International Journal of Scientific Advances
ISSN: 2708-7972
Volume: 4 | Issue: 1 | Jan – Feb 2023 Available Online: www.ijscia.com
DOI: 10.51542/ijscia.v4i1.15

Electrical Injuries: Cardiovascular implication and management

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ABSTRACT

Electrical injury is one of the most common public health problems and is often associated with high morbidity and mortality. In patients who survived, a particular concern relates to cardiac injury and the risk of delayed cardiovascular complications. Currently, there is no widely accepted protocol for the management of these patients. As a result, physicians are often uncomfortable dealing with these cases due to the sparse literature on this phenomenon. This review aims to summarize various studies on the effects of electrical injuries on the cardiovascular system and ultimately to improve physicians' awareness to provide optimal management to this common but relatively unfamiliar situation. Current evidence suggests that patients exposed to electrical injury with unstable vital functions and/or risk factors and/or an abnormal ECG should be admitted to the intensive care unit, while asymptomatic patients with no risk factors and a normal initial ECG need no inpatient cardiac monitoring and may be discharged from hospital. While troponins could be a relevant marker in electrical accidents due to their high specificity for cardiac damages and represent a potentially promising tool in the future to aid decisions.

Keywords: electrical injury; cardiac injury; delayed arrhythmia; cardiac monitoring

INTRODUCTION

Electrical injury is one of the most common public health problems in both developing and developed countries and occurs in both domestic and workplace settings.[1] It occurs when a person becomes part of an electrical circuit. which can be classified by the underlying voltage as low-voltage (< 1000 alternating current or < 1500 direct current) and high-voltage (≥ 1000 alternating current or ≥ 1500 direct current) injuries.[2,3] These injuries, depending on a wide range of factors, are diverse, and often associated with high morbidity and mortality, ranging from minor skin burns to extensive life-threatening injuries of internal organs causing immediate respiratory and cardiac arrest.[4] In survivors, a particular concern relates to cardiac disturbances, arrhythmias, heart failure, cardiomyopathy, and myocardial infarction.[2,5,6]

The Occupational Safety and Health Administration (OSHA) reported that electrical injuries are the third leading cause of occupation-related deaths in the United States.[2] The reported mortality associated with electrical injuries ranges from 1% to 9.1%. Cardiac complications related to electrical injuries include arrhythmias and myocardial tissue injuries, with a reported incidence of cardiac complications ranging from 3% to 40%. In South Korea, Han *et al.* reported that the incidence rate of electrical injury was 9.6% and in a report by Choi *et al.*, cardiac complications occurrence was 14.8%.[1] The exact number of electrical accidents remains challenging to estimate precisely, a variable proportion of them do not end in medical consultation or hospitalization.[4]

Current evidence suggests that patients who have normal ECG on admission after a low-voltage injury, those with short contact with the electrical source and with no loss of consciousness or initial cardiac arrest may be discharged home after a quick clinical assessment.[2] However there is no widely accepted management protocol for the management of persons with electrical injuries.

Consequently, it is common practice in many clinical centers to admit patients with electrical injuries to monitoring units—even if no associated signs and symptoms or diagnostic findings are present.[3,7] According to Blackwell and Hayllar[5], in late 1992 after an employee developed a transient but symptomatic bradycardia due to electrical exposure, a local employer in Australia began to refer all victims of electrical injury to a hospital for cardiac monitoring. Even if they have no risk factors, such persons are often hospitalized and observed in the intensive care unit out of concern that cardiac arrhythmia might arise sometime after the initial accident. Prompted by the substantial increase in cases presenting to the emergency department, they decided to conduct a prospective study of patients presenting after electrical injury and as a result proposed a protocol.

Clinical situations involving electrical mishaps are not uncommon, however, physicians are often uncomfortable dealing with these cases due to the absence of standardized guidelines on this phenomenon. This review aims to summarize various studies on the effects of electrical injuries on the cardiovascular system and ultimately to improve physicians' awareness to provide the optimal management of this common but relatively unfamiliar situation.

