

Detecting Heart Tissue Injury in Electrocution Human Cases Using Heart-type Fatty Acid-Binding Protein 3

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Abstract

Introduction: In the medicolegal daily practice, electrocution is a traumatic cause of death owing to wide use of electricity and electrical devices in different activities of modern life at home and workplaces. Electrical current passage through tissues elaborates different types of energy (the electrical, thermal, and mechanical energies) which can cause skin lesions, multiorgan damage, and even death. The severity and extent of tissue injuries depend on the current type (alternating current [AC] or direct current), its strength (amperage), voltage (low or high), frequency, tissue resistance, duration of exposure, and its pathway through the body. Microscopic examination of tissue samples from the heart may show nonspecific findings to electrocution, but sometimes none is detected by conventional hematoxylin and eosin stains (H and E). Therefore, immunohistochemical studies could help the forensic pathologists in their diagnosis, especially cases with less typical findings or obscure circumstances. Heart-type fatty acid-binding protein 3 (H-FABP3) is a small cytoplasmic protein of (15 kDa), composed of 133 amino acids, involves in active fatty acid metabolism, and transports fatty acids from the cell membrane to mitochondria for oxidation. Due to its cytoplasmic location and small molecular weight, it released from cardiac myocytes into the circulation following an ischemic episode. **Objective:** This study was conducted to evaluate the effect of electric current on the expression of H-FABP3 in human heart tissue autopsy samples. **Methods:** Human heart tissue samples were collected during the period from January 1 2016 to June 30, 2016, through autopsy of 30 medicolegal cases of electrocution as well as 30 cases of fatal head injuries which were used as control. They were examined by conventional histopathological H and E stain and immunohistochemical technique so that H-FABP3 was detected using FABP3 polyclonal antibody and demonstrated by ready to use biotin-free, one-step horseradish peroxidase polymer anti-mouse, rat, and rabbit immunoglobulin G with 3,3'-diaminobenzidine to achieve the aim of this study. **Results:** This study shows that electric shock was the fifth cause of traumatic death, being responsible for death of only 4.5% of cases referred to the medicolegal directorate in Baghdad during the period of study. It is almost accidental death in Iraqi society with higher incidence to be due to contact with low-voltage household AC sources with young males at the age of (15–20 years old) are being more vulnerable to fatal electrical injury than females during their early productive life (with male:female ratio = 6:1). Heart tissue ischemia is a major cause of death following electrocution, especially when victim being in contact with household low-voltage AC in the presence of transthoracic pathway to the ground and low body resistance due to skin wet which can cause death within a minute in association with mild if any electrical skin burns. Electrocution has a significant effect on H-FABP3 stain total index as it causes depletion of FABP3 total stain index with mean of $0.28 \pm 0.149177SD$ for tissue sections of the heart muscle in the affected areas of human cases. **Conclusions:** Immunohistochemical heart tissue samples' examination which shows dramatic depletion in H-FABP3 total stain index in affected area(s) is of value in detecting heart tissue injury caused by electrocution during the early period after death even in the absence of grossly and microscopically visible lesion(s).

Keywords: Electrical cardiac injury, electrocution, heart-type fatty acid-binding protein 3

INTRODUCTION

Electricity or electric current (measured by the ampere [amp]) is the directed flow of the negatively charged electrons in a closed circuit through any conductor which is directed by the electromotive force (measured in volts [V]) and undergoes opposition to their motion by resistance (measured in

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ohm [Ω]); therefore, “The amount of current flowing through a conductor is directly proportional to voltage and inversely related to resistance.”^[1] Moreover, due to the presence of different resistances in different materials, electrical current will produce energy (heat) throughout its pathway in the conductor; the heat generated is proportional to the amperage squared as defined by Joule’s law.^[2]

Electrical current could be alternating current (AC) or direct current (DC). AC is the most commonly used in households and offices, at a frequency of 60 cycles/sec (60 Hz), while DC is produced by various batteries and is used in certain medical equipment such as defibrillators, pacemakers, and electric scalpels.^[3] Power lines used by utility companies are classified according to their voltage into from “low-voltage” when they carry <600 V to “high-voltage” when >600 or 1000 V to “ultrahigh” with voltage of 1 million V. Most buildings in the United States and Canada have a 120/240 V, single-phase system that provides the 240 V for the high-power appliances and the 120 V for general use, while the household voltage in most other countries (Europe, Australia, and Asia) is usually higher (220 V).^[4]

Therefore, the great development in the use of electric power in industry and homes has led to the emergence of a new category of injuries caused by contact with electric currents. These injuries are less frequent in the country where electricity has been common for a long time as modern industrialized societies, and the majority of severe electrical accidents are limited to electrical utility employees or construction workers.^[5] In the other hand, they are relatively frequent in the newly electrified country where the infrastructure is less developed, and there is more theft of electrical power, and the majority of electrical accidents occur to amateurs, for example, there were more electrical injuries than gunshot injuries in Baghdad in 2009 in males.^[6]

Very often, the terms “electrical injury,” “electrical shock,” and “electrocution” are alternatively used whenever body trauma was due to the exposure to an electric current. However, in general, the electrical injury is defined as tissue damage caused by passage of generated (manmade) electrical current through the body with or without contact with generated electrical power.^[7] While, the term “electrocution” is used whenever death was caused by the passage of electric current into the body.^[8]

Pathophysiology of electrocution

The exposure to electrical current can induce variable tissue injury through the following mechanisms:

Thermal energy

Electrical current can cause massive tissue destruction and coagulative necrosis due to the conversion of the electrical energy into thermal energy as it traverses through different body tissues.^[9,10]

Electrical energy and electroporation

The electrical current energy can cause direct tissue damage and eliciting muscular tetany by altering the cell membrane

resting potential by only electroporation when electrical charges are too small to produce thermal damage leads to configurational protein changes that threaten cell wall integrity and cellular function.^[11,12]

Mechanical energy

Electrocuted individual may exhibit tissue injuries due to the mechanical effects of the electric current result from either the violent muscle contractions (e.g., avulsion fractures) or due to falls (from ladder, roof, wall, or electric tower) which result in fractures or dislocation of joints and internal organ injuries.^[13,14]

Electrical heart tissue injury

Cardiac arrest is the most serious presentation of electrical injury. Low-voltage AC injuries are commonly associated with ventricular fibrillation (VF), whereas asystole is often seen with DC and high-voltage electric shock. The underlying mechanism of cardiac arrhythmias induced by electricity is not entirely clear, but it might involve the occurrence of patchy areas of the heart tissue necrosis that acts as an arrhythmogenic foci, in addition to a probable increased in cardiac cells sodium–potassium pumping activity. Myocardial tissue injury may occur through the direct thermal effect of the electric current or indirect damage through ischemia precipitated by arrhythmia-induced hypotension or rarely coronary artery spasm. In addition, electrical shock causes autonomic dysregulation which results in serious cardiovascular complications related to the release of catecholamines such as cardiac arrest, transient hypertension, tachycardia, vasovagal syncope, thermal dysregulation, and vasoconstriction.^[14-16]

Fatty acid-binding protein 3

Regarding fatty acid-binding protein 3 (FABP3), the heart-type FABP (H-FABP) is a 132 amino acids soluble cytosolic protein, with general characteristics resembling myoglobin. In the heart of mammals, H-FABP stands for “4%–8% of the cytoplasmic protein, and it is highly expressed in skeletal muscle and heart but to a lesser amount in other tissues like brain, lung, stomach, and mammary gland.” and because of its low molecular weight (15 KD) and cytoplasmic location, it constitutes a biologic marker readily released into the circulation after myocardial injury.^[17-19]

The existence of H-FABP in circulation had been anticipated as an early biochemical marker of “acute myocardial injury,” because it is quickly released from the heart tissues to circulation following any cells destruction.^[20-23] Hence, H-FABP could be used for the accurate and early diagnosis of myocardial injury such as early acute myocardial infarction (MI) in acute coronary syndrome (ACS) patients and can distinguish it from unstable angina. Qualitative H-FABP test showed an excellent sensitivity, with higher peak value after 3–4 h from onset of chest pain than the measurements of both cardiac Troponin I and creatinine kinase (CK) MB on admission time, as well as high specificity in group of patients with ACS then its plasma level normalized at 24 h.^[24-26]

Plasma H-FABP test is superior compared to electrocardiography in diagnosing acute MI as well as it is advantageous in comparison to CK being done within 20 min; therefore, it is considered as an acceptable mode of fast diagnostic tool for MI in the emergency department.^[27]

This study was conducted to demonstrate the role of immunohistochemical staining technique in the medicolegal diagnosis of heart tissue injury as a cause of death following electric shock by evaluate the effect of electric current on the expression of FABP3 in heart tissue autopsy samples in human.

Study design

The study was conducted for the period from January 1, 2016 to June 30, 2016, during which randomly selected 30 cases died following electrical shock and 30 cases died following lethal head injury were referred to the medicolegal directorate (MLD) in Baghdad by written request to carry out a medicolegal autopsy at the behest of police authorities in different police stations in Iraq to be subjected to medicolegal autopsy.

The deceased personal data, death circumstances, and external and internal findings were recorded in a prepared inquiry form. Police records and witnesses were used as the source of general and forensic information and information related to the site and circumstances of the incident. The data on victim's sex and age, occupation, manner of death, place and time of injury, weather condition, type of current (AC or DC and low or high voltage), duration of exposure as well as place and time of death, and presence and site of electrical thermal marks on the body, as well as time of autopsy all were collected and reported.

Interesting external and internal organ and tissues damages were captured by digital camera for documentation. Following examination of their clothes and complete exposure of the body a thorough external examination of the deceased was done with respect to their skin, hair, and eyes' color, weight, length, the stages of livor mortis and rigor mortis as well as looking for electrical burn, current entrance or/and exit, mineralization, and other injuries.

Then, medicolegal autopsy was done so that heart tissue samples from affected and nonaffected areas were taken, formalin-fixed, paraffin-embedded, sectioned to 5- μ m slices, mounted on positive charge slide. After deparaffinization, tissue slides stained with hematoxylin and eosin (H and E) stain and H-FABP3 was detected by primary antibodies (FABP3, muscle, and H-FABP3 [N-Term] polyclonal antibody from Bioss [antibodies-online GmbH, Germany] catalog no. ABIN2778143) and demonstrated by ready-to-use biotin-free, one-step horseradish peroxidase polymer anti-mouse, rat, and rabbit immunoglobulin G with 3,3'-diaminobenzidine (from BioVision incorporation [USA]/catalog no. k405-50).

For each section, five regions of interest were randomly selected and examined at $\times 40$, $\times 100$, and $\times 400$, and digital images were captured using Leica[®] DM4000B LED Microscope (Germany) with built-in capturing software LAS (v. 4.5). Images were taken at a resolution of 1290 $\times$ 1080 ppi and transferred to

Adobe Photoshop software (CC 14.5) for digital analysis regarding histological changes as well as the expression of H-FABP3 cardiac cells of tissue samples. The average stain intensity (I) of each marker graded as weak, +1; moderate, +2; and strong, +3, while stain percent (P) graded as 0 <5%; 1 = 5%–25%; 2 = 25%–50%; 3 = 50%–75%; and 4 = >75, then total score (Q) was calculated to be $Q = I \times P$ for each section.

