PHYSIOPATHOLOGY OF ELECTRICAL BURNS: ARTICLE REVIEW

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ABSTRACT

SUMMARY: Electric burns are considered one of the most drastic traumas to which an individual can be exposed; directly or indirectly affecting almost all the systems of the human body. This type of trauma has local and systemic effects that are poorly understood by most health personnel.

The objective of this article is to offer a complete explanation, allowing the reader to better understand the pathophysiology of this type of trauma and therefore manifest in the daily actions of health personnel.

KEYWORD

Physiopathology ,electrical Burns

ARTICLE HISTORY

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INTRODUCTION

Electric burns are considered a special type of injury because they have a unique, varied and complex patho physiology; based on the understanding of the physical properties of electricity and the route of current flow through tissues and organs.

When the human body comes in contact with the electric current, the damage can be devastating depending on the factors already mentioned, causing from superficial and / or deep injuries, to compromise of internal organs and tissues or even multi-organ involvement. Electric burns are considered by their severity, the large masked.

This article seeks to briefly explore the physical and physiopathological foundations of electrical burns.

HISTORY

The first recorded death by electric burn was in Lyon (France), when a carpenter in 1879 had contact with a high power generator; likewise years later a record of a North American citizen named Samuel W. Smith is known who in 1881 suffers electrocution by a generator in Buffalo, New York.

Through time, the human being has always been and will be in contact with the electric current due to its necessary use for daily life. The majority of reported cases happen accidentally at home or at work sites.

EPIDEMIOLOGY

Burns are a public health problem worldwide and cause around 180,000 deaths a year.2 Some figures from developed countries show that of the total number of burns worldwide, electric burns could still be 5-8%. The United States registers approximately 1000 deaths / year and 3000 admissions to hospitals for this cause 4-6.5% are income to burn unit; 3-12% are hospital admissions in general and it is estimated that in 10% of the cases presented, it is necessary to amputate the affected member 3.4. The average age of this type of injury is between 11 and 20 years probably secondary to lack of experience or knowledge about electrical system manipulation. 5. The prevalence is higher in the male gender, 91.9% of the cases occur. : 1 (male: female) 3.6.7.

It is evident to observe that it affects more people of productive age, in fact, in adults, it is the fourth cause of death at work level 7. people who work with electrical circuits or construction area 50% suffer from accidents high voltage due to contact with power lines and 25% due to tools and machines in poor condition; other causes are also determined due to worker ignorance and lack of occupational protection elements 3.4.5

children are more prevalent burns by low voltage current, 67.74%, generating lesions in the mouth by cable bite, generally in children aged 0-3 years or by contact with outlets as of the group of 3-6 years, that occur in the home 8.

Cases in which electricity is used for suicidal or homicidal purposes have been reported, but are less frequent than those already mentioned 6.

Unlike other types of burns, electric ones, mean a longer hospital stay for the patient, a greater number of surgical procedures and a high possibility of death 6.

GENERAL ASPECTS OF ELECTRICITY

Electricity is defined as the passage of electrons from one atom to another and the movement of these through a conductor is what is known as electric power 9.

The properties of electricity include current, voltage, resistance, conductance and intensity, which influence the mechanisms of injury and are predictors of the final state of injury.

1. Electric current: It is the flow of electrons or charges within a closed electrical circuit and is classified as direct-direct and alternating 3.

Continuous or direct: It is unidirectional; the flow of electrons goes in the same direction; A good example is that generated by batteries. It usually generates a single muscle contraction that removes the victim from the source, so it is considered low risk, although the degree of injury depends on the type of trauma generated by the impact.

Alternating: It is the one in which electrons change direction periodically; each time they return to their initial position, a cycle is generated. It is 3 to 4 times more dangerous, since it generates muscle contractions (40-110 times per second) continuously called tetany that can cause the electric current to retain the victim preventing the release of its contact site, lengthening the time of exposure and increasing the damage, finally generating abnormal contraction of thoracic muscles, preventing adequate breathing and causing abnormal heart rhythms. .

