Case Report

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Forensic tools for the diagnosis of electrocution death: Case study and literature review

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Abstract
Diagnosis of death by electrocution may be difficult when electric marking is not visible or unclear. Accordingly, the body of a man who appeared to have died from accidental electrocution was carefully forensically analysed. Macroscopic and microscopic analysis of the current mark was carried out using a variable-pressure scanning electron microscope equipped with energy dispersive X-ray microanalyser to highlight skin metallisation, indicating the presence of iron and zinc. The histological findings of electrocution myocardial damage were supported by the results of biochemical analysis which demonstrated the creatine kinase-MB and cardiac troponin I elevation. The effects of electric current flow were also highlighted by perforations of endothelial surface of a pulmonary artery using scanning electron microscope, and all the results were analysed by the main tools suggested in the literature.

Keywords
Electrocution death, metallisation, biochemical analysis, energy dispersive X-ray analysis, endothelial perforation, scanning electron microscope

Introduction

The diagnosis of electrocution depends on the morphological findings of the current mark and the circumstances of death.[1] Some electrocution deaths occur without detectable current marks on the skin, making forensic determination of the cause of death more difficult,[2,3] especially in regard to including different or concurrent factors,[4] and all forensic tools currently available should be used.

We report a case study of electrocution death, where the current mark on the skin was biochemically analysed, along with lung scanning electron microscope (SEM) analysis and metallisation assessment by variable-pressure scanning electron microscope (VP-SEM) with energy dispersive X-ray microanalyser (EDX). This case study highlights the usefulness of the forensic investigations, proving also a brief review of the literature on the main diagnostic tools for the diagnosis of electrocution which may also be helpful in cases where no electrical mark can be found.

Case report

The body of a 47-year-old man was found on a public road hanging with his legs attached to the electric wires of a light pole. Preliminary judicial investigation concluded that the man was trying to steal the galvanised steel ropes of the light pole. Relatives reported that the subject did not suffer from pathologies. After the crime scene investigation, an autopsy was ordered to assess the cause and manner of the death.

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An autopsy was performed after 24 h that revealed electrical lesions as small crater injuries with a charred bottom on the left hand palm and on the left second and third fingers (Figure 1). Macroscopic examination showed a localised area of haemorrhage on the heart apex and multiple petechiae on the lateral wall of the left ventricle. There was also pulmonary congestion and oedema.

Concerning the histopathology, the skin and the heart showed the most important evidence. Epidermal nuclear elongation, intraepidermal separation as microvescicles and wavy skeletal myocells were observed on the left hand skin (Figure 2). The heart highlighted areas of wavy fibres, contractions band and also myofibre break-up.

Biochemical analysis

Biochemical analysis was performed on right heart blood taken during autopsy, and the analytes were measured as part of routine laboratory investigation. The most important results regarded creatine kinase-MB (CK-MB) and cardiac troponin I (cTnI) that were elevated, 1121 ng/ml and 830 ng/ml, respectively.

Figure 1. Macroscopic findings. Electrical lesions on the left hand palm and on the left second and third fingers.

VP-SEM with EDX analysis

A formalin-fixed tissue of the left hand skin was dried at room temperature and directly glued on the sample stage without any further preparation. The specimens were observed by VP-SEM equipped with EDX microanalyser. The operating conditions of the VP-SEM were: accelerating voltages 25.10 kV; chamber pressure, 30 Pa; temperature of the sample stage −25°C.

For each fragment, large field detector (LFD) scans and corresponding back scattered electrons (BSE) scans were acquired to detect the presence of heavy particles (Figure 3(a) and (b)). Then, the particles were subjected to spectral analysis with EDX method to evaluate their composition and particularly to research metals. The EDX spectrum of the deposits indicated iron and zinc peaks (Figure 3(c)).

SEM analysis

Sections of pulmonary arteries were fixed in the 2% glutaraldehyde solution with pH 7.4 and then dehydrated with gradient ethanol alcohol. The samples were subsequently dried by carbon dioxide critical point and coated with gold at a thickness of 15 Å. The samples were examined by an SEM. The analysis showed some oval and round pores on the endothelial cells with non-uniform and non-consecutive distribution (Figure 4).