Data analysis was performed using IBM SPSS Version 24 software (IBM, Armonk, New York, USA). Numerical data were presented as mean $\pm$ standard deviation (SD) then tested statistically with suitable tests at a confidence interval of 95% with $P < 0.05$ were considered statistically significant and those < 0.01 had high statistical significance.

RESULTS

Throughout the total period of collecting samples for the study which extended from January 1, to June 30, 2016, death due to exposure to variable sources of electricity was recorded in only 137 out of 3038 cases referred to the MLD in Baghdad, i.e., electrocution was the fifth cause of death being responsible for only 4.5% of cases referred to MLD during the period of study.

From the randomly selected 30 cases of electrocution which were included in this study, only 17% were females while 83% were males with (male: female ratio = 6:1), and their age mean value of 21.97 years $\pm$ (13.808) SD, median and mode values of 19 years, respectively.

According to the results of police and witnesses' reports at the time and site of incidents as well as results of external physical examination and internal autopsy, all cases of electrocution involved in this study were exposed to electricity accidentally (i.e., 100% were accidental) whether in workplaces, outdoor, or at home. Hence, there was no evidence that the electric shocks cases in this study were suicidal or homicide.

Source of electricity

All electrocution cases involved in this study occurred following exposure of victims to variable technical sources of electricity with different current intensity (domestic and nondomestic) and voltage (low and high voltage). However, electrocution by electrical weapons and natural sources such as lightning, biological, and static electricity were not recorded during the period of this study [Figure 1].

The current pathway

By analyzing the collected data regarding the crime scene reports and witnesses as well as the external finding on the victims' body with paying a special attention to the thermal effect of AC on their skin (i.e., the electrical burns at entrance and exit site), the current pathway across the body was assumed to be represent the shortest imaginary line connected from entrance to exit, and the frequency and percent for each pathway are represented in [Table 1].

According to Table 1, the current pathway was vertical (head to feet) in most of the cases (96.7%) with only one

case (3.3%) as horizontal pathway (hand to hand) had been recorded when an 8-year-old student stepped with her left foot on alive wire (dropped in small water spot in the street) to be shocked once her right foot touch the ground near her school gate, after early morning rain, to fall down the ground and die following successive shocks within few minutes.

Furthermore, the victims came into contact with the source by their left hands in 53.3% of cases with high incident that the current would exit their bodies from both feet (36.7%) then left foot only in 13.3% and right foot only in 3.3% of cases.

While the remaining 43.3% of cases used their right hands during the accidents and the current exits from both feet in 40% but only 3.3% at the left foot only, according to the point of contact with the ground [Figure 2].

Cardiac tissue injury

Thorough gross and microscopic examination of the heart tissue of all victims at autopsy was of great value in detecting the multisystemic effect of current passage through the body even in the absence of any visible electrothermal skin lesion(s) because heart tissue of almost all of the victims proved to be effected with variable severity by electrocution, and the heart tissue damage had been seen grossly and detected microscopically (using H and E and immunohistochemical [IHC] stains) in all cases at variable current intensity, different voltage, with or without the presence of relative body resistance, and at variable periods of exposure to the electrical current. Also IHC stain index level for H-FABP3 was highly sensitive to suggest structural cardiac injury when cut value for (Q) was less than 8.

Heart tissue injuries that had been detected include heart tissue burn (16.7%) [Figure 3], petechial hemorrhage only (56.7%) [Figure 4], congestion and/or edema (16.7%), and microscopic focal coagulative necrosis (6.7%), in addition to myofibers separation, loss of myocytes striations, and square configuration of myocytes nuclei in almost all cases [Figures 5 and 6].

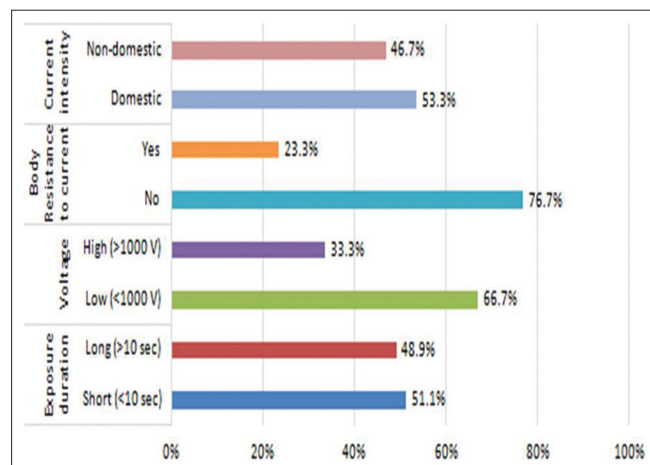


Figure 1: Electrical current parameters distribution among cases

In this study, data suggesting that the right side of the heart is commonly affected (50% of cases) by electrocution and lesion(s) was seen at the walls of the right ventricle alone in 30% of cases and in combination with the left ventricle in 20% of them. While the walls of left ventricle exhibit tissue damage in 27% of cases and only 7% of them, their lesion was restricted to the interventricular septum [Figure 7]. Furthermore, these lesions were located at the posterior aspect of the heart (57%) more than its anterior surface (13%), septum (7%), and apex (3%).

Heart-type fatty acid-binding protein 3

In this study, a microscopic evaluation with a magnification of $\times 40$, $\times 100$, and $\times 400$ was performed for myocardial tissue samples taken from affected areas (a) and nonaffected areas (b) (used as internal control) in hearts from electrocuted cases (exposed group) [Figures 5,6,8 and 9] and samples taken from control cases (c) that were not subjected to electric shock (used as external control) [Figures 10 and 11] for the purpose of comparison of the effect of electricity and its specifications on expression of H-FABP3 (regarding its intensity, area stained, and total index) between these groups in the cells of the heart muscle for all subjects involved in this study as follow.

Heart-type fatty acid-binding protein 3 positively stained tissue area

According to Table 2, there were statistically highly significant differences ($P < 0.01$) in the H-FABP3 positively stained tissue percent between affected area and nonaffected area in one hand as well as between affected area of exposed cases and the nonexposed control in the other hand. Meanwhile, only a statistically significant difference ($P < 0.05$) in tissue area stained positive for H-FABP3 had been noticed between exposed nonaffected and nonexposed (control) tissue samples.

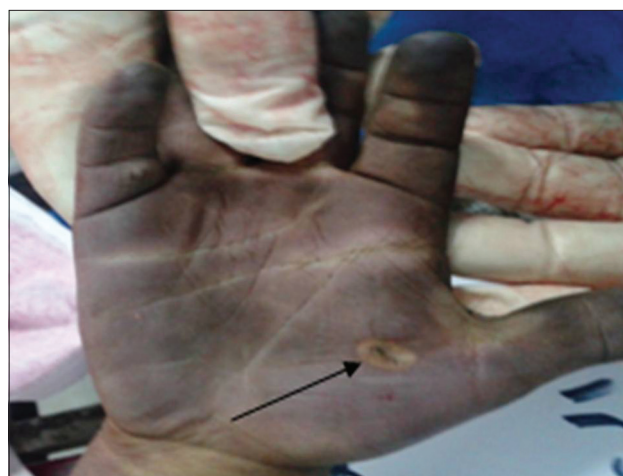


Figure 2: The right hand of a 5-year-old male child was witnessed to be in direct contact with an active source of domestic alternating current (220 V, 13 Amp, 50 Hertz) for <60 s, while he walking with barefoot on the wet floor. He died immediately following electrical shock. Examination reveals an oval shape direct contact electrical burn (entrance)-dark arrow – with extensive peripheral cyanosis

Heart-type fatty acid-binding protein 3 stain intensity

Table 3 shows that there are only statistically significant differences ($P < 0.05$) in H-FABP3 stain intensity between cases and control, and it tends to be weak in cases rather than the control.

Heart-type fatty acid-binding protein 3 stain total index

From Table 4, there were statistically highly significant

differences ($P < 0.01$) in the H-FABP3 total index between affected area and nonaffected area in one hand as well as between affected area of exposed cases and the nonexposed control in the other hand.

Meanwhile, there was no statistically significant difference ($P > 0.05$) to be estimated in H-FABP3 total index between exposed nonaffected and nonexposed (control) tissue samples.

DISCUSSION**Electrocution**

Although it seems difficult to live today's life rhythm without the existence of electricity, electricity by itself has its own black side, since it is responsible for many fatalities annually all over the world.

Moreover, in spite of the dramatic improvement in the electrical devices safety, electrical shock still one of the causes of death in our society with the wide spread use of electrical utilities, devices, and connection in the last years, in such way that in this study the electrocution was the fifth cause of death among cases referred by the police authorities

Table 1: The current pathway across the victims' body was assumed to be the imaginary line connecting between current entrance and its exit toward the ground

Current pathway		Frequency	Percentage
From	To		
Left hand	Left foot	4	13.3%
Left hand	Both feet	11	36.7%
hand*	hand*	1	3.3%
Neck	Both feet	1	3.3%
Right hand	Left foot	1	3.3%
Right hand	Both feet	12	40%
Total		30	100%

*Horizontal pathway

Table 2: Heart-type fatty acid-binding protein 3 (H-FABP3) positively stained tissue area in electrocution exposed (affected and non-affected) and non-exposed heart samples expressed as mean staining percent + standard deviation

	Subgroups		
	Exposed to Electrocution (case)		Non-exposed to electrocution (control)
	Affected area (a)	Non-affected area (b)	Tissue area (c)
H-FABP3 +ve stain area%	23.6%**b,c	75.1%*c	64.2%
SD	12.9%	12.1%	21.7%

** $P < 0.01$, * $P < 0.05$

Table 3: Distribution of Heart-type fatty acid-binding protein 3 stain intensity in tissue of electrocution exposed (affected and non-affected) and non-exposed heart samples expressed as score mean percent

Subgroups				
FABP3 staining intensity	Score	Exposed to Electrocution (case)		Non -Exposed to Electrocution (control)
		Affected tissue area (a)	Non - Affected tissue area (b)	Tissue sample (c)
Weak	+1	76.7% * c	76.7% * c	40%
Moderate	+2	10% * c	10%	23.3%
Strong	+3	13.3% * c	13.3%	36.7%

* $P < 0.05$

Table 4: Heart-type fatty acid-binding protein 3 stain total index in electrocution exposed (affected and non-affected) and non-exposed heart samples expressed as mean + standard deviation

	Subgroups		
	Exposed to Electrocution (case)		Non-exposed to electrocution (control)
	Affected area (a)	Non-affected area (b)	Tissue area (c)
H-FABP3 stain total index	0.28 ** b , c	1.03	1.41
SD	0.149177	0.592862	0.894104

** $P < 0.01$

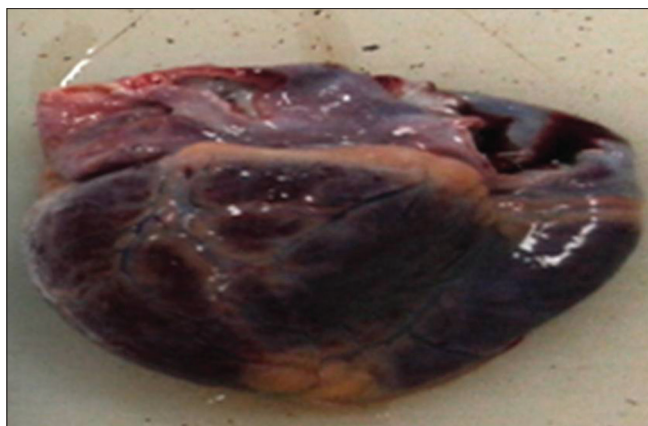


Figure 3: Heart of case in Figure 2 show generalized congestion with no obvious focal lesion(s)

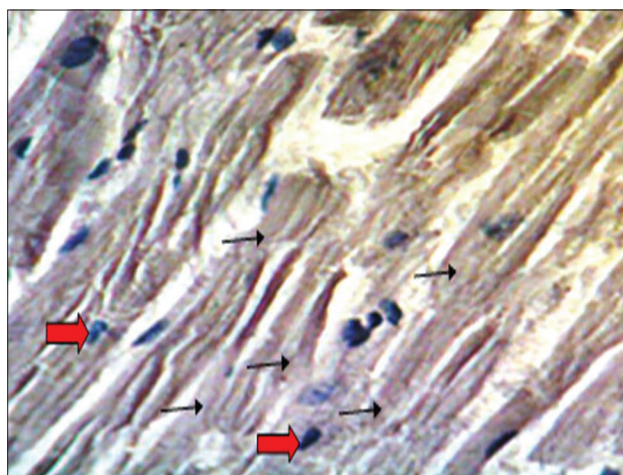


Figure 5: Immunohistochemical microscopic examination of Formalin-fixed, paraffin-embedded heart tissue of case in Figure 2: shows myofibers separation, loss of striation, myocytes cytoplasm weakly stained (+1) in <50% of the section for fatty acid-binding protein 3 (brown colored detected by 3,3'-diaminobenzidine chromogen) - (black arrows) - and nuclear square configuration (red arrows) counterstained with hematoxylin $\times 400$

to the MLD in Baghdad during only the first half of the year and constituted >4.5% of cases during that period, which is considered relatively high in comparison to 1.5% of all cases subjected to medicolegal autopsy in MDL in Baghdad during the year 2005,^[28] and even higher than what Shrigiriwar *et al.* reported during their 6-year study (from January 2001 to December 2006) for electrocution in India which were only 86 cases,^[29] keep in consideration that the incidence of electrocution in other different countries all over the world, especially the developed - is further more less than its rate in this study. For instance, electrical injuries were responsible of only 500 deaths per year in USA, less than 1 per million per year in Australia and New Zealand and 0.2–0.6 per million for Europe in years 2000–2011.^[30–32] This difference is probably related to less awareness to the hazards of electricity in our society and the use of electric equipment not as per standards

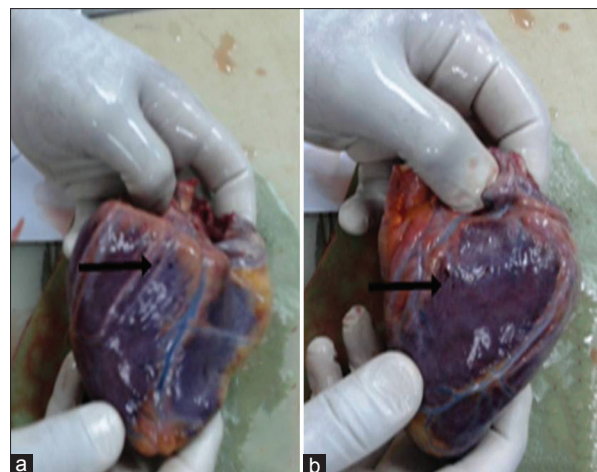


Figure 4: Dark arrows point to petechial hemorrhages on the posterior aspect of; (a) left and (b) right ventricles seen on the heart of case shown in Figures 12 and 13



Figure 6: Immunohistochemical microscopic examination of formalin-fixed, paraffin-embedded heart tissue of case in Figure 8. Slide shows myofibers separation, loss of striation, myocytes cytoplasm weakly stained (+1) in 10% of the section (+1) for fatty acid-binding protein 3 (detected by 3,3'-diaminobenzidine chromogen) - brown colored- and nuclear square configuration (counterstained with hematoxylin) - red arrows, $\times 400$

laid down, being at low cost and high risk of electrical shock to the users.

Similar to what it had been noticed by authors, the majority of cases were male with male-to-female ratio 6:1, and this male sex predominance seen all over age groups, which is more likely because male usually take the risk of repairing and dealing with malfunctioning electrical devices or connections more than the females whether at home or workplace as well as due to their occupational predisposition.^[13,31–34]

Although all age groups are at relative risk of exposure to electrical injury due to the wide use of electricity supply and equipment and devices, the highest fatality was encountered in age group 15–20 years (10 cases out of 30,

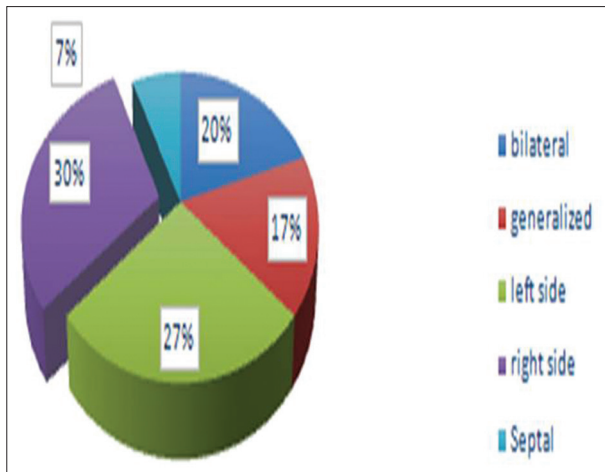


Figure 7: Sites of cardiac tissue injury in electrocution cases

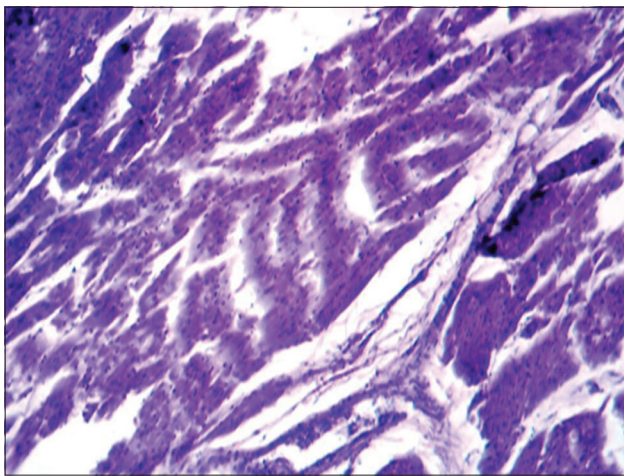


Figure 9: Immunohistochemical microscopic examination of formalin-fixed, paraffin-embedded heart tissue in Figure 4, shows myofiber separation, myocyte cytoplasm show no stain in almost all the tissue section of the affected area (0 score) for fatty acid-binding protein 3 (detected by 3,3'-diaminobenzidine chromogen counterstained with hematoxylin) $\times 100$

i.e., 33.3%), followed by age group <5 years (5 out of 30, i.e., 16.7%) with mean of 21.97 years $\pm$ 13.808 SD which probably reflect the exposure opportunities rather than the differences in susceptibility, in constant with mean age value of 24.8 years (SD = 18.8) reported by Mashreky *et al.*,^[35] in Bangladesh during 2003, also age distribution was constant with Baker and Chiaviello and Kym *et al.* who suggested bimodal age distribution of electrical injuries. According to their studies, toddler is being more vulnerable to electrical shock, especially from household low-voltage current socket and cords due to their limited mobility within a relatively confined environment at home and the habit of sucking and chewing the ends of electrical extension cords, while at adolescence, they would engaged in more risky behaviors around the electrical power lines.^[36,37] While the results of this study were disagreed with Al-Hadithi and Manish studies which confirmed that the highest affected age groups were

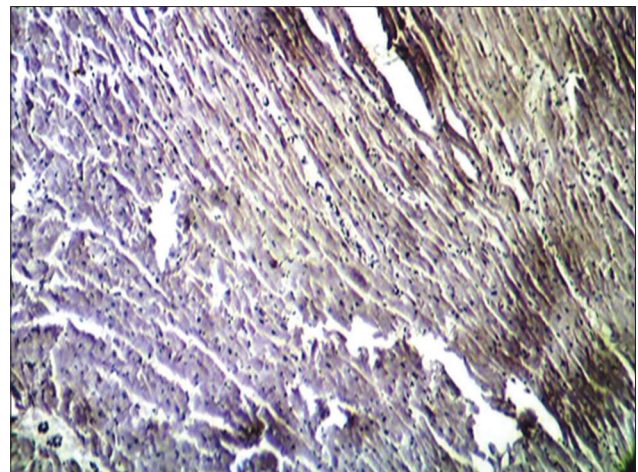


Figure 8: Immunohistochemistry microscopic examination of formalin-fixed, paraffin-embedded heart tissue of 18-year-old male who was exposed to an active source of domestic alternative current (220V, 13 Amp, 50 Hertz) for <10 s. He died immediately following electrical shock. Autopsy revealed peripheral and central cyanosis, but neither electrical entrance burn nor exit burn and internal organs including the heart was all looking normal with no obvious gross lesion. Tissue section shows myocyte cytoplasm weakly stained (+1) in 10% of the section (+1) for fatty acid-binding protein 3 (detected by 3,3'-diaminobenzidine chromogen)-brown color-(counterstained with hematoxylin) $\times 100$

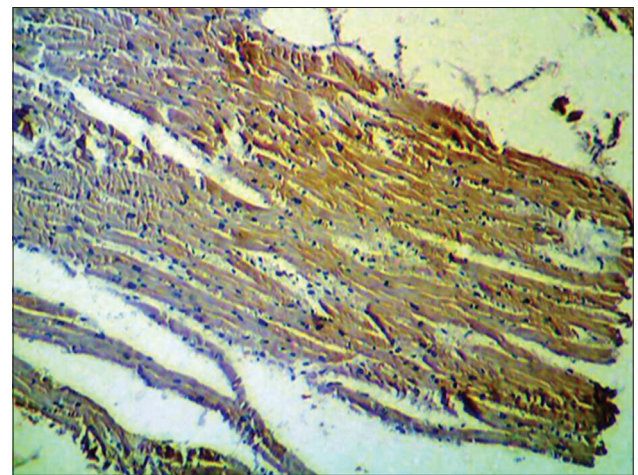


Figure 10: Immunohistochemical microscopic examination of formalin-fixed, paraffin-embedded heart tissue of individual died immediately following bullet injury to head (used as external control), PMI <12 h. Myocyte cytoplasm moderately stained (+2) in 75% of the tissue section for heart-type fatty acid-binding protein 3 with total index of (8) detected by 3,3'-diaminobenzidine chromogen and counter-stained with hematoxylin $\times 100$

30–39 and 21–30 years, respectively, and they attributing the reason to be that at this age adults may work with electricity to earn their livelihood.^[28,29]

Regarding the manner of death, all electrocution cases in this study were accidental in nature and no one of them was suicidal or homicidal, and this finding agreed with almost of other previous Iraqi and foreign studies that concluded the rarity of use of electricity to commit suicide or crimes and the majority

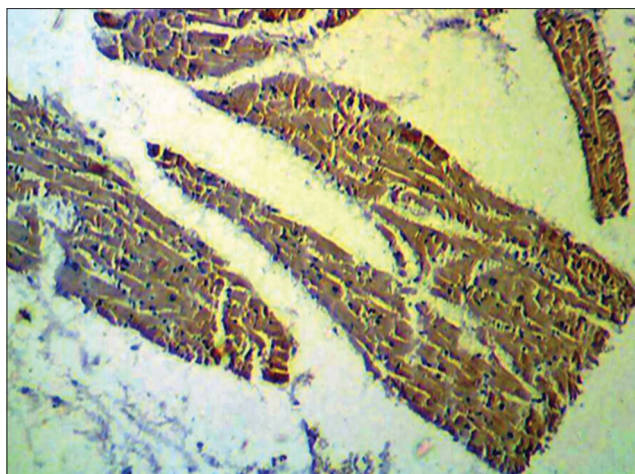


Figure 11: Immunohistochemical microscopic examination of formalin-fixed, paraffin-embedded heart tissue of individual died immediately following bullet injury to head (used as external control), PMI <12 h. Myocytes cytoplasm strongly stained (+3) in almost all the tissue section for heart-type fatty acid-binding protein 3-detected by 3,3'-diaminobenzidine chromogen - brown colored and counterstained with hematoxyline, $\times 100$

of them being accidental manner of death, occur usually to amateurs and to a lesser extent to professionals who exposed to electricity without safety measures and proper precautions or the use of malfunctioning equipment or misuse of electrical devices and connections.^[5,28-37]

Most of electrocution cases occur at victims' home, which are usually supplied by low voltage (220–240 V), low-intensity domestic AC in Iraq similar to most of other countries in Asia;^[4] therefore, electrical injuries from AC with low voltage and domestic intensity predominate over injuries from exposure to current with high voltage and high intensity which were restricted to workplace and street, agreed with finding in most of the other authors regarding this concept, except for two cases (husband and his wife) who died at their house immediately after electrically shocked from high-voltage intensity current when he was at the roof holding one end of a satellite cable with its insulator cover being removed by friction as he dropped it over nearby high-tension line to be held by his wife at the ground and both of them stand on a wet floor with barefeet.

Furthermore, autopsy examination reveals the presence of cutaneous electrothermal effect at the electric source contact site (entrance burn) without exit in 40% of cases, and entrance and exit burns were absent in only 0.3% because of short duration of exposure, wide area affected, low-current strength, and low skin resistance due to humidity or water at exit and/or entrance, respectively, meanwhile both of them exist in 53.3% of cases involved in the study due to the effects of Kouwenhoven's factors, with the prolonged duration of exposure to current to be the most effective factor in making the cutaneous electrothermal effects even more obvious, more severe and extensive at the source contact and the ground contact sites irrespective to current type, voltage, intensity, and skin



Figure 12: (a) Direct contact 2nd and 3rd degree burns on the right palm and fingers at the entrance of the electrical current and (b) 4th degree burns along current pathway in right forearm in a 19-year-old construction worker who used a metal bar by his right hand to encourage a chicken to get off a high tension line that it had already stood on after the rain stopped. Hence, he exposed to the risk of being shocked with alternative current of high voltage >1800 v and 360 Amp. for no >60 s

resistance [Figures 12 and 13]. These findings are in accordance with many previous Iraqi and foreign studies.^[5,7,8,28-39]

Cardiac tissue injury

One of the most common causes of fatal outcome of electrocution is the passage of electric current through the heart, which in turn causes functional disturbances and/or structural tissue damages varies in their extent and severity according to Kouwenhoven's factors.

Czuczman *et al.* suggested that electrocution can cause heart tissue damage either directly due to the electrothermal effect on myocardial tissue represented by coagulative necrosis through the vertical (head to foot) electric current flow or indirectly through ischemic injury precipitated either by arrhythmia-induced hypotension which is common with low-voltage AC shock or rarely due to acute coronary artery occlusion.^[13]

In contradictory to Al-Khateeb and Ghazi^[40] and Al-Hadithi *et al.*^[28] findings which suggested that heart tissue injury is neither significant nor specific to electrocution, respectively, and that there were no histopathological changes to be seen in heart tissue samples in >92.2% of electrocution cases and only nonspecific vascular congestion detected in 7.8% of heart tissue samples. This study shows that heart tissue injury was constantly accompanied almost all cases of electrocution and this may be due to three main reasons:

First, the victims' hearts lay along the transthoracic vertical pathway of the current in 96.7% of cases as well as along the transthoracic horizontal pathway in the remaining case which makes the heart more vulnerable to the direct and indirect effect of current.^[13]

Second, all cases exposed to AC with low voltage (in 66.7%) and not DC. The former is considered to be three times more



Figure 13: Fifth and 6th degree dry burns on feet and toes at the exit of the current as it passes through the body to the earth in case shown in Figure 12. The right second toe had been totally lost

dangerous than DC of the same voltage because its repetitive nature that triggers tetanic muscle contraction, prevents the victim from releasing the source, and increases the duration of exposure which in turn increases the likelihood of delivering the current to the myocardium causing VF and/or extensive cardiac tissue necrosis.^[9,14,33]

Moreover, finally, >76.7% of cases in this study, their skin conductivity was relatively increased due to low resistance owing to the presence of water spots, rain, and high humidity at death scene which enhanced the flow of current into the underlying tissues, especially the heart tissue whose internal resistance along the fibers is relatively low (130–230 Ω cm) and heart's high anisotropy results in simultaneous clockwise and counterclockwise current flow in cardiac ventricle making heart tissue damage even more worse.^[12]

Therefore, moreover, as a result of the already mentioned reasons, heart tissue damages of variable severity and extent had been seen in almost all electrocution cases involved in this study, represented by focal hemorrhage in 56.7%, extensive heart tissue burn in 16.7%, and multiple focal coagulative necrosis alternating with viable tissue areas in 6.7%, congestion and/or interstitial edema in 16.7%, myofibers separation and fragmentation, loss of myocytes striations, square configuration of myocytes nuclei in almost all cases, which is in concordance with other authors.^[14,29,34,35,41]

Although most of these gross and microscopic features are not specific for electrocution and VF is believed to be the most common cause of death following electric shock, these cardiac histological changes still helpful in supporting the diagnosis in forensic practice to reach a proper explanation regarding the cause of death in cases with less typical skin lesions or obscure circumstances and even to differentiate electrocution cases (usually associated with multiple organ tissue injuries, especially nervous, pulmonary, and cardiovascular systems) from cases of exclusively skin burn due to exposure to flame as well as from cases of acute MI which are usually associated

with inflammatory response according to the length of postinfarction interval, whereas myocardial necrosis due to the electrocution was not accompanied by inflammatory reaction in most of cases suggesting that death was rapid, so there was no time for inflammatory reaction to develop.^[10,14,15,42,43]

Therefore, these cardiac tissue changes should be looked for during autopsy, tissue sampling, and microscopic examination, keeping in mind that this study shows that cardiac injuries were mostly involved the posterior walls of the ventricles (57%) more than their anterior walls (13%), and the right side of the heart (50%) more than the left side (27%), at sites usually opposite to entry and direction of the current pathway across the heart.

Heart-type fatty acid-binding protein 3 immunohistochemical expression

In the current study, heart tissue samples of human cases who were electrically shocked till death, demonstrate a significant effect of AC shock on the extent, intensity, and the total optic density score of the intracytoplasmic expression of H-FABP3.

From the results analysis, it was obvious that the passage of AC across the heart causes severe and easily detected depletion in the H-FABP3-positive stain among myocardial cells, especially autopsy samples of necrotic tissue areas which was positively stained for H-FABP3 in no more than $23.6\% \pm 12.9$ SD of the affected tissue sections, predominated weak stain intensity of (+1) in 76.7% of tissue sections and total stain index to be no more than 0.28 ± 0.149177 SD in comparison to heart tissue samples taken from the nonelectrocuted control that showed positive stain for H-FABP3 in $64.2\% \pm 21.7$ SD of tissue sections area, moderately to strongly stained in 60% of tissue section and total stain index of 1.41 ± 0.894104 SD.

Therefore, the depletion in H-FABP3 stained area, intensity, and total index are considered an indicator of the presence of heart tissue injury because its H-FABP3 has a cytoplasmic location and low molecular weight of (15 KD) both make it readily to be released into the circulation after any myocardial injury.^[17,19,44]

Thus, H-FABP3 stain depletion reflecting the highly significant effect of electric shock on the functional and/or the structural well-being of human heart tissue with $P < 0.01$, which will assist in the diagnosis of heart tissue damage as a cause of death following electrical injury.

Moreover, in this concern, Özdemir *et al.* in their study found that increased serum H-FABP levels were significantly associated with the higher voltage immediately after electrocution and may have significant diagnostic value in early postmortem period accompanied with significant immunostaining loss for H-FABP in myocardial in electrocuted rats.^[45]

This is, furthermore, supported by the fact that during autopsy even the grossly normal looking heart tissues of electrocuted cases that are microscopically show no signs of ischemia

using H and E stain, still demonstrates weak H-FABP3 stain in 76.7% of randomly selected tissue sections despite the wide distribution of the stain, suggesting that H-FABP3 is a highly sensitive tissue marker for myocardial injury following electrocution in concurrence with other studies.^[21,23,46-48]

CONCLUSIONS

Electric shock is the fifth cause of traumatic death among cases referred to the MLD in Baghdad during the period of study. It represents a cause of preventable, almost accidental death in our society with higher incidence to be due to accidental contact with low-voltage household AC sources with young age males are being more vulnerable to fatal electrical injury than females during their early productive life due to negligence, nonprecautions, reckless behaviors or lack of experience and safety measures during repairing electrical devices, and maintenance works for the electric network at homes or workplaces.

Heart tissue ischemia is a major cause of death following electrocution, especially when victim being in contact with household low-voltage AC in the presence of transthoracic pathway to the ground and low body resistance due to skin wet by perspiration or rain which can cause death within minute in associated with mild if any electrical skin burns.

Thorough autopsy examination of the internal organs, especially the heart and proper tissue sampling, is of great value in determine the cause of death and assists in the diagnosis of electrocution, especially when incident circumstances is not clear and skin electrothermal lesions are absent.

Furthermore, since electrocution is a probable cause of negative autopsy; therefore, immunohistochemical heart tissue samples examination for H-FABP3 depletion is valuable in detecting heart tissue injury caused by electrocution during the early period after death even in the absence of grossly visible heart lesion(s) and/or the absence of microscopic heart tissue changes using (H and E) tissue stains.

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Conflicts of interest

There are no conflicts of interest.

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