2. The voltage: the force that allows the movement of electrons from one atom to another; whose unit are volts 9.

Low voltage (<1000 volts). It is the most common type of electrical injury, whose common victims are children or young people in the home. In this group, injuries to the hands or mouth are frequent due to direct contact with electrical outlets in homes; in adults they are presented by the use of defective power tools.
Contractions have been observed that can be so strong that they cause dislocations or secondary fractures and skin lesions due to burns that may be similar to thermal burns. 10

High voltage (> 1000 volts) 3,11: It is very common in work accidents, due to the contact with external power lines. It generates from superficial lesions on the skin to deep lesions that compromise the muscles causing rhabdomyolysis and myoglobinuria, which lead to acute renal failure. Other manifestations are hyperkalemia, acidosis, myoglobin in the blood, elevation of creatinine and creatine phosphokinase, as well as damage to the nervous system.

Lightning 11: Injury associated with high mortality, generated by high voltage and amperage, of short duration. It is a massive unidirectional current, which is directed to the ground, however, a large part of it passes through the body.

The injuries associated with lightning impact depend on 6 physical mechanisms that are: direct blow, contact injury, proximity injury, ground current, updraft and blunt trauma 12. Manifesting clinically as Mild loss of consciousness until hemodynamic compromise and Stop cardiorespiratory that requires immediate intervention. In Skin A typical sign is generated, a Lichtenberg figure that is characterized by an arborescent pattern that disappears after 24 hours (Figure 1).

3. The resistance: It is the opposition that generates an object to the passage of the current through itself; its unit is 10 ohms. The resistance of each tissue is directly proportional to the degree of injury, that is, to greater resistance greater injury 1.9.

Less resistance (1,500 ohms): Muscle, nerves, blood vessels.

Intermediate resistance: Dry skin 5,000 ohms and wet skin 1,000 ohms.

Greater resistance (900,000 ohms): Bones, fat and tendons 13.

The resistance of a fabric depends on some physical properties: humidity and temperature. The skin is a bad insulator of electricity; if it is dry, it is more resistant, on the contrary, if it is wet, it reduces the resistance generating greater electrical current conduction; which causes more possibility of death by electrocution.

Another example is the bone that generates greater resistance to the passage of electricity, which generates greater heat, that is, greater transformation of electrical energy to thermal energy; causing the tissue to heat up and / or clot 4.12.

4. **Conductance:** It is the ability to transmit the current 3.
5. The electric current intensity: It is the relationship between the time elapsed and the flow of electric current. Your unit is amp 9.

1-3mAmp: Threshold of perception: direct current feeling of heat on contact and in the tingling alternating current.

20-50 mAmp: contractions at the level of the skeletal muscle (Tetany). Paralysis of the respiratory muscles.

50-100 mAmp: Ventricular fibrillation.
2.5 Amp: Asistolia.

DURATION OF CONTACT

The degree of injury and the transformation of electrical energy to thermal energy will be directly proportional to the time in contact with the electrical source;

longer contact time with electricity, the greater the severity of the injury; however, there is one exception, lightning burns, which are short but have a higher amperage and are high voltage (millions of volts); generate injuries that compromise life 4.

Finally, injuries due to electric burns are based mainly on two laws 1:

1. Law of Omh: The intensity of the electric current is directly proportional to the voltage and inversely proportional to the resistance of the affected tissue, because the exposure of different parts of the body to the same voltage will generate a different current because the resistance varies significantly between different tissues 13.

2. Joule's Law: The heat generated by the electric current is directly proportional to the tissue resistance, the greater the resistance offered by a tissue to the passage of current, the greater the potential for transforming electrical energy into thermal energy 14

Figure 1. Sign of Lichtenberg.

PATHOPHYSIOLOGY OF ELECTRIC BURN
MECHANISMS OF INJURY

The 4 main mechanisms of injury due to electricity are12:

Direct tissue damage: generates alterations in the resting potential of the cellular membrane of the cell, generating muscle contraction (tetany).

The transformation of electrical energy to thermal (Joule's law): generates extensive destruction and coagulative necrosis in the tissues produced by thermal energy.

Injuries caused by violent muscular contractions or falls, after contact with the electric current.

Theory of electroporation: alteration of the proteins of the cell membranes is generated, altering their function and integrity 4.

Burns produced by an exogenous agent such as electricity are generally nonthermal, however when the electric current interacts with the tissues; this is transformed to thermal, generating heat injury due to their resistance12.

The non-thermal components, cause depolarization of excitable tissues such as the heart; causing cardiac arrest, ventricular fibrillation or other types of arrhythmias. In brain there is alteration of the state of consciousness and the presence of electric current at the respiratory center of the medulla can generate respiratory arrest11.

In the thermal, the resistance generated by the skin to the flow of electric current produces heat (Joule effect), caused the carbonization of the contact points, called points of entry and / or exit, from there continuous through the limb causing the heating of the bone as well as the clothes that the individual wears and produce a certain degree of burn11.

Muscle and nerve cells (tissues with greater conductance, that is, less resistance) are more susceptible to damage and ruptures due to electrical current 3.

The route taken by the electric current in the body will determine the possible injuries; For example, a burn that travels from one arm to another (horizontal plane), where the path is close to the heart has a greater commitment to life than an electric burn that has entry into the lower limb and passes to the ground 3. Other paths As the head can generate direct compromise in the brain causing respiratory arrest, seizures or paralysis.

However, there are certain differences between an electrical burn and other types of burns; Mild or superficial injuries that can go unnoticed can cause really serious injuries in internal organs, such as the heart and brain 12.

TYPES OF INJURY

There are 5 types of injury by electric current: direct, indirect or flame injury, electro-electric arc, ignition and mixed3 9 12:

Direct injury (burn by contact): The damage is thermal and the degree of injury depends on the duration, frequency and magnitude; in addition to the resistance of each affected tissue.

Indirect injury (arc-flame and flash): Disruptive discharges are generated. This case occurs when the electric current travels through an object, that is, it hits a tree and it continues along a path of least resistance and finally reaches the person.

Electro-electric injury by electric arc: It occurs by the jump of electricity between two surfaces that are electrically charged and are not in contact, generating spark, resulting in an arc, when a current is generated from the atoms of the conductive object; The temperature of this arc can range between 2500 to 10000 degrees Celsius, it is more frequent in areas where flexion is performed as armpit, popliteal area, wrists and / or elbows.

Ignition injury: This occurs when a burn is generated by fire, that is, the electric current ignites the clothing of the individual or some nearby object and this causes injury to the person near or in contact.

Mixed: It is the burn generated by direct contact and electric arc.

SIGN OF THE ICEBERG

Burns generated by high voltage electrical currents generate greater tissue damage; it is considered that in most cases a small burn can be observed in extension on the body surface of the first contact (sometimes even punctiform) and a large lesion in deep tissue is not evident, a sign commonly called the iceberg sign .10 (Figure 2)

COMMITMENT FOR SYSTEMS:
CARDIOVASCULAR SYSTEM:

Electric burns can generate two types of injuries at the cardiac level; a Direct lesion that generates necrosis in the myocardium caused by the type of current and voltage, with more extensive high voltage; and indirect with cardiac arrhythmias, which are produced by contact with low currents and which generate arrhythmogenic foci secondary to myocardial necrosis and / or damage to the sinus node. 15

Initially plasma leakage is observed, which increases the cardiac output 2 to 3 times, generating release of catecholamines due to the stress caused by the electric current; it then acts on the nerve endings near the capillaries, joining alpha adrenergic receptors, finally generating vasoconstriction of small blood vessels, which increases blood pressure 10.

The myocardial lesion generates changes in ST waves, prolongation of the reversible QT segment, atrial fibrillation and branch blocks. When the patient presents with ventricular fibrillation, it does not revert spontaneously and may be the most frequent cause of mortality due to low electric currents. voltage 4.8, 9.

Vascular alterations vary according to their size. The great vessels do not present major compromise because the high flow allows to dissipate the heat generated by the electric burn; However, it can present lesions such as necrosis, aneurysms or rupture, small vessels are the most affected, especially those of the extremities where thrombosis, edema and progressive necrosis occur, generating limitation in the lymphatic drainage with massive accumulation of liquids at the level of the corporal compartments, causing severe closed compartmental syndromes 12.

RESPIRATORY SYSTEM:

Respiratory arrest is one of the most common causes of death due to electrical injury secondary to tetany of the respiratory muscles. Upper and lower airway injuries have been reported by inhalation of smoke or toxic gases produced by flames generated by electric current. These events being more frequent in work accidents 9,12,15.