DISCUSSION

A. Electrical Injury

Electrical injury is a set of pathophysiological events resulting from the action of an electric current on the human body. Electrical injuries involve both direct and indirect mechanisms. Direct damages are caused by contact with electrical energy or electricity arc (an arc is a flow of electrons through a gas, such as air) to a victim at ground potential (supplying an alternative path to ground).

It results from both the direct effects of current on cell membranes, cellular depolarization and electroporation (creation of pores in cell membranes), as well as from the conversion of electric energy into heat energy as current passes through body tissues. While indirect injuries may be linked to secondary mechanical trauma due to falls or burns due to flash from the heat generated by an electrical arc and flame from the ignition of clothing or other combustible materials.[4]

The majority of patients exposed to electrical injury are of the male gender, younger age, and work-related injuries.[2] These work-related injuries are mostly caused by high-voltage injuries, whereas low-voltage injuries mainly occur in a domestic environment. Related mortality and morbidity are proportional to the magnitude of voltage (V), the amount of energy (W), the intensity of current (I), the resistance of the body (Ohm), exposure to either direct current (DC) or alternating current (AC), duration of exposure, the current pathway through the body. Besides the thermic damage to the body, diffuse destruction of the cell membrane, secondary detriments of the microcirculation, and cardiac arrhythmias caused by the electrophysiological impact of the current are dreaded complications. Moreover, the electricity that transverse the myocardium is more likely to be fatal, especially if it has a transthoracic pathway.[3]

It is often thought that the magnitude of electrical hazard is proportional to voltage, but in fact, it depends more on the intensity (I in Amperes), which is linked both to voltage and resistance. Thus, even a low voltage shock can be fatal,[8] In case of decreased resistance, with a ventricular fibrillation threshold of 50–100 mA (Table 1). However, voltage is often the only variable known with certainty after exposure to electricity and as such is the most important factor used to categorize electrical shocks (low-voltage electrical shocks are less than 1000 V and high-voltage are 1000 V or more).[2] (Table 2)

TABLE 1: Estimated effects of 60 Hz alternative currents[4].

Current Intensity (I)	Effect
1 mA	Tingling, barely perceptible
16 mA	Maximum current a person can grasp and 'let go'
20 mA	Muscle tetanization
20-50 mA	Paralysis of respiratory muscles, respiratory arrest
50-100 mA	Ventricular fibrillation threshold
2 A	Cardiac standstill and internal organ damage
15-30 A	Common household circuit breakers

TABLE 2: Main current origins with associated voltage[4].

Voltage	Current's origin
High Voltage	
45 000 – 400 000	High voltage line
25 000	Rail network
1500	Overhead line
Low voltage	
960	Mines
750	Third-rail subway conductor
380	Workshops
110/220	Domestic (USA/Europe)

There are various factors that affect electrical current conductivity, such as the type of tissue the electrical current travels through (for example due to its high water content, the vascular bed is an excellent conductor), the existence of moisture (increasing conductivity), the duration of contact with the current (tetanic muscle contractions due to alternating current may result in an ability to let go of the conductor) thereby converting what ordinarily might be a minor low-voltage injury with superficial tissue damage into a life-threatening shock, by allowing more current to pass to deeper structures, resulting in more extensive injury to internal organs.[2, 4]

B. Cardiovascular Complications

When the chest is situated along the path that connects the entrance and exit points, the heart is often affected because the electric current actually follows vascular axes, which present the lowest resistance along the nerves. Horizontal (hand-to-hand) as well as vertical current passages (hand-to-foot or head-to-foot) can thus lead to cardiac injury.[4] But among other pathways, transthoracic pathways have the highest mortality rate due to the potential for an increased spinal cord, and myocardial damage. The electric shock can cause immediate respiratory and cardiac arrest.[2, 9]

Most cardiac events occur immediately after the accident resulting from the proarrhythmic effect of electric shock, but delayed cardiac complications have also been reported in several reports. The major issue in electrical accidents lies primarily in the risk stratification of survivors, to identify those at a high risk of developing a serious cardiac event, thus requiring continuous electrocardiogram (ECG) monitoring in an intensive care unit from a subgroup of low-risk patients where rapid discharge is safe. ECG on admission appears to be the most predictive element of cardiac complications. Most cardiac arrhythmias in patients following the electrical injury can be diagnosed by an initial ECG.[6]

The European Resuscitation Council (ERC) in 2010 recommends hospital monitoring in patients with important risk factors such as (i) cardiopulmonary arrest, (ii) loss of consciousness, (iii) electrocardiographic abnormalities, and (iv) soft-tissue damage and burns. The risk of serious cardiac injury is considered high in patients fulfilling one of these ERC's criteria. Other factors such as transthoracic current pathway, high-voltage injury, cardiac arrhythmias, symptomatic patients (palpitations, chest pain, dyspnea, tetanic muscle contraction, neurologic problems), pregnancy, abnormal laboratory (elevated cardiac enzymes and/or troponin levels) should also be approached carefully.[10]

Despite the recommendations, only a minority of hospitals follow these recommendations closely, due to the fear of delayed cardiac complications primarily fuelled by case reports.[7] The newly published ERC Guidelines 2021, did not include an updated section on the electrical injury.

C. Arrhythmias

Arrhythmias such as sinus tachycardia and ventricular premature beats resulting from the electrical injury are the most common cardiac complication of electric injury. However, atrial fibrillation, ventricular tachycardia, ventricular fibrillation, and conduction disturbances, like sinus bradycardia or bundle-branch blocks or various degrees of atrioventricular blocks can occur following electrical shocks. Electrical injuries seem to have a predilection for the sinoatrial and atrioventricular nodes.[1,4] While exposure to high-voltage (like lightning) or direct current will most likely cause ventricular asystole, even low-voltage alternating current can also cause sudden cardiac death by ventricular fibrillation.[8] Current transversing the myocardium during its vulnerable period, analogous to an 'R-on-T phenomenon', may trigger ventricular fibrillation.[3 4]

The mechanism concerning electrically induced cardiac arrhythmias is not yet fully understood, however, endometrial biopsy results revealed arrhythmogenic foci in patchy myocardial fibrosis and increased numbers of Na+ and K+ pumps, as well as changes to membrane potential. Consequently, arrhythmias may be triggered by these pathological areas, enhancing abnormal automaticity several hours after the injury.[1]

While most arrhythmias occur soon after the electrical shock, delayed cardiac arrhythmias have been also reported in several reports.[11-13] Little is known about the long-term consequences of survivors who arrive at emergency wards or are admitted for observation. In 2019, Pilecky *et al.* published a study on the risk of developing cardiac arrhythmias after electrical accidents. This study included 480 patients with a 0% 30-day mortality rate. In the study, sinus bradycardia and sinus tachycardia were the most common arrhythmic cardiac abnormalities associated with electrical injuries. All of them were asymptomatic and none required any intervention.[14]

A similar outcome is reported by Searle *et al.* in a 2013 study to determine the incidence of delayed cardiac arrhythmias following an electrical accident conducted at the Charité Hospital, Berlin. Based on hospital data of 268 patients admitted to the hospital due to electrical injuries during the 8-year study period, none of the patients developed cardiac arrhythmia requiring treatment during their hospital stay, even with all ERC risk factors requiring cardiac monitoring present in the cohort.[7]