Discussion and conclusions

The results of all the investigations showed that cause of death was from electrocution. A literature review was conducted employing the PubMed database using

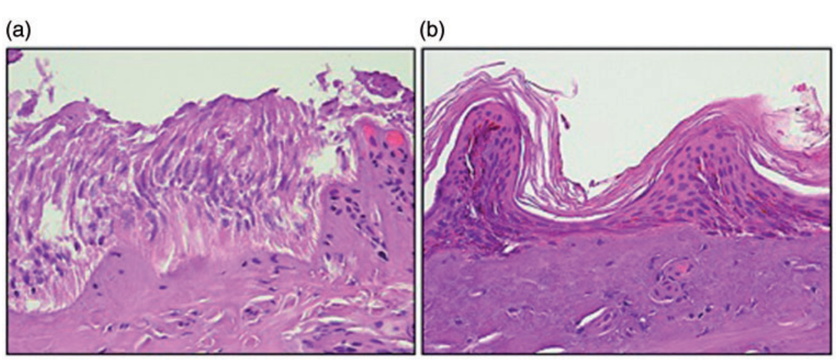

Figure 2. Histological findings of the skin. (a) Elongated nuclei and cells of the epidermidis perpendicularly oriented. (b) Microvescicles separating the epidermal superficial layers and plurifocal coagulative necrosis of the dermis. Haematoxylin and eosin stain. (a) and (b) 10×.

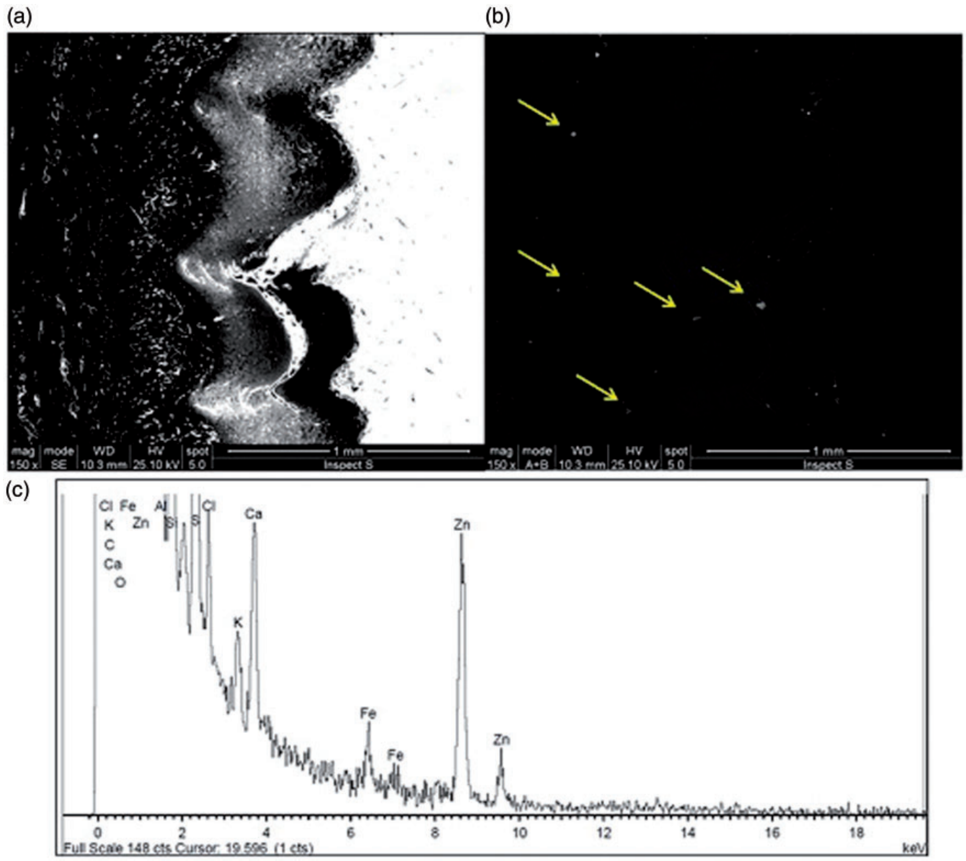

Figure 3. VP-SEM with EDX analysis. (a) LFD scan of the left hand skin scrap. (b) Corresponding image with BSE scan showing the presence of heavy particles (yellow arrows). Scanning electron microscopy. (a) and (b) 150×. (c) The energy dispersive X-ray spectrum of the deposits indicating the peaks of iron and zinc.

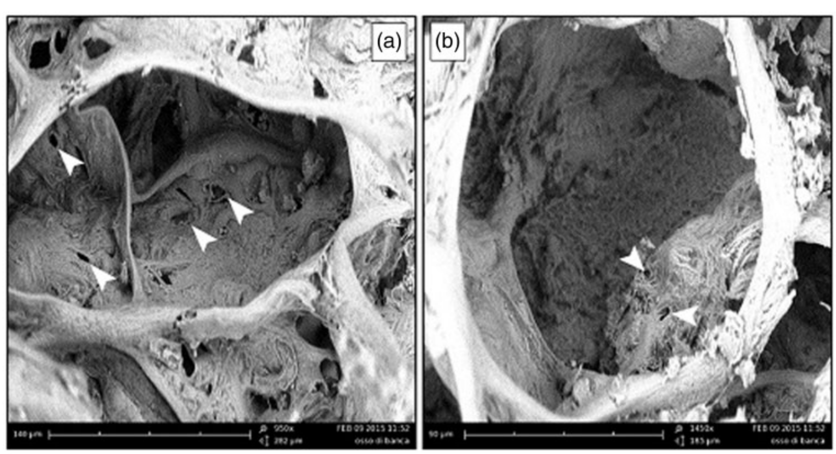

Figure 4. Pulmonary artery analysis by SEM. Pores on endothelial surface in a pulmonary artery (white arrows). Scanning electron microscopy. (a) 950× and (b) 1450×.

the key terms ‘electrocution’ AND ‘forensic diagnosis’; the inclusion criteria were English language, year of publication from 1980 and relevance to the topic in question. In light of this, 23 studies are discussed.

Electrocution causes damage to the tissue through which the electric current passes and the only gross evidence is the electrical mark localised on the skin at the point of contact with the conductor. In some cases, the current mark is not detectable and the diagnosis of death due to electrocution is a challenge for forensic pathologists. For this reason, many studies to test auxiliary investigations were carried out.

Skin lesions caused by electrocution show histological patterns such as intraepidermal separation or intraepidermal and subepidermal separation and epidermal nuclear elongations.[5] The increased heat from the electrical current determines tissue fluid evaporation and separation of epidermal cells or subepidermal cells according to the various voltages. At the same time, the electromagnetic effects of electricity cause pyknotic and elongated nuclei which were arranged in the direction of electric burns. However, these patterns cannot be considered pathognomonic because they also occur in thermal burns.[6] In these cases, skin metallisation analysis can be useful to distinguish between electric injury and thermal injury. When current passes from the metal to the skin, electrolysis occurs and metallic ions are embedded in the skin and subcutaneous tissues, so the metallisation is a characteristic sign of electrocution.[7,8] There are many methods to identify the metallic ions on the skin. Many authors suggest the histological technique using the Timm's method to detect copper which is a sensitive, economical and easily repeatable in every laboratory method.[9] Other studies highlighted the usefulness of SEM equipped with EDX microanalysis that allows observation of the surface of specimens and performs the chemical analysis to assess the composition of microparticles.[10,11] In the reported case, the EDX spectrum of deposits indicated the peaks of iron and zinc confirming the metallisation due to electrocution. Notably, these findings provide evidence that the electrocution occurred as a result of contact with a conductor made of galvanised steel ropes.

The review of literature showed that the Fourier transform infrared spectroscopy in combination with chemometrics is another method which provides a more accurate diagnosis of a current mark. In fact, this analysis was applied to characterise protein conformations of the electrical mark on the human skin and demonstrated differences of protein structural profile between the electrical mark and normal skin.[12]

There are reported studies of histological investigations carried out to define any morphological signs due to the flow of electric current, and there have been some experimental studies on animal samples about the damage to the cells of the nervous system (i.e. Purkinje cell, Hippocampal cells),[13,14] the electric current effect was studied especially on the heart.

In fact, because electrical injuries may affect the heart either by causing cardiac arrhythmia or direct necrosis of the myocardium, some studies showed cardiac myofibres break-up or patchy necrosis of myocardium.[15–18] These findings are neither specific nor sensitive in the absence of recognisable skin marks or definite postmortem morphological findings, and hