and its connection to the body by cables tied to the extremities or around the waist. In some cases of "death in bathtub" (suicide by immersion of an electric device - usually hair dryer- in the bathtub containing water), it was possible to connect to a power outlet located outside the bathroom using one or more extension cables.





"Death in the bathtub": woman lying in a bathtub and holding a hair dryer (suicide)



Complex system of different sockets and electric cables to connect the hair dryer to a socket outside the bathroom (suicide)

Moreover, as also postulated in previous studies, the cases of suicide with the use of low-voltage current are in the vast majority carried out in a domestic environment (92% of cases).

In a total of 4 cases of suicide, all with the use of low voltage energy, a certain "connection" was found between the work activity or the interests of the subject and electricity.

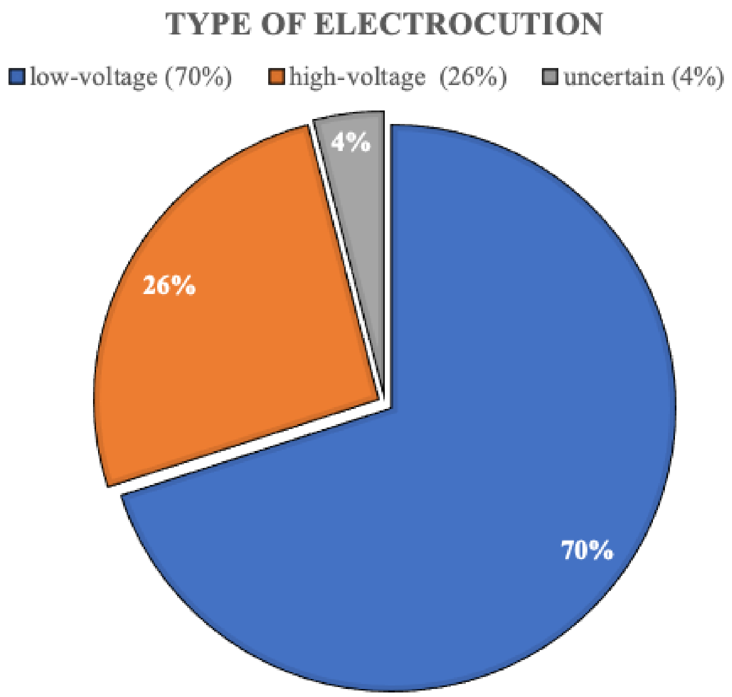
In one case the subject worked as an electrician. In another case, the subject worked as an electrical engineer.

In one case the subject was always interested in electricity and in the construction of electrical circuits as a hobby.

In one case (15-year-old male victim) there was a particular interest of the individual in chemistry and physics as school subjects: in this case the victim immersed himself in a bathtub full of water and committed suicide by using a hair dryer. As demonstrated by the discovery of a receipt at home, the salt was bought by the victim on the same day by a close supermarket and then poured into the water with the aim of to increasing its conductivity and help transmission of the electric flow to the body.

<u>Type of electrocution</u>

In the majority of the analysed cases (70%) the electric current responsible for the electrocution was of domestic origin and therefore at low-voltage, while in the remaining cases the responsible current was at high-voltage.



In 2 cases the analysis of the investigation files did not allow the identification of the involved type of electrical current. Both were accidental cases at work (workers operating electrical circuits); whether they were related to low or high-voltage was not ascertainable from the investigation files.

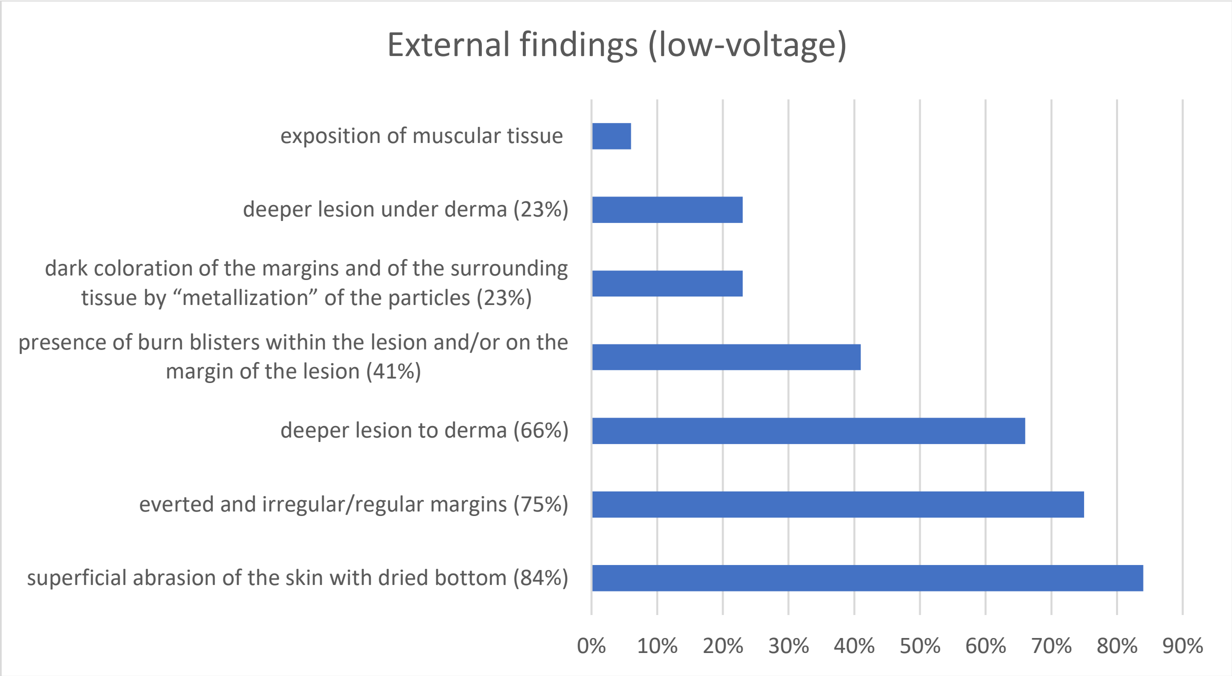
External findings (low-voltage)

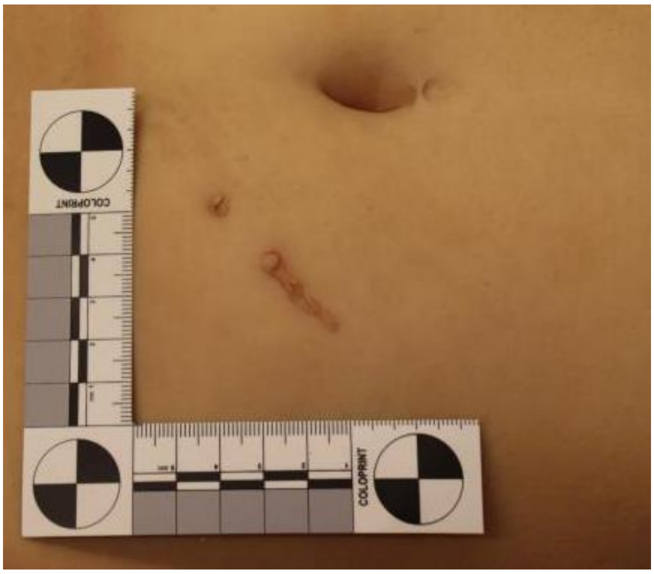
In 82% of the cases of low-voltage energy transmission, the presence of electrical burns/marks was found. When a documented contact between the source of the electric current (or its means of transmission) and the body was present, the percentage increased to 94%.

The main characteristics of the electrical burns for low-voltage energy transmission, in order of observed frequency were:

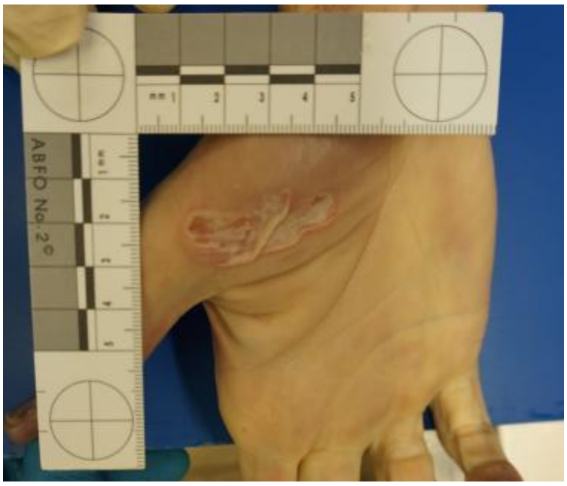
- superficial abrasion of the skin with dried bottom;
- everted and irregular/regular margins;
- presence of burn blisters within the lesion and/or on the margin of the lesion
- dark coloration of the margins and of the surrounding tissue by "metallization" of the particles
- deeper lesion to derma
- deeper lesion under derma

- exposition of muscular tissue.

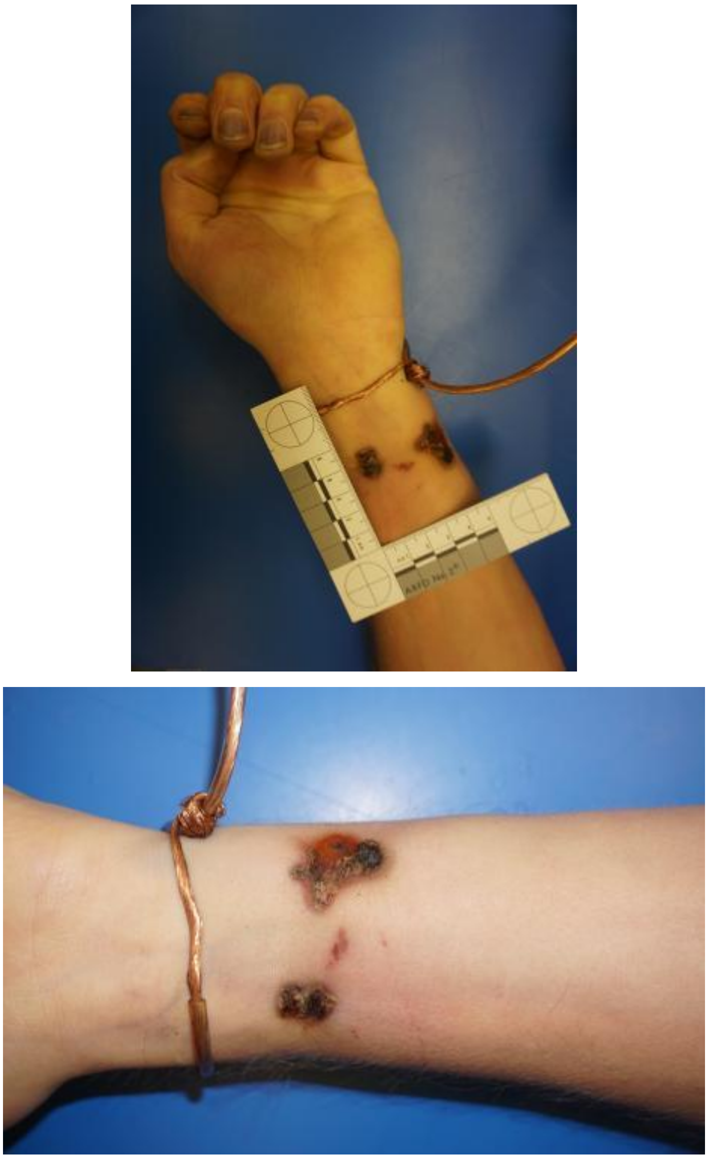




Electrical mark on the skin of the abdomen: presence of superficial abrasion, blisters, slightly inverted margins (accidental event: contact with electric cable near the tracks of a subway station)



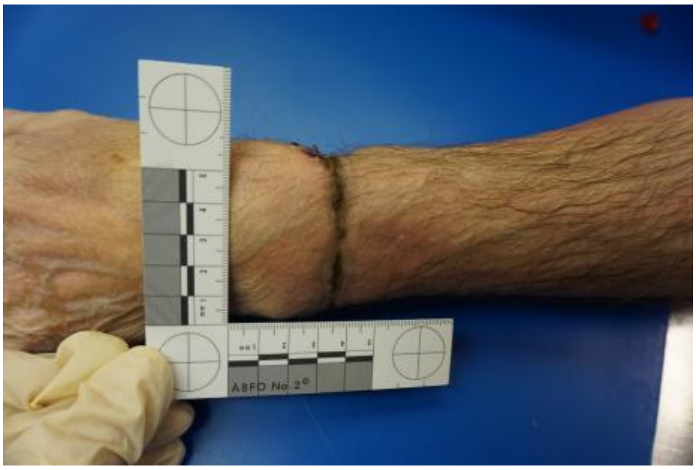
Electrical mark on the hand: superficial blisters (suicide with electric cables)



Electrical mark on the link wrist: excoriation with red-brownish background, drying of the margins and surrounding tissue. Nearby: electric cable without insulation (case of suicide)

In a specific case it was also possible to recognize the specific shape of the conductor placed in contact with the skin in the electrical mark. In this case the individual had connected several uncoated electrical cables which he then wrapped around different parts of his body.

Electrical mark on the ankle: small multiple and superficial excoriations with imprint of the handler (case of suicide)

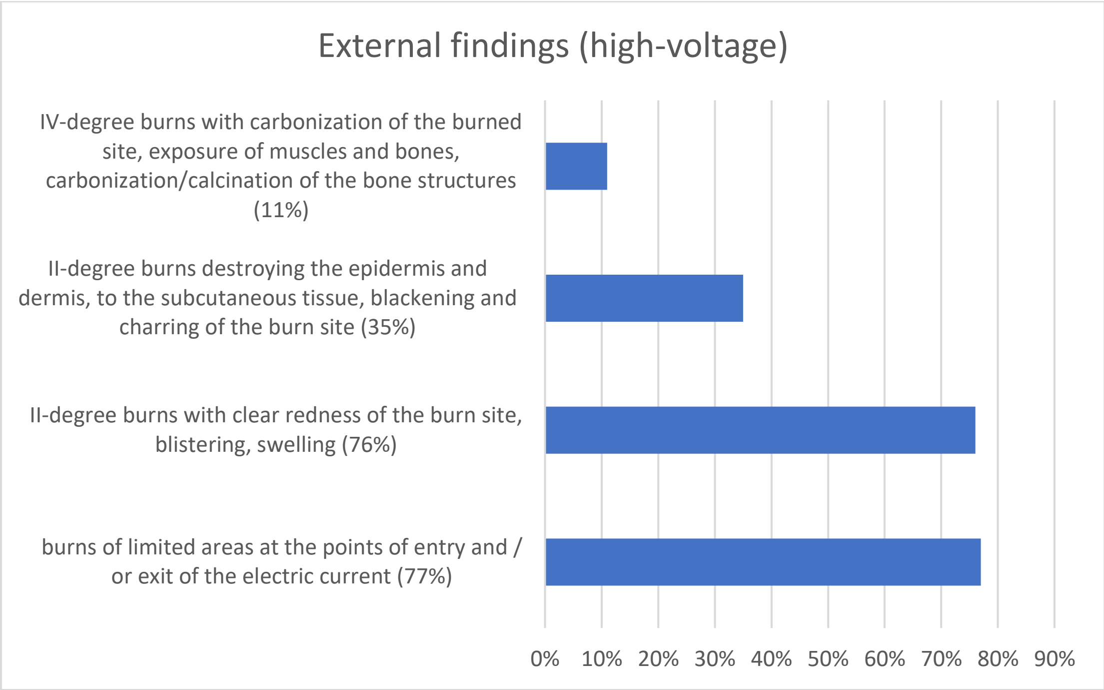


Electrical mark on the wrist: blackish abrasion with "metallization" (case of suicide with metallic cables connected to an electric generator)

<u>External findings (high-voltage)</u>

In case of electrocution due to high-voltage energy, the external characteristics that have been most frequently detected are:

- burns of limited areas at the points of entry and / or exit of the electric current.
- II-degree burns with clear redness of the burn site, blistering, swelling;
- III-degree burns destroying the epidermis and dermis, to the subcutaneous tissue, blackening and charring of the burn site.
- IV-degree burns with carbonization of the burned site, exposure of muscles and bones, carbonization/calcination of the bone structures.



Localized (degree II) burn in a case of high voltage transmission

Several burns of the face in a high voltage transmission case

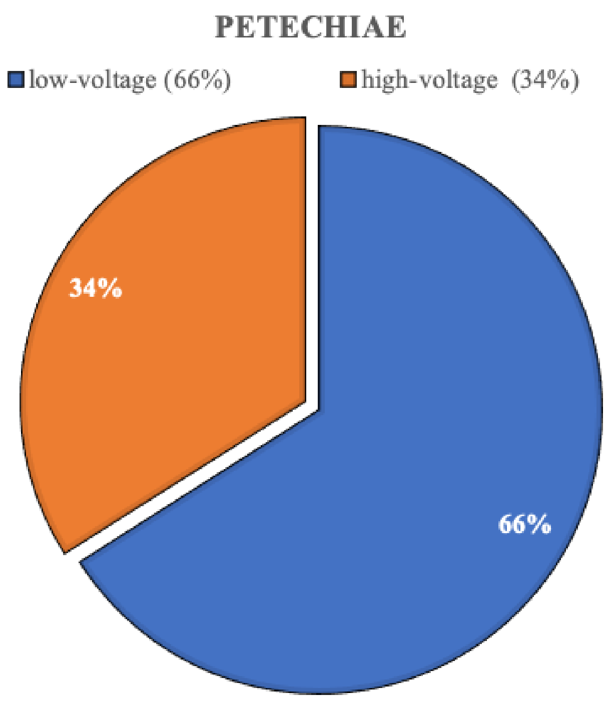
Multiple exit points of the current flow to the left foot with relative damage to clothing in a case of lightning

Internal findings

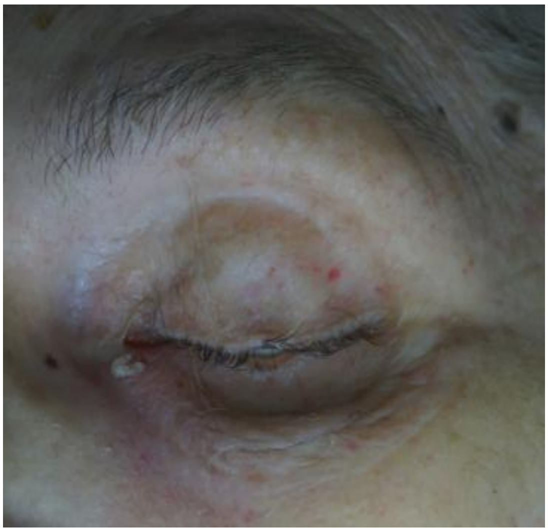
In most cases the presence of macroscopic signs was found, usually indicative of a rapid death and cardiorespiratory central arrest (affecting the central nervous system) or a sudden arrest of the heartbeat. A common finding on internal examination was the presence of fluid blood, cerebral oedema, pulmonary oedema and congestion of internal organs.

The presence of petechiae was reported in 44% of cases: these were found, in order of frequency, in the lungs, heart, internal serous linings (for example pleura or pericardial sac), conjunctiva and eyelids. These were found in a higher percentage in cases of low voltage energy electrocution (54%) while in cases of high voltage energy transmission they were found in 29% of cases.

Considering all the cases in which petechiae were found, in 66% of cases these were due to low-voltage energy transmission, in the remaining 34% due to high-voltage energy.



Petechiae in the conjunctiva



Petechiae in the eyelid

Pericardial petechiae

In 4 cases of electrocution due to low-voltage energy transmission, haemorrhagic infiltration in the underlying tissues (subcutaneous and adipose tissue) in the area of direct current transmission (in the area of the electrical burn). The following have been the most frequent macroscopic findings of the main organs:

- *Brain*: oedema and congestion;
- *Lungs*: oedema and congestion, weight gain, presence of pleural petechiae;

Pulmonary petechiae

Pericardial petechiae and haemorrhages

- *Heart*: enlargement of the right heart chambers, areas of pallor indicative of a possible ischemic area, presence of epicardial and endocardial petechiae, little haemorrhages of the surface. No macroscopic coronary artery thrombosis or heart muscle infarcts have been reported;
- *Liver*: congestion;
- *Kidneys*: congestion.

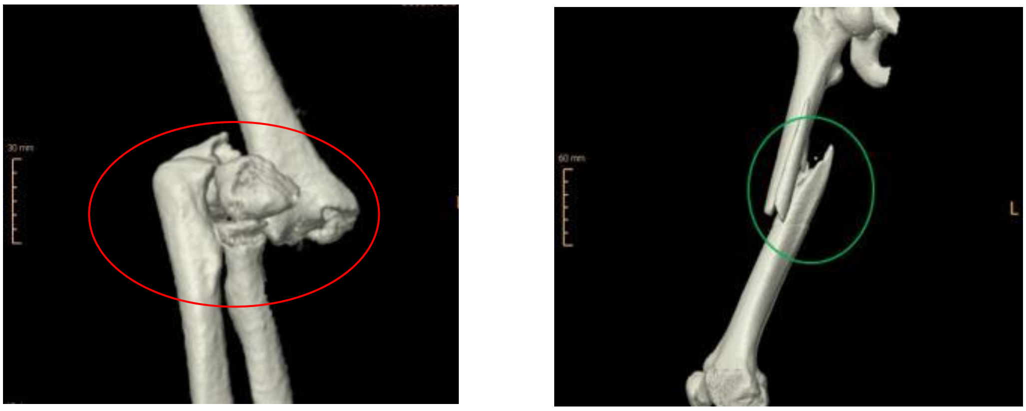
Toxicological findings

The toxicological investigations showed completely negative results in 42% of the cases for drugs, medicaments and alcohol. In 38% of cases the presence of medicines within the therapeutic range was found (subjects with a positive history of medicine intake for therapeutic reasons).

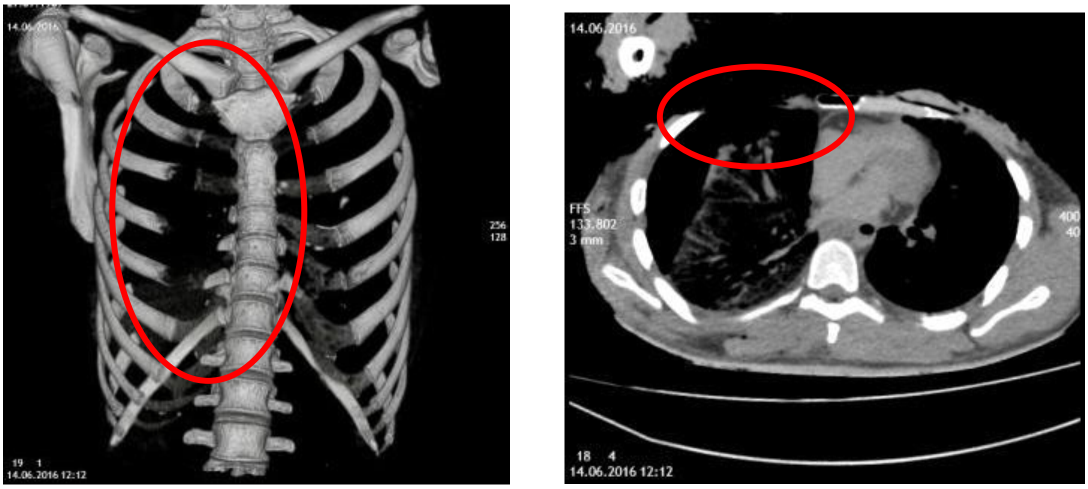
Increased alcohol levels were detected in 22% of cases. In 5 cases the blood alcohol concentrations were considered sufficient to cause a reduction in the subject's ability to act, even if not directly involved in the cause and mechanism of death. In two cases in which the subject ingested neuroleptic substances before committing suicide by electrocution (in one case by means of a hair dryer immersed in the bathtub full of water, in the other by connecting some cables without insulating material wrapped around the body), these substances were found within the gastric contents but not in concentrations such as to have had an effect on the cause of death. In a case of high-voltage energy transmission and consequent development of flames that involved carbonization of the body, a high concentration of carbon monoxide in the blood was found. Such a finding was considered of crucial importance in determining death (see following discussion).

Post-mortem CT scan

In a total of 11 cases a post-mortem CT scan was performed before the autopsy. The radiographic examination allowed in all cases a precise analysis of the signs of external and internal damage. In two cases the appearance of fractures and dislocations of the upper limbs was reconstructed. In cases of carbonization of the corpse, the 3D reconstruction showed the external damage linked to the carbonization processes.



Bone fractures caused by electrocution:
- left: fracture and dislocation of the humerus-radius-ulna joint (high voltage - accidental event)
- right: fracture of the humeral shaft (high voltage - suicide)



Large loss of part of the rib cage due to extensive carbonization following transmission of high voltage electricity (accidental event)

<u>Histological findings</u>

The following are the most frequent microscopic findings in the cases of electrocution of the present study.

As previously stated in the "Materials and Methods" section, only microscopic findings showing correlation with the mechanisms / modalities of death were considered for the present study

<u>Lungs</u>

The most frequent features were congestion and pulmonary oedema. The blood content in the pulmonary vessels (arteries and veins) was high, corresponding to the characteristic images of a strongly pronounced "acute blood congestion". No indicators of inflammatory processes were discovered. Large parts of the lung tissue were characterized by a pronounced acute pulmonary oedema with filling of the alveoli with a pale pink oedema fluid.

Within oedema fluid many histiocytic phagocytes (alveolar macrophages) with cytoplasmic deposits of black-brownish coloured condensate were detected. The air content of the alveoli (alveoli) was very heterogeneous due to an intense diffuse alveolar pulmonary oedema with a strong accumulation of pale pink oedema fluid in almost all alveolar clearances. Some of the alveolar clearings also contain erythrocytes (red blood cells) corresponding to focal alveolar bleeding.

There was no evidence of organizational processes or degradation phenomena on the blood cells. Occasionally, single histiocytic phagocytes (alveolar macrophages) in the oedema fluid without cytoplasmic pigment or condensate deposits were present. Acute pulmonary congestion with dilation (widening) and excessive blood flow in all blood vessels in the lungs.

Lung lymph nodes were also heavily congested with blood and with different levels of deposition of anthracotic pigment. Tissue layers showed occasionally small follicular aggregations of lymphocytes in the outer wall layers of encountered bronchi (parts of the airway system in the lungs).

Liver

The main findings showed a congestion of the liver tissue. The sinusoids, especially in the central and intermediate lobule areas, were clearly widened and contained more blood, corresponding to typical signs of “acute hepatic congestion”.

Spleen

The spleen follicles were relatively sharply demarcated by the widened red spleen pulp.

The widening of the red pulp of the spleen is caused by an acute congestion of blood that is also evident in this organ.

Kidneys

The capillaries and the other kidney vessels, especially in the medullary area, were clearly widened and contained more blood, corresponding to acute kidney congestion.

Skin

The electrical injury has usually the highest amount of nuclear streaming as compared to other conditions. Other features like dermal/epidermal separation and coagulative necrosis were frequently observed.

The so-called current marks on the skin showed extensive necrosis of the epidermis and adjacent parts of the dermis with intraepidermal blistering, elongation of the epithelial cell nuclei in the epidermis and signs of focal metallization.

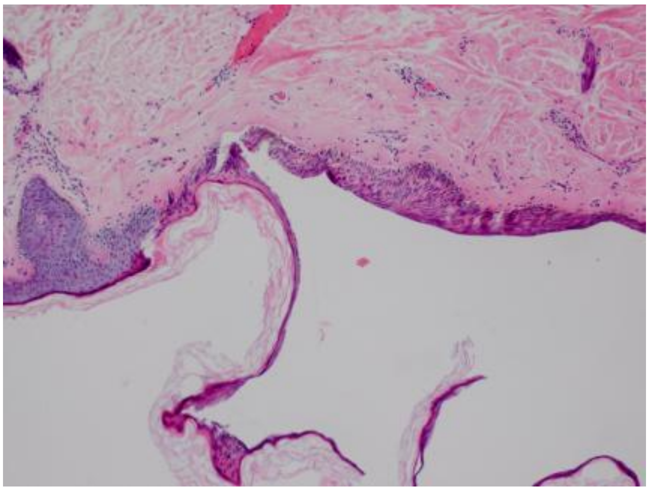
Areas with acute necrosis (tissue death) affecting parts of the epidermis and dermis were observed. The necrotic sections of the epidermis were microscopically characterized by a stronger, more intense staining, intraepidermal blistering with detachment of the upper layers of the epidermis from the basal cell layer.

An evident, intensive elongation of the cell nuclei of all layers of the epidermis was detected. The cell nuclei formed conspicuously palisade-like over long stretches. In the haemorrhagic dermis, the sweat glands are also involved in the necrosis. A focally sparse leukocyte (granulocyte) infiltration in the deeper layers of the dermis and adjacent areas of the subcutaneous fat tissue was identifiable.

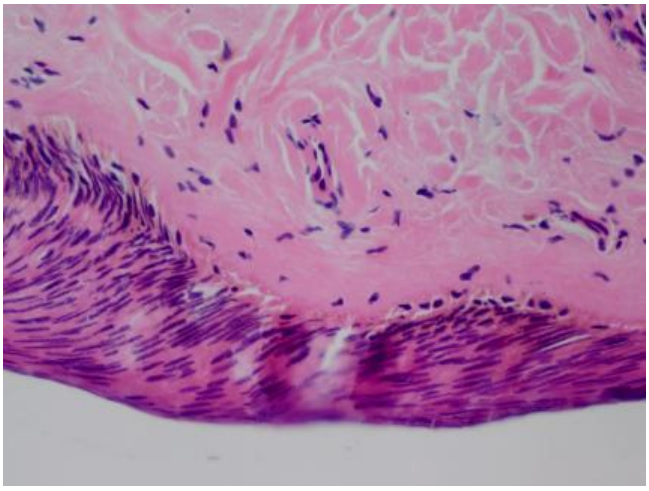
Some parts of the epidermis appeared completely deformed and look charred under the microscope. In other areas, the necrosis showed a stronger staining and noticeable elongation of the cell nuclei of all layers of the epidermis or epidermis. Here, too, one occasionally encounters smaller intraepidermal blister formations. Small groups of sweat glands located in the upper parts of the dermis are involved in the necrosis. Bleeding or leukocyte (granulocytic) infiltration recede into the background on the skin.

Noticeable on the surface of the necrotic epidermis are brownish, sometimes granular deposits and in the upper layers of the dermis there are groups of small, granular black particles, which are presumably deposits or cracks of small metallic structures, corresponding to so-called "metallization".

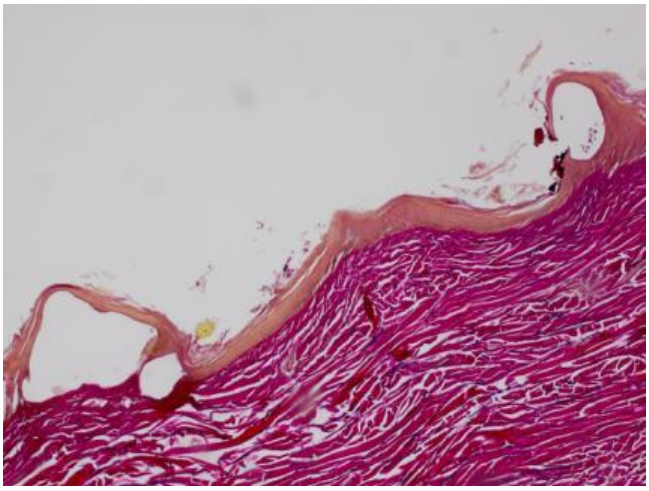
Other findings on the skin included elongation and pyknotic appearance - moreover with tight packing - of the nuclei of epidermis (so-called "nuclear streaming"), especially within the basal layer and evident at the outskirts of the lesion. Another modification that has been detected was intraepidermal separation, shown as a sub-corneal separation. The separation between dermis and epidermis was also observed, along with formation of microscopic blisters.



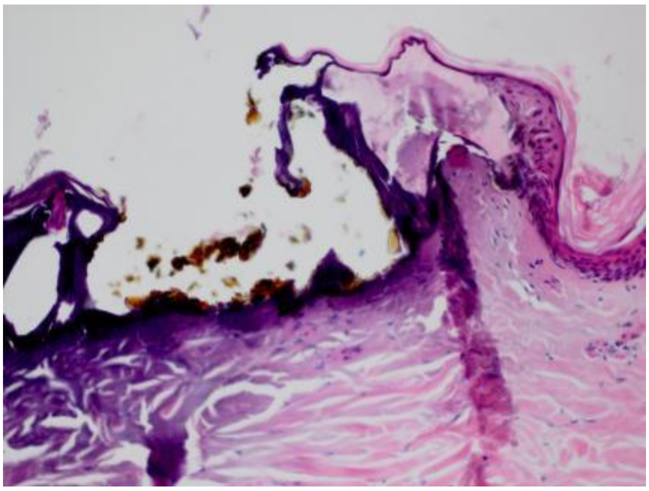
Intraepidermal blistering with detachment of the upper layers of the epidermis from the basal cell layer (HE, 10x)



Elongation of the cell nuclei of all layers of the epidermis (HE, 40x)



Intraepidermal blister formation (Van Gieson, 10x)



Black-brownish deposits ("metallization") (HE, 40x)

Discussion

The evidence provided by the analysis of the results enabled the following considerations on the pathological-forensic study of the electrocution cases.

- ***Characteristics of the victims and manner of death***

Working with electricity has traditionally been considered a "man's job". According to such an assumption, the research detected a strong predominance of male victims, as already stated in other studies.[34]

As a matter of fact, it is well known that men have more frequently to deal with electricity (for work purposes or at home) explaining the greater incidence in case of accidental events. Moreover, even in case of suicide males have shown, in accordance with previous studies, a greater predisposition to carry out this particular and unusual type of suicide.

The age range in our study sample was very broad, indicating potential hazards of electricity for any age group. A peculiar evidence is related to the fact that the youngest victim (15 years) as well as the oldest (94 years) concern suicides through the immersion of a hair dryer inside the bathtub full of water. As if to say, this method of committing suicide "has no age".

In accordance with previous studies, the majority of deaths occurred due to low-voltage electricity (70%), which is commonly used in households and at workplaces. This could be related to the increased accessibility to domestic low-voltage and alternating current power lines with which people are much more often familiar and which are much more easily accessible. The remaining cases were due to high-voltage electricity, which is used in industrial facilities, on construction sites, in aerial power lines, railway, and similar.

The consequence is that the number of deaths due to high-voltage energy is lower as it is more linked to accidental events and work environments. Furthermore, considering suicides,

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[34] *Tirasci Y, Goren S, Subasi M, Gurkan F. Electrocution-related mortality: A review of 123 deaths in Diyarbakir, Turkey between 1996 and 2002. Tohoku J Exp Med 2006;208:141-5.*
Liu S, Yu Y, Huang Q, Luo B, Liao X. Electrocution-related mortality: A review of 71 deaths by low-voltage electrical current in Guangdong, China, 2001-2010. Am J Forensic Med Pathol 2014;35:193-6.
Cawley JC, Homce GT. Occupational electrical injuries in the United States, 1992-1998, and recommendations for safety research. J Safety Res 2003;34:241-8.
Dokov W. Electrocution-related mortality: A review of 351 deaths by low-voltage electrical current. Ulus Travma Acil Cerrahi Derg 2010;16:139-43.
Lindström R, Bylund PO, Eriksson A. Accidental deaths caused by electricity in Sweden, 1975-2000. J Forensic Sci 2006;51:1383-8.

the greater number of cases due to the use of low-voltage is related to the availability and the possibility of having a "controlled" and “quiet” environment where they can commit the act.

- ***The occurrence and characteristics of electrical burns***

The presence of a macroscopic detectable electrical burn was found in 82% of cases of low-voltage energy transmission. This is in agreement with the data previously reported in the literature. In previous studies on the same topic, extremely variable percentages on the electrical burn´s presence rate have been reported, always between 50 and 83%. The percentage was evidently lower when cases of "death in the bathtub", without direct contact between the skin and the transmission material of electricity, were analysed. The presence of these signs is therefore frequent but not constant and depends on the type of current and above all on the type of flow transmission. [35]

This happens because the mechanism of internal electrical injury is not necessarily “thermal”. Burning is the result of a function of heating and localized resistance, directly proportional to voltage and inversely proportional to resistance between entry and exit points. Energy imparted is also related to time. If there is enough current density, resistance and time to elevate the skin locally to a temperature that will induce a burn, then an electrical burn will occur on the skin. Without those factors, a burn will not occur. As a matter of fact, wet skin causing lower resistance and wider entry site causing lower current density can reduce the chance of burning. The electric wound is produced due to endogenous heat production and the damage due to heat production depends upon the area involved, duration of current flow and amount of current flow. So due to these different factors, electric wound is not produced in every case of electric injury. Electrical burns and/or current marks were found more frequently in high- than in low-voltage deaths, which is in accordance with previous studies.[36] Therefore, the absence of an electrical mark poses further problems for the forensic investigation.

The usual macroscopic aspect of electrical marks is with a rounded or oval shape, sometimes an imprint of the form of the electro-conductive object was detectable. The central

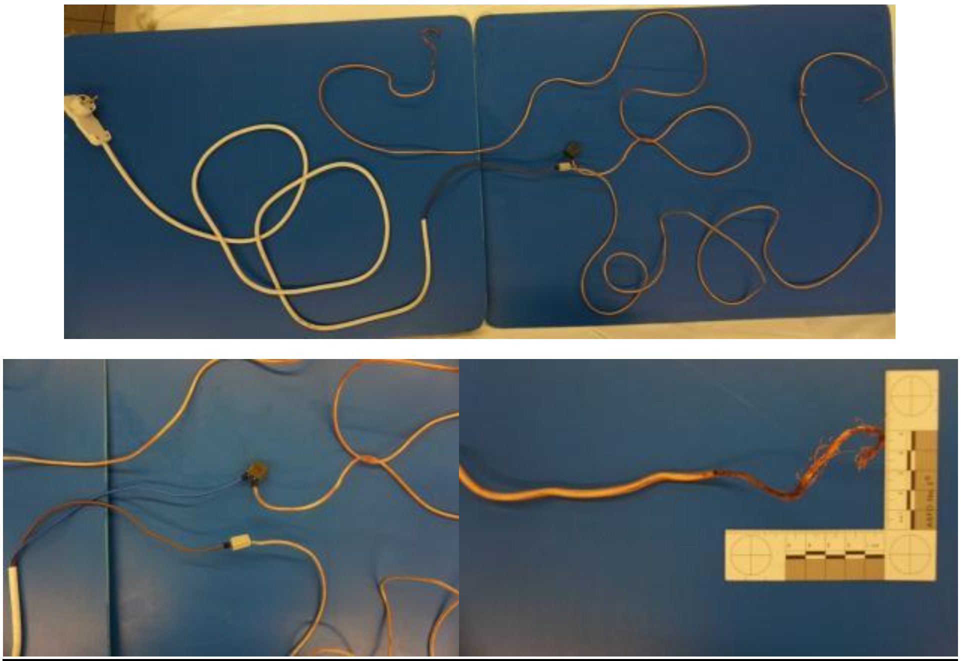
[35] *Kuhtic I, Bakovic M, Mayer D, Strinovic D, Petrovecki V. Electrical Mark in Electrocution Deaths – A 20-Years Study. The Open Forensic Science Journal, 2012, 5, 23-27.*
Wright RK, Davis JH. The investigation of electrical deaths: a report of 220 fatalities. J Forensic Sci 1980 Jul;25(3):514-21.
Mondello C, Micali A, Cardia L, Argo A, Zerbo S, Spagnolo EV. Forensic tools for the diagnosis of electrocution death: Case study and literature review. Med Leg J 2018 Jun;86(2):89-93.

[36] *S. Pollak, Pathomorphologische Befundkonstellationen beim Tod durch hochgespannten elektrischen Strom, Arch. Kriminol. 165 (1980) 1–6.*

area was hollow and the edges were frequently above the level of the surrounding skin. The skin in the damaged area is dry, thick grey-yellowish in colour. Moreover, burn blisters within the lesion and/or on the margin of the lesion and dark coloration of the margins and of the surrounding tissue by "metallization" of the particles may be detected. These characteristics are in agreement with what already described in the previous available studies. In such a scenario, it is crucial to underline, that the detection of an electrical burn on the skin does not certainly identify the cause of death for electrocution. Electrical flow through the body can lead to electrical marks even when death already occurred due to other reasons. The mark will macroscopically show the same characteristics of a lesion produced in life. In this case the histological examination can be decisive to evaluate the effect of electricity on the cells and the vitality of the lesion.

- ***<u>The greater incidence of suicides</u>***

Compared to series from other countries,[37] accidents occurred less frequently while low-voltage electrocutions and suicides occurred more frequently in this study.

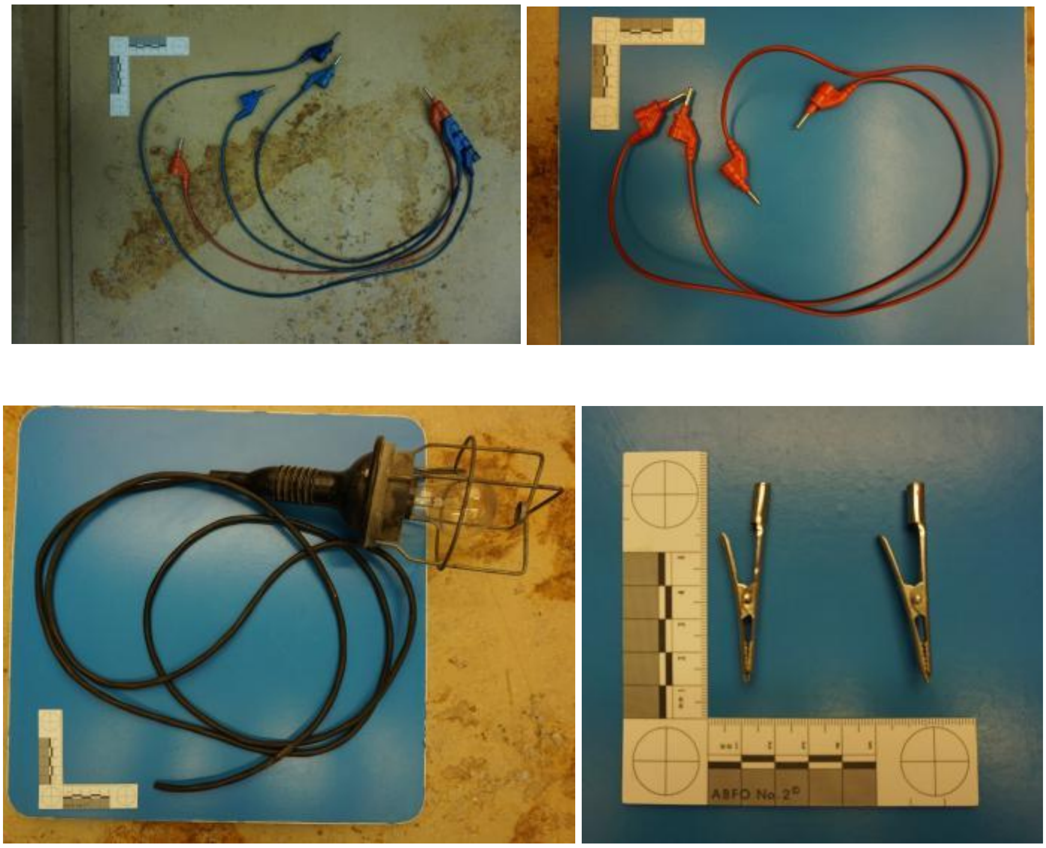


Electrical circuit created by connecting several cables and isolating the ends (suicide)

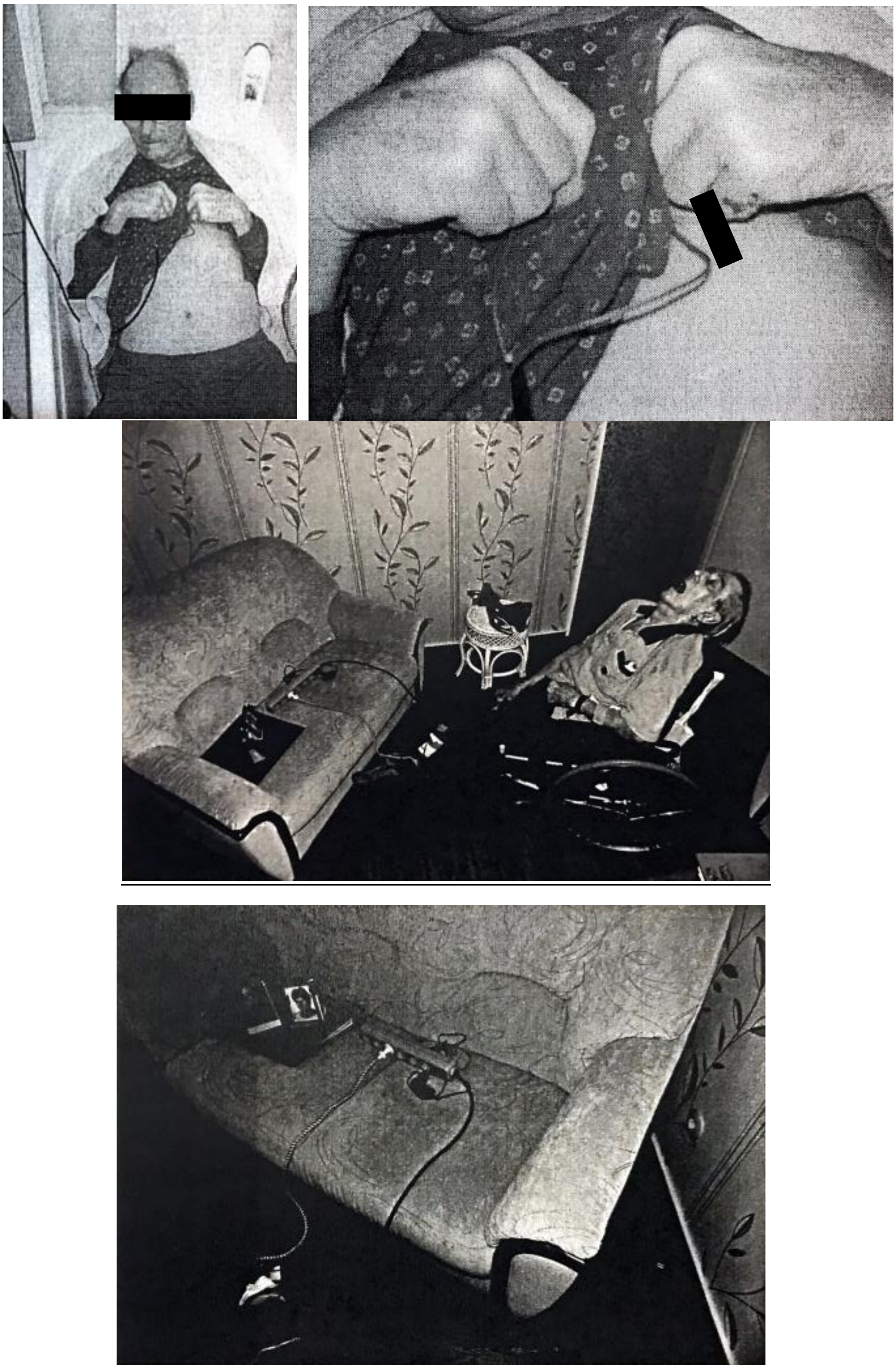
[37] *Wright RK, Davies JH, The investigation of electrical deaths: a report of 220 fatalities, J. Forensic Sci. 25 (1980) 514–521 80.*
Brinkmann B, Schaefer, Der Elektrounfall, Springer, Berlin, 1982. P.F. Mellen, V.W. Weedn, G. Kao, Electrocution: a review of
155 cases with emphasis on human factors, J. Forensic Sci. 37 (1992) 1016–1022.
D.J. DiMaio, V.J.M. DiMaio, Forensic Pathology, Elsevier, New York, 1989.

An element of difference and diversity from the statistics shown by previous studies was the prevalence of suicides compared to accidental events. This is quite surprising considering that American statistics report a very low suicide rate. The factors that may have led to these particularities in case studies are not known. The characteristics of suicides, however, show the characteristics that have been previously described in the literature: suicides usually occur in the home environment, for the victim “quiet” and “protected”.

The characteristics of the scene and the construction of the electrical energy transmission devices show an extensive planning and design of the gesture.



Complex electrical circuit created by connecting several cables, a lamp with extension and clamps



Typical domestic environment of suicides (cables tight in the hands, corpse lying in the bathtub – above - or sitting on the wheelchair – under -)

- **Internal findings and petechiae**

As postulated, an almost constant finding in the cases analysed by the present study was the finding of autoptic characteristics which, despite unspecific, are characteristic of "sudden" deaths as characterized by a sudden stop of the cardiocirculatory function with a very short or absent period of agony. These characteristics are frequent detected in association with deaths by asphyxiation.

In 44% of cases, the presence of petechiae was detected. These were localized on the surface of lungs, heart, internal serous linings (for example, the pleura or pericardial sac), conjunctiva and the eyelids. In case of electrocution, these have been described as “electrical petechiae”. As already postulated by previous studies, the occurrence of petechiae is independent from the type of current (low- or high-voltage) or from the path of electricity through the body.

As a matter of fact, it has been already hypothesized that petechiae may not be directly related to asphyxia, but may derive from a combination of venous congestion (related to sudden cardiac arrest) and rise in blood pressure as directly determined by muscle contraction due to fibrillation and tetanic contraction of the extrinsic muscles of respiration.[38]

Therefore, petechiae may be considered as a non-specific but frequent finding, with no specific relation to the mechanism of death. Moreover, whereas the electrical mark does not represent a sure sign of vitality (since it can also be produced post-mortem), the presence of petechiae is instead an index of the subject's vitality at the time of the event. Even if petechiae have been observed in low-voltage as well as in high-voltage deaths (as further detected in previous studies), their occurrence is more likely when the current flow is low. At the same time, the evidence that they were not restricted to cases of low-voltage flow points out that they may therefore not be due to asphyxia alone. They can evidently be due to massive congestion following sudden cardio-circulatory arrest. Moreover, even a sudden rise in blood pressure may cause petechiae.[39] It is in fact quite reasonable to consider that a short hypertensive crisis may also occur following the flow of current through the body.

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[38] *W.R. Lee, The mechanism of death from electric shock, Med. Sci. Law 5 (1965) 23–28.*
K. Mant, Heat, cold, and electricity. in: Gradewohl’s Legal Medicine, 2nd Edition, Bristol, J. Wright & Sons, 1968, pp. 379–390.
O. Prokop, R. Wabnitz, Vorkommen von Bindehautblutungen bei Lebenden und Toten, dargestellt in 10 Tabellen, Zeitschrift Rechtsmed 67 (1970) 249–257.
C. Simonin, Me´dicine Le´gale Judiciaire, 3rd Edition, Librairie Maloine, Paris, 1955.
Z. Peng, C. Shikui, Study on electrocution death by low voltage, Forensic Sci. Int. 76 (1995) 115–119.

[39] *F. Pietrusky, Experimentelle Untersuchungen über die Wirkung mittel und hochgespannter Ströme auf den lebenden Körper, Dtsch. Zeitschr. Gerichtl. Med. 6 (1926) 535–559.*

This may be due to tetanic muscle contractions along with electrically induced contraction of the vessels. Such an ascertainment is moreover demonstrated by the experimental formation of petechiae with intra-cardiac electrocution and with electric transcranial unifocal stimulation.[40] Although non-specific, their occurrence may in any case provide a valuable help in the differential diagnosis. Moreover, they can additionally be regarded as a “vital sign” since the mechanism of formation requires a living organism.

- **Further investigations: Toxicology, Histology, Post-mortem CT scan**

The importance of toxicological analysis was demonstrated to understand the subject's condition at the time of the event. This is essential in accidental cases to understand the influence of drugs / medications / alcohol in the dynamics of the event (e.g. fall of the subject or accidental contact with electric lines) or in cases of suicide (taking medicines) as well as in the mechanisms of death (e.g. carbon monoxide poisoning in the event of a fire caused by electric shock).

The microscopic characteristics already described in previous studies were found on the histological examination, underlining the importance of the histological investigation for a complete pathological-forensic analysis. This examination proved to be fundamental to recognize the effects of the current on the tissues and their vitality. This is crucial in a differential diagnosis process.

Another important contribution was provided by post-mortem CT for the recognition of bone fractures, organic lesions, pneumothorax, as well as for identification purposes in the case of non-identifiable corpses due to extensive carbonization of the body.

- **Crime scene investigation**

The study demonstrates the importance of a thorough scene investigation, which can provide crucial details. In fact, not only the combined analysis of the autopsy findings and other types of investigations is of utmost importance. In peculiar cases the study of the scene

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H. Gerstner, U¨ber die Wirkung des elektrischen Starkstoms auf den Blutdruck, Naunyn-Schmiedebergs Arch. 185 (1937) 184–189.
S. Koeppen, F. Panse, Klinische Elektropathologie, Thieme, Stuttgart, 1955.
A. Oberdorf, O. Wilcke, Untersuchungen u¨ber die Wirkung kleiner und mittlerer Stromsta¨rken auf den Kreislauf, Zeitschr. Exp. Med. 124 (1954) 209–228.
H. Schaefer, Die Einwirkung des elektrischen Stromes auf wichtige innere Organe, Dt. Zeitschr. Gerichtl. Med. 47 (1958) 5–28.

[40] *G. Sancesario, R. Massa, S. Petrillo, S.A. Nottola, S. Correr, P.M. Rossini, Transcranial unifocal stimulation in rabbit: subcutaneous and meningeal changes, Eur. Neurol. 29 (1989) 93–98.*

can represent the only way to understand and recognize an electrocution and the modalities of death (especially when no electrical marks on the corpse are present). This is valid for low- as well as for high-voltage electrocution deaths.

Some examples may be postulated: in cases occurring in a domestic environment, such as in the bathtub, the analysis of the scene can be fundamental for two main reasons: to recognize the origin of the possible electric shock and to distinguish between homicide and suicide. Moreover, relevant criteria include witnesses, presence of farewell letters, the discover of the victim in a remote place (no disturbance, late discovery), specific knowledge of the victim (e.g. familiarity with electricity/electrotechnics), meticulous construction, purposeful modus operandi.[41]

In cases of an accident with technical electricity: the forensic expert needs to determine if there is a contact with source of electricity – wires, devices etc., and the position of the victim in relation to them. The specialist has to look for circumstances facilitating the accident, such as increased dampness, wet clothes, lack of protective clothing, gloves, shoes, etc. Signs of electrical influence (burns, other electrical sings) can be found on clothes; on the shoes there might be breaks at the points of entrance or exit of the electric chain; melted nails; magnetized metal objects. The outer inspection of the body can provide evidence of mechanic injuries - a result of falling from electrical pylon or a roof, or other untypical burns. In the case of a suicide, uncovered wires can be wrapped or fixed in some way to the body, and a letter might be left.

Information for the beginning and the course of the accident should be collected from witnesses during the process of inspection, together with information on the clinical picture before the time of death of the victim.

In cases caused by high voltage technical electricity or electric arc – deep local burns or even carbonization at the point of contact can be found, metallization, stings or burns of hairs, external traumatic injuries due to throwing back of the body.

In cases of an injury with atmospheric electricity there is a specific surrounding situation. The victim is most often in the open, after a lightning storm, under a tree. Signs of atmospheric electrical influence in the surrounding environment can be found – burns or tree splitting, melted or magnetized metal objects or parts of constructions. Very often the clothes of the victim are severely torn and the body might be denuded. Hairs on the head might be singed, hairs on the chest or genitals might be intertwined, and the typical for electrical

[41] Földes V, Lászik A. Ein besonderer Fall des Selbstmordes durch elektrischen Strom. Arch Kriminol 1992;189:140–144.

influence sequelae as burns of different stages can be observed including carbonization of parts of the body.

- **<u>Occupation-related suicide</u>**

The study showed in some cases a relationship between the activity / interests of the individual and suicide by electrocution.

Although suicides committed using professional knowledge are unusual, the topic of suicides with an occupation-related background have been described and show usually peculiar and uncommon methods of realization as well as peculiar pathological findings that may be tough to identify and analyse.

For example, a relationship between occupation and suicide has been described for medical professionals (e.g. with the use of medicines or medical devices), farmers, police officers and military personnel.[42] An important reason for such a correlation is the ease of having access to proven and well-known methods which can be perfected by specific knowledge or skills.[43]

In such a scenario, the self-application of electricity (electrocution) can be considered as a rare method of committing suicide. According to previous studies, an occurrence about less than 1% has been detected. A possible reason is also related to the fact that an easily accessible electric current is frequently placed in confined areas, being the cause of concerns to the individual being discovered or having unwanted witnesses. The topic was previously dealt with in the literature and three main ways of suicidal electrocution have been postulated:[44]

- individual climbing up a structure dedicated to the transmission of electricity (e.g. a pylon) and voluntarily touching the power line (high-voltage line) with both hands.

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[42] *Colucci AP, Gagliano-Candela R, Aventaggiato L, De Donno A, Leonardi S, Strisciullo G, et al. Suicide by self-administration of a drug mixture (propofol, midazolam, and zolpidem) in an anesthesiologist: the first case report in Italy. J Forensic Sci. 2013;58:837–41.*
[43] *Milner A,Witt K, Maheen H, LaMontagne AD. Access tomeans of suicide, occupation and the risk of suicide: a national study over 12 years of coronial data. BMC Psychiatry. 2017;17:125.*

[44] *Buhtz G. Selbstmord mit dem Strom der Lichtleitung. Dtsch Z ges Gerichtl Med 1930;14:443–448.*
Munck W. Selbstmord durch Gleichstrom von 220 Volt. Dtsch Z ges Gerichtl Med 1934;23:97–109.
Somogyi E, Orovecz B, Irányi J. Angaben zu dem Problem der durch elektrischen Strom begangenen Selbstmorde. Dtsch Z ges Gerichtl Med 1961;52:52–59.
Lafrenz M, Rötzscher K. Suicid durch elektrischen Gebrauchsstrom. Arch Kriminol 1966;138:172–178.
Leygraf E. Suizidale Stromtodesfälle außerhalb der Badewanne. Beitr Gerichtl Med 1990;48:551–559.
Földes V, Lászik A. Ein besonderer Fall des Selbstmordes durch elektrischen Strom. Arch Kriminol 1992;189:140–144.

- individual fastening a wire around the wrist and throwing the loose end over the high-voltage power line.

- individual connecting himself to a supply system of electric current with two cables.

The latter method is considered as expression of a certain degree of knowledge and familiarity with electrotechnical matters.

Thus, suicide by electrocution is widely regarded as an example of occupation-related suicide. Retrospective analyses reported in previous studies detected a previous occupational activity with relationship to electric current in 20% of the victims. In most of the previously described cases low-voltage alternating current was used through power outlets, modified electrical devices and electric cables are fixed to the body. In some cases, complex circuits and systems, including clocks and time switches, have been described.[45]

- **Differential diagnosis**

A complete and detailed analysis of all the pathological-forensic findings, from the crime scene to the autopsy findings, up to the toxicological and histological analyses, is very important, to make a correct differential diagnosis regarding the cause and manner of death. Sometimes the presence of a possible source of electrical energy can actually be misleading for the recognition of a cause of death, that may have not to deal with electrocution or where electrocution itself represents a contributing cause of death and not the sole genesis.

Effective examples of the importance of such a multidisciplinary approach can be provided by 3 cases analysed in the present study.

Differential diagnosis: the importance of the autopsy

The first case concerns a teenager found by his mother inside the bathtub full of water. In the water a hair dryer was found. This was directly connected to the current through a socket in the same bathroom. The circumstances of the discovery indicated a suicidal event.

Inside the bathroom a farewell letter and two packs of kitchen salt were found: this was poured into the tub, presumably with the intention of increasing the electrical conductivity of the water (which also makes this suicide similar to a sort of "knowledge-related suicide", as previously discussed). However, at autopsy no electrical burn was detected because of the large surface of transmission of the electric current given by the presence of the body in the

[45] *Weimann W. Selbsttötungen nach der Uhrzeit. Arch Kriminol 1961;127:127–136.*
Anders S, Matschke J, Tsokos M. Internal current mark in a case of suicide by electrocution. Am J Forensic Med Pathol 2001;22:370–373.

water. At the autopsy, however, macroscopic signs typical of drowning were found: the presence of hyper-expanded lungs and almost in contact at the level of the midline (so-called "kissing lungs"), clear fluid inside the sphenoid sinuses, typical "three layers" disposition of gastric contents by ingestion of water.

The cause of death was therefore identified in drowning. It is clear that in this case the transmission of electric current was not the direct cause of the death, but caused the loss of consciousness with subsequent inhalation of water and death by drowning. It is also absolutely rational to think that the victim's young age provided greater resistance to electrical stress, not directly causing death from cardiac arrest.

Therefore, the modalities of death (suicide) have been clarified by the circumstances of the discovery and analysis of the scene, while reconstruction of the sequence that led to death was allowed by the analysis of the autopsy results.

Differential diagnosis: the importance of the histological examination

Another case can be taken as an example to demonstrate the importance of a multidisciplinary analysis and which posed different challenges for a differential diagnosis and for the reconstruction of the dynamics. A man was working inside a cabin on top of a reach stacker and was setting up an electrical system when he was suddenly seen by his colleagues collapsing inside the cabin. None of the witnesses reported signs of an electrical discharge. An electrocution was suspected due to the fact that he was working with electric currents. Alternatively, a natural death was assumed. By the external examination there was the finding of a linear abrasion, with a dried bottom and a slight elevation of the surrounding skin at the level of a forearm. This finding therefore raised the suspicion of electrocution.

However, other elements had to be evaluated, considering that the subject was working in proximity to the electric current and that he was affected by heart disease, so the presence of an electrical mark could also be determined by the sole contact with the electric current after he lost consciousness for other reasons (for example, a cardiocirculatory insufficiency for a cardiac ischemia). Macroscopic examination of the heart showed severe atherosclerotic modifications of the coronary arteries and the presence of scars in the heart muscle from previous ischemic events.

However, clear findings of acute cardiac ischemia or recent coronary thrombosis were not present. Furthermore, any other possible cause of gross death was macroscopically excluded (e.g., cerebral ischemia). The general findings were those of a central death (cerebral oedema and congestion, pulmonary oedema) which, however, may also be found in cases of cardiac death. For this reason, autopsy macroscopic analysis was not sufficient to recognize the cause and manner of death. An in-depth study was then carried out through toxicological and histological tests. The toxicological tests gave completely negative results.

By the histological analysis the analysed organs showed typical findings of a generalized congestion and a sudden arrest of cardio-circulatory functions. The analysis of the heart tissue, however, showed an ischemic area to be traced back to a recent ischemic event, with sub-acute onset, which was therefore considered responsible for a collapse of the subject while he was on the structure he used for work.

The question of the cause of death, however, remained to be discussed: the collapse had been responsible for the contact between the individual and the electrical contact causing death by electrocution, or the subject had already died when he had contact with the flow of current?

The answer is again provided by the histological investigation: in the skin sample of the "suspected electrical mark" the presence of alterations caused by the electric current was found but without any evidence of vital reactions of the tissue. The cause of death was thus attributed to the heart failure caused by the ischemic event. In this case, therefore, together with the circumstantial analysis and the autopsy findings, the histological analysis was fundamental to reconstruct the causes and modalities of death.

Differential diagnosis: the importance of the toxicological examination

The case concerns an individual whose body was found in flames on the tracks of a railway station, after he was involved in a high-voltage electric discharge with the formation of an electric arc.

It was not possible to access the body due to the presence of high current cables, which had to be deactivated in order to carry out the intervention. At the autopsy the corpse showed extensive and widespread carbonization with partial amputation of the upper limbs, loss of part of the rib cage and exposure of the internal organs that were widely affected by the effect of heat. Although the direct effect of the fire on the corpse was clear, and the circumstances of the incident and of the discovery made death by electrocution absolutely probable, the autopsy alone was not able to clarify the real effect of an electrocution (the corpse was extensively charred and it was not possible to recognize signs of a possible electrical mark) and the role of fire itself in the cause of death.

Did the burning of the corpse in fact develop when it was already dead due to the electrocution, or did the fire also play a role in causing death?

In this case the toxicological examination on the biological liquids collected during the autopsy was fundamental: in the cardiac blood a value of Carboxyhaemoglobin (CO-Hb) of 24.7% was found, to be considered at the lower levels of the toxicity range. From this finding, it could be deduced that the individual inhaled toxic CO-containing gases from the fire, which may have clouded his consciousness. In addition, a high concentration of alcohol was also found in the blood. From this it follows the conclusion that a possible transmission of high voltage electricity was not directly responsible for the death, and above all it was not the only factor responsible for the death. The subject was therefore still alive after the transmission of the electric current and the development of the fire. The resulting inhalation of carbon monoxide and the condition of high alcohol content therefore contributed overall to the death. In this case, therefore, toxicological investigations were essential to recognize the cause and mechanisms of death.

Conclusion

At present the diagnosis “death from electrical injury” quite often is based on indirect criteria.

When electrocution is suspected, the entire investigation requires a team approach in which all the steps are crucial and must be faced with the utmost discipline and caution: the recognition of the precise dynamics, of the causes of death, can be a "journey in stages" in which each element can be decisive. As a matter of fact, it is necessary to start from a complete and accurate analysis of the crime scene including detailed photographic documentation of the cadaver and every electrical device/conductor that may be involved in the scene. Already on the crime scene, a deep analysis of the electrical circuitries near the body or directly connected to it by qualified personnel in electrical assessment. Of course, represents the first premise: the analysis of the scene is fundamental and already allows to have many elements of investigation on the type of electricity (low / high), type of event (suicide / accidental / homicide) and points of possible contact between the victim and the current flow.

The autopsy is the following crucial step: a complete autopsy with thorough external examination of the body and of the clothing for the search of subtle electrical marks is strictly required. Clothes may show burns corresponding to contact with metallic conductors and torn clothing with burned shoes may implicate lightning. Every particular element to the external examination must be adequately described and documented, with particular attention not only to the electrical brand, but also to other elements that can provide indications, such as the presence of petechiae, associated with death by electrocution in a certain percentage of cases.

In the points of possible contact between the skin and electricity, it is also advisable to evaluate the subcutaneous tissues below the suspected lesions in search of haemorrhagic infiltrations that may indicate vitality.

The internal examination of the cadaver for evidence of underlying natural diseases such as cardiovascular conditions is also important, as these may have predisposed the victim to coming in contact with live circuitry, or may have reduced the victim’s capacity to survive an electric shock.

All further investigations are also fundamental: post-mortem CT for recognition and characterization of lesions and pathological alterations, toxicological tests to evaluate possible causes or contributing causes of death as well as the abilities of the subject at the time of his contact with electricity.

The most important in this case is perhaps the histopathological investigation, with which the main characteristics of the electrical brand and its vitality can be identified and characterized, thus providing a fundamental contribution to the recognition of the intervention of electricity in the event, in its effect on the skin and body of the individual, on the vitality of the subject at the time of the electric discharge.

To complete the analysis, especially in cases of suicide, it is also essential to analyse the patient's history and family / work context, as well as the implementation of suicide.

From all these elements the multiple difficulties of the diagnosis and reconstruction of these cases are clear. The extensive study carried out in this research represents a valuable element of analysis and constructiveness for forensic pathology.