URINARY SYSTEM:
Renal failure is the most frequent complication, resulting from deposits in the renal tubules of hemoglobin secondary to the destruction of erythrocytes and myoglobin by tissue destruction of skeletal muscle. This, added to the ischemia of the renal cortex and a decrease in filtration due to generalized hypovolemia, produces a greater injury at a renal level that is difficult to manage9, 15 ..

MUSCULO-SKELETAL SYSTEM:
The contact of the electric current with the muscle is transformed into heat, generating necrosis in the contact area. the lesion in the intima layer of the blood vessels, generates in response the release of inflammatory mediators such as thromboxane A2, which favors vasoconstriction and thrombus formation; generating lack of oxygenation which eventually leads to progressive ischemia at the level of the microcirculation; generating necrosis 4.9.
At the bone level, fractures, dislocations or multiple traumas are observed in the skull, thorax, abdomen, pelvis, as well as periosteum necrosis 3,9,12.

NERVOUS SYSTEM:
Electrical burns can alter both the central and peripheral nervous system, 80-86%. The nervous tissue has a very low electrical resistance which makes it particularly vulnerable to damage to cell membranes; altering the cellular permeability and the electrochemical balance between the intra and extracellular compartments, generating protein denaturation that leads to vasogenic edema and potentially irreversible tissue damage 17.

High voltage discharges most frequently cause lesions at the level of the central nervous system, causing loss of consciousness, traumatic brain injuries and, in the worst case, coma and / or death10; secondary to a mechanism of inhibition of the central nervous system or hypoxia due to alteration of the cardiorespiratory system, which generates cerebral ischemia and spinal or cerebral injury, which leads to complications such as bronchial aspiration and obstruction of the upper airway 10.

Alterations in the peripheral nervous system are secondary to electrical conductivity disorders when there is coagulative necrosis in the nerve (similar to muscle), or indirect damage in the myelin or compression of blood vessels that nourish the nerve from progressive edema secondary to compartment syndrome, generating greater nerve damage 4.

TEGUMENTARY SYSTEM:
The most common site of primary contact with electrical current is the skin of the hand and head.

The burns generated can be painless, of a yellow-gray color, depressed or with punctate areas with central, multiple or very deep necrosis as in the secondary contact points of lower limbs.

Linear burns are usually superficial and are frequent in places where water and sweat accumulate causing vaporizations such as chest and arm. 3.4, 15. (Figures 3 and 4)

Figure 4. Intermediate and deep Grade II burns in the Toraco-abdominal region.

Figure 4. Grade III burn in the Toraco-abdominal region

GASTROINTESTINAL SYSTEM:
Injuries are due to direct contact of electricity with the viscus or secondary to stress such as so-called curling ulcers; A mechanism of splanchnic vasoconstriction is created to help redistribute the blood flow to the main organs: Brain, heart and lung, leaving this system hypoperfused. Intestinal hemorrhage, paralytic ileus, mesenteric thrombosis and / or necrosis of the pancreas, liver or gallbladder may also occur9.

ORGANS OF THE SENSES:
- Ears: Otorrhagia and / or tympanic perforation; In most cases there is improvement, or sequelae such as hemotimpano, otoliquia, alteration of the ossicular chain of the ear and the mastoid 3 4 15 ..
- Eyes: Cataracts, 6% of the cases of electric burn by high voltage, product of a late effect caused by the realignment of the collagen fibers at ocular level, occur up to 3 years after the event, when the electric current has passed per head or neck 9.12.

Other types of lesions are retinal detachment, choroidoretinitis, ocular atrophy, hyphema, vitreous hemorrhage, iridocyclitis, uveitis and corneal lesions.

ELECTRICAL SHOCK: sudden death due to atrial fibrillation and / or respiratory paralysis due to alteration of the respiratory center 12.

SEQUENTIAL SHOCK AND MULTIORGANIC FAULT:
These are late complications of electrical burns. The tissue destruction and necrosis predisposes the affected patient to bacterial colonization, which is why area cleaning, debridement and / or amputation should be performed in cases considered necessary to avoid complications such as sepsis 15.

COMPLICATIONS
The main complications are: cardiac arrest, respiratory paralysis, acute renal failure, central and peripheral neurological disorders, sepsis. 12

The lethal complications occur in the first 24 hours, causing death by ventricular tachycardia, ventricular fibrillation or asystole in 10% of cases.