Another study by Hansen *et al.* in 2017, a Danish nationwide cohort study with a total of 11 462 electric shock patients who visited an emergency ward or were admitted to the hospital from 1994 to 2011, examined whether electrical shock patients had an increased risk of developing the cardiac disease, arrhythmias, or death compared to the general Danish population. They found that there was a tendency for admitted patients to have a marginally increased risk of cardiac arrhythmias and injury, although this finding needs to be interpreted carefully as it may be likely due to observation bias because the electric shock patients were subject to a number of examinations that the control group was not. Despite that, patients with observed arrhythmias were not associated with a significant effect on mortality and a number of cardiac procedures. The study also concluded that late cardiac arrhythmias following an electrical injury were extremely rare. (0 % - 0.3 % at <31 days after exposure; 0 % - 0.1 % at 31 – 365 days after exposure). The researchers were able to review case files of 15 patients who had a cardiac procedure within 30 days after the electric shock, and the cardiac diseases were found to be unlikely because of the electric shock, as they were chronic in nature. This large nationwide cohort study did not identify excess mortality in patients exposed to electric shock compared to the general population.[9]

A 10-year retrospective study conducted at the University Hospital Basel, Switzerland concluded that among a total of 240 patients, in which ECG was performed in 234 (97.5%) patients and cardiac monitoring in 149 patients (62.1%) no potential late serious dysrhythmia requiring medical intervention was recorded. No cardiac complications occurred during the emergency ward stay or during the 90-day follow-up period. The study suggests that an initial ECG is advisable, but the need for continued cardiac monitoring is not supported by their data.[15]

D. Cardiovascular Injury & Role of Myocardial Damage Parameters

The direct effects of electric current (electrothermal conversion and electroporation) can also result in myocardial damage. Myocardial infarction by coronary spasm or thrombosis, myocardial contusion by cardiopulmonary resuscitation with subsequent hematoma formation in small coronary arteries, extensive catecholamine release or autonomic stimulation causing hypertension, tachycardia, non-specific ECG changes and coronary blood flow reduction secondary to generalized severe hypotension compromising myocardial perfusion have all been proposed.[4,10,16]

Initial abnormal ECG on admission is reportedly to be the most predictive of cardiac complications. Whereas the use of cardiac injury markers, such as creatine kinase-MB and troponin assays is controversial following electrical injury. Data indicate that creatine kinase-MB is an unreliable marker for electrical injuries due to inadequate sensitivity and potential confusion with a peripheral skeletal muscle injury. In the practical algorithm of the recommendations published by Waldmann *et al.*[4] in 2018, it may be appropriate to perform a systematic assay of troponin and monitoring of troponin elevation. The text, however also highlights that "no significant studies exist concerning the use of troponin in these clinical situations". Currently, its use in routine practice for all patients remains debatable due to the lack of assessment of its use in studies.[6] In the absence of clear guidelines to guide decision-making, actual practices differ. Nevertheless, the widespread availability of troponin level measurement in the emergency departments and its greater cardiac specificity represents a potentially promising tool in the future to aid decisions regarding patient management.

Delphine *et al.* in 2015 published a multicentre study based on a 15-year period of data, analysing the rate of Major adverse cardiac events (MACEs) and the performance of initial troponin and subsequent troponin elevation in order to predict MACEs in all 875 patients with electrical injuries admitted to the ED. The threshold used for troponin elevation is based on the European Society of Cardiology guidelines for patients presenting without persistent ST-segment elevation. It was found that the occurrence of MACE is rare following an electrical accident. Patients with an electrical injury have a highly variable risk of MACEs. In this study, the ERC's 4-high-risk clinical items obtained excellent values to exclude the occurrence of MACE (sensitivity 100%; specificity 76.6%). To predict a MACE, the initial positive troponin assay had a sensitivity of 83.3 % and a specificity of 97.7%, while the troponin rise had a sensitivity of 33.3 % and a specificity of 99.2 %. This study shows that performing troponins in all patients presenting to the ED without having previously assessed the clinical severity and an ECG does not seem useful, however, it may still be appropriate to reserve troponin assays for those at high risk.[6]

A retrospective study by Choi *et al.* in 2019, which was conducted from 2007 to 2017 at The Hallym Burn Center at Hangang Sacred Heart Hospital, the largest burn centre in South Korea that serves as a regional referral for burn patient care from all over the country. For this reason, burn patients come from all over the country to receive care at this center. Cardiac complications were defined as: (a) abnormal parameters of myocardial damage, such as a creatine kinase-MB isoenzyme and creatine kinase level fraction (CK-MB/CK) ratio of >3 or Troponin I level of >0.15ng/ mL, (b) abnormal regional wall motion detected via echocardiogram, (c) newly detected dysrhythmias found via initial ECG, such as bradycardia, including sinus node dysfunction and atrioventricular block and paroxysmal atrial flutter/fibrillation and (d) sudden detected ventricular tachycardia or fibrillation after electrical injury. The study demonstrated that cardiac complication occurred in 14.8 % (n=721) of burn-related patients and 74.8% (n=80) of these patients showed Troponin I elevation on their first day of treatment.

The ICU admission rate and admission duration were also higher in the cardiac complication group compared to those without complication, but diagnosis can be challenging, because chest pain is frequently absent and the injury may manifest only as non-specific changes in the electrocardiogram. Although elevated parameters of myocardial damage, such as CK-MB isoenzyme and troponin levels, could indicate cardiac complications related to electrical injuries on the basis of several reports, more researches are needed to confirm its significant use in routine practice.[1]

Interestingly, cardiac injury was reported to be frequent (43 %) among electric shock patients in a Chinese 10-year retrospective study by Ding et al.[17] The study identified cardiac injury based on elevated CK-MB and ECG abnormalities. However other studies indicate that CK-MB is an unreliable marker, with inadequate sensibility and potential confounding by peripheral skeletal muscle injury.[4]

Other than arrythmias and direct cardiac injury, vascular damages may also occur. Due to its high-water content, the vascular bed is an excellent conductor. Damages are usually associated with high voltage electric shock, preferentially affect small vessels which are susceptible to medial necrosis with aneurysm formation and rupture at a later point of time. These arterial intimal damage in smaller vessels can be immediate or delayed up to several weeks, and may result in partial or complete thrombosis and occlusion, resulting in necrosis.[4]

E. Management

No modification of standard ACLS care is required for victims of electric injury, with the exception of paying attention to possible cervical spine injury. If spontaneous respiration or circulation is absent, immediately initiate standard resuscitation care. Airway control measures and maintaining spinal immobilisation should be established if there is a likelihood of head or neck trauma. Muscular paralysis, especially after high voltage contact, may persist for several hours and so ventilatory support is required during this period. For victims with significant tissue destruction and in whom a pulse is regained, rapid IV fluid administration using lactated or acetated Ringer's solution according to Parkland formulas and target urinary outputs of 0.5 ml/kg/h is indicated to counteract distributive/hypovolemic shock and to correct ongoing fluid losses due to third spacing. Vigorous fluid therapy is required in cases of electrical injury to maintain diuresis and facilitate excretion of myoglobin and other by-products of tissue destruction. Patients with major burns and trauma should be referred to a burn-trauma center for immediate escharotomy or fasciotomy.[18,19]

All those who survive electrical injury should be monitored in hospital if they have a history of cardiorespiratory problems or have had:[10,18]

- Loss of consciousness;
- Cardiac arrest;
- Electrocardiographic abnormalities;
- Soft-tissue damage and burns

There is no general consensus on the most effective cardiac monitoring duration for patients satisfying the 4 ERC's clinical items. It is crucial to obtain an initial ECG on all patients with an electrical injury, regardless of the voltage involved. Overall, the duration of cardiac monitoring is not well established, although some authors suggest monitoring for at least 24 hours after the injury or after arrhythmia resolution.[1]

In 1986, Purdue and Hunt asked whether monitoring for all patients was a "necessity or a luxury" and proposed the use of clinical history and ECG as a basis for patient selection.[20] One of the key questions in electrically injured patient without extensive burn or history of cardiorespiratory problems is whether hospitalization thus providing ECG monitoring in an intensive care unit is a necessity. So far, there is no uniform, standardized cardiac monitoring protocol for the treatment of persons with electrical injury. Even with no risk factors, such persons are often hospitalized and observed on an intensive care unit due to fear of fatal delayed cardiac arrhythmias or injuries.

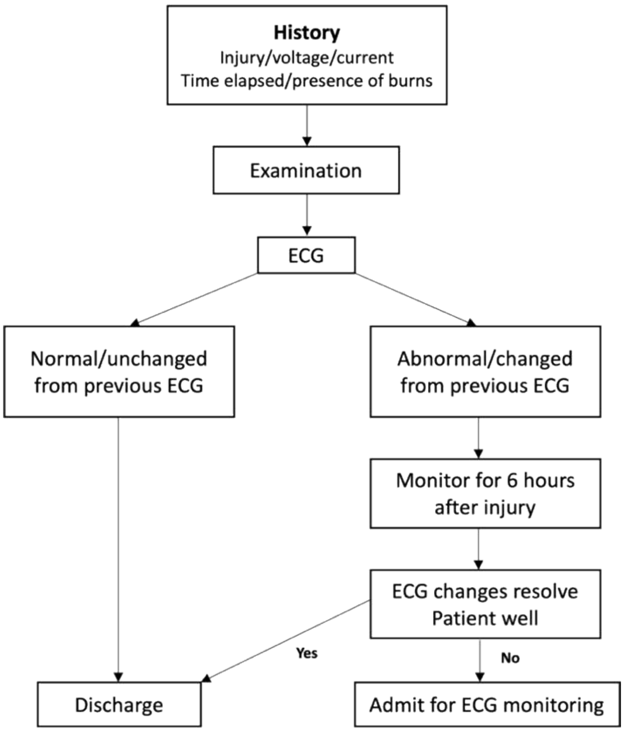


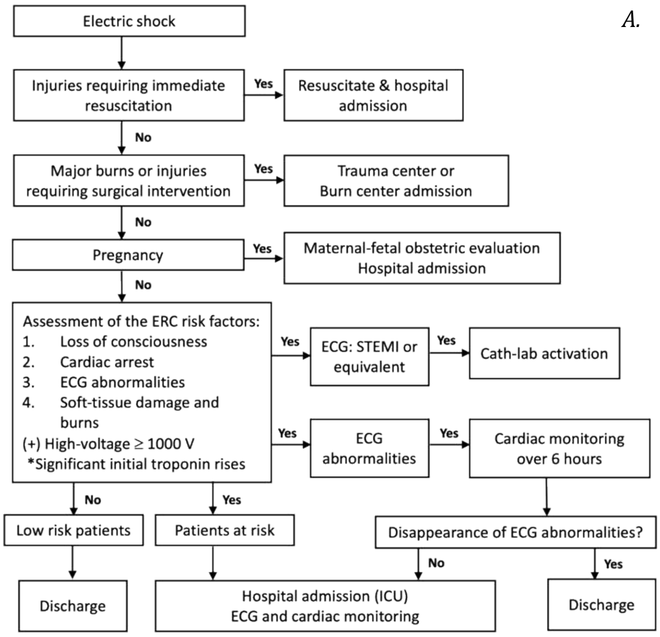
FIGURE 1: Electrical injury management protocol (Blackwell and Hayllar)[5].

Blackwell and Hayllar prospectively monitored 186 patients (196 presentations) after electrical injury using a standardised protocol (Figure 1) and none of these patients showed delayed arrhythmias. As a result of the study, the authors developed a new algorithm for the treatment of patients after electrical injury. Patients with significant symptoms or ECG changes should be monitored for at least six hours. If the ECG changes disappear and the patient continues to feel well, the patient could be discharged; if not, the patient would be admitted to hospital for further cardiac monitoring. In contrast, asymptomatic patients with no ERC risk factors and no ECG changes would be directly discharged from hospital, meaning they would not receive cardiac monitoring. In the four years since implementation of this protocol there have been no deaths or representations as a result of electrical injury.[5]

Studies have shown that clinically relevant cardiac complications are rare, with low risk of significant arrhythmias and a low risk of mortality, and these usually manifested immediately after an electrical injury. These imply that conscious patients exposed to low voltage electric shock may be discharged safely from the emergency ward. Conversely, patients with high-voltage injuries, loss of consciousness, cardiac injury, cardiac arrhythmia, suggestions of an underlying previously undetected cardiac disease, or traumatic injury, will still be recommended for an admission of at least 24-h observation.