CONCLUSIONS
Electric burns are an important cause of morbidity and mortality in the population, affecting men of productive age; without ignoring that any individual can be exposed; It is important to determine the impact time since affected systems may exist in a masked manner. Knowing how the body responds to this type of burns allows the doctor to better understand this pathology and leads it to offer a more

complete, accurate and adequate management.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest in the preparation of this review.

REFERENCES

1. Price T, Cooper M.A. Electrical and Lightning Injuries. Emergency Medicine pag.1893-1902. Available at https://clinicalgate.com/electrical-and-lightning-injuries-2/.
2. WHO: World Health Organization. 2016. [updated 6 Mar 2013; quoted 24 Apr 2018]. Available at: http://www.who.int/ en/ news-room/fact-sheets/detail/ burns
3. Dzhokic G, Jovchevska J, Dika A. Electrical Injuries: Etiology, Pathophysiology and Mechanism of Injury. Maced J Med Sci 2008; 1 (2): 54-58. Available at: https://www.degruyter.com/view/j/mjms.2008.1.issue-2/MJMS.1857-5773.2008.0019/mjms.1857-5773.2008.0019.xml
4. Rodriguez J.C., Orchards Mª. J., Ruiz-Cabello Mª. A. et al. Injuries for electricity and lightning [internet]. Spain. Principles of Emergencies, Emergencies and Critical Care. Vol 9. Cap 9 (2) available at: https://www.uninet.edu/ tratado/indautor.html
5. Gaitan H. Electric Burns. [thesis]. Guatemala: University of San Carlos; 2017
6. Bharath Kumar Guntheti, Sheikh Khaja, Uday .P. Singh. Pattern of Injuries due to Electric Current. J Indian Acad Forensic Med. 2012; 34 (1) 44-488.
7. Ramos G, Ambriz A, Rodriguez R et al. Results in the management of electrical burns in a tertiary hospital. Cir. Gen.2012. vol.34 (3). Available at: http://www.scielo.org.mx/ scielo. php?script=sci_arttext&pid=S1405-00992012000300007
8. Arnoldo B, Klein M, Gibran N. Practice Guidelines for the Management of Electrical Injuries. J Burn Care Res. 2006. vol 27 (4): 439-447.
9. The W tower, electric burns: Epidemiological Clinical Study in the Guillermo Almenara Irigoyen National Hospital 1997-2001. [Thesis degree]. Peru: National University of San Marcos; 2003
10. Luna A, Rosazza R. Patient with Electrical Burns, Clinical Case. SCIENTIFY 2008. vol 6 (1) available at: http://www.revistasbolivianas.org.bo/scielo.php?pid=S1813-00542008000100010&script=sci_arttext.
11. Tor Wo Chu, Burd A. Electrical burns. Key Topics in plastic and reconstructive surgery. Taylor & Francis, animprint of the Taylor & Francis Group. 2005
12. Patiño J F. Management of electrical burns. Department of Surgery, Santa Fe Foundation of Bogotá. Cap 8. p. 205-208.
13. Leyva J.C, Carvajal F. Electric injuries, Review Article. Univ. Méd. Bogotá .56 (1): 63-74. 2015 available at: http://revistas.javeriana.edu.co/index.php/vnimedica/article/viewFile/16343/13125.
14. Ungureanu M. Electrocutions: treatment strategy (case presentation). J Med Life 2014; 7 (4): 623-626. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4316151/.
15. Koumbourlis A. Electrical injuries. Crit Care Med. 2002 Vol. 30 (11) 424-430. Available at: https://www.ncbi. nlm.nih.gov/pubmed/12528784.
16. Leyva J.C, Carvajal F. Electric injuries, Review Article. Univ. Méd. Bogotá .56 (1): 63-74. 2015 available at: http://revistas.javeriana.edu.co/index.php/vnimedica/article/viewFile/16343/13125.
17. Darcia S, Solís W. Electric Trauma. Costa Rica. Legal Medicine. Vol. 33 (1) .2016. available at: http://www.scielo.sa.cr/pdf/mlcr/v33n1/1409-0015-mlcr-33-01-00063.pdf