This conclusion is supported by several large studies, with several authors proposing protocols for patients with electrical injury which have been summarized in the following algorithm flowchart (Figure 2).

Also, in special circumstance, Sparić *et al.* stated that electric shock in pregnancy may cause vital endangerment for the mother and can also lead to severe harm to the fetus, due to a number of physiologic changes that occur during pregnancy, which may alter the pathophysiology of electric shock during pregnancy. The authors recommend that women who suffered electric shock in pregnancy, even if it was a minor one, require a complete obstetric evaluation. It is advisable to carry out cardiotocographic monitoring of the fetus for four hours after the injury; a 24-h electrocardiographic and cardiotocographic monitoring in cases of maternal loss of consciousness and electrocardiogram abnormalities, as well as in cases of cardiovascular disorders of the mother.[21]



A.

FIGURE 2: Flowchart for the management for patients with electrical injury (based on the paper by Kramer *et al.*[3], Waldmann *et al.*[4], Blackwell and Hayllar.[5], Searle *et al.*[7])

CONCLUSIONS

Clinical situations involving electrical mishaps are not uncommon, however physicians are often uncomfortable dealing with these cases due to the sparse literatures regarding the optimal management of injured patient, especially those without extensive burn or history of cardiorespiratory problems. Multiple large population studies have shown that clinically relevant delayed cardiac complications are rare and the presence of mortality and cardiac morbidity and mortality after a survived electrical accident appears to be very low, as most cardiac fatality occur immediately after an electrical accident.

An abnormal ECG on admission is reportedly to be the most predictive element of cardiac complications, thus it is crucial to obtain an initial ECG on all patients with an electrical injury, regardless of the voltage involved. Patients exposed to electrical injury, presenting with any of the 4 ERC's risk factors: (i) cardiopulmonary arrest, (ii) loss of consciousness, (iii) electrocardiographic abnormalities and (iv) soft-tissue damage and burns, are regarded as high-risk patients requiring continuous cardiac monitoring in the intensive care unit.

While conversely conscious patients without any risk factors, need no inpatient cardiac monitoring after electrical injury. Although controversial, troponins could be a relevant marker in electrical accidents due to its high specificity for cardiac damages and represents a potential promising tool in the future to aid decisions regarding patient management.

As most evidence is based on literature review and retrospective studies, researches may have missed cases in which documentation was inadequate or the possibility of selection bias. Further prospective studies are needed to establish an optimal management to better manage patients at risk of electrical cardiac injury.

DISCLOSURE

• Conflict of Interests

Author certify that no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

• Funding

This manuscript did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

[1] Choi J, Han D, Kang S, Yoon C, Cho J, Kym D. Retrospective study of prognosis and relating factors of cardiac complications associated with electrical injuries at a single centre in Korea. BMJ Open. 2019;9(e028741):1–7.

[2] Ahmed J, Stenkula C, Omar S, Ghanima J, Bremtun F, Bergan J, et al. Patient outcomes after electrical injury – a retrospective study. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine. 2021;29(114):1–6.

[3] Kramer C, Pfister R, Boekels T, Michels G. Cardiac monitoring always required after electrical injuries? 111. 2015;8:708–14.

[4] Waldmann V, Narayanan K, Combes N, Jost D, Jouven X, Marijon E. Electrical cardiac injuries: current concepts and management. European Heart Journal. 2018;39:1459–65.

[5] Blackwell N, Hayllar J. A three year prospective audit of 212 presentations to the emergency department after electrical injury with a management protocol. Postgrad Med J. 2002;78:283–5.

[6] Delphine D, Stéphanie K, Yara A, Benjamin G, Idriss A, Dominique S, et al. Use of troponin assay after electrical injuries: a 15-year multicentre retrospective cohort in emergency departments. Scand J Trauma Resusc Emerg Med. 2021;29(141):1–10.

[7] Searle J, Slagman A, Maaß W, Möckel M. Cardiac monitoring in patients with electrical injuries—an analysis of 268 patients at the Charité hospital. Dtsch Arztebl Int. 2013;110(50):847–53.

[8] Guimarãs F, Camões J, Mesquita A, Gomes E, Araujo R. A Case Report: Low voltage electric injuries culminating in cardiac arrest and direct lung injury. 12. 10(e11261):1–4.

[9] Hansen S, Riahi S, Hjortshøj S, Mortensen R, Køber L, Søgaard P, et al. Mortality and risk of cardiac complications among immediate survivors of accidental electric shock: a Danish nationwide cohort study. BMJ Open. 2017;7(e015967):1–9.

[10] Soar J, Perkins G, Abbas G, Alfonzo A, Barelli A, Bierens J, et al. European Resuscitation Council Guidelines for Resuscitation 2010. Section 8. Cardiac arrest in special circumstances: Electrolyte abnormalities, poisoning, drowning, accidental hypothermia, hyperthermia, asthma, anaphylaxis, cardiac surgery, trauma, pregnancy, electrocution. Resuscitation. 2010;(81):1400–33.

[11] Koren O, Paz E, Rozner E, Mahamid M. Late myocardial sequelae of electrical injury. Clin Case Rep. 2020;8(3):3407–10.

[12] Langford A, Dayer M. Electrocution-induced atrial fibrillation: a novel cause of a familiar arrhythmia. BMJ Case Reports. 2012;1–3.

[13] Navinan M, Kandeepan T, Kulatunga A. A case of paroxysmal atrial fibrillation following low voltage electrocution. BMC Research Notes. 2013;6(384):1–4.

[14] Pilecky D, Vamos M, Bogyi P, Muk B, Stauder D, Racz H, et al. Risk of cardiac arrhythmias after electrical accident: a single-center study of 480 patient. Clin Res Cardiol. 2019;108(8):901–8.

[15] Pawlik A, Lampart A, Stephan F, Bingisser R, Ummenhofer W, Nickel C. Outcomes of electrical injuries in the emergency department: a 10-year retrospective study. Eur J Emerg Med. 2016;23(6):448–54.

[16] Gursul E, Bayata S, Aksit E, Ugurlu B. Development of ST Elevation Myocardial Infarction and Atrial Fibrillation after an Electrical Injury. Case Reports in Emergency Medicine. 2015;1–3.

[17] Ding H, Huang M, Li D, Lin Y, Qian W. Epidemiology of electrical burns: a 10-year retrospective analysis of 376 cases at a burn centre in South China. Journal of International Medical Research. 2019;48(3):1–10.

[18] Vanden Hoek T, Morrison L, Shuster M, Donnino M, Sinz E, Lavonas E, et al. Part 12: Cardiac Arrest in Special Situations 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation. 2010;(122):S829-861.

[19] Gille J, Schmidt T, Dragu A, Emich D, Hilbert-Carius P, Kremer T, et al. Electrical injury – a dual center analysis of patient characteristics, therapeutic specifics and outcome predictors. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine. 2018;26(43):1–9.

[20] Purdue G, Hunt J. Electrocardiographic monitoring after electrical injury: necessity or luxury. J Trauma. 1986;26(2):166–7.

[21] Sparić R, Malvasi A, Nejković L, Tinelli A. Electric shock in pregnancy: a review. The Journal of Maternal-Fetal & Neonatal Medicine. 2016;29(2):317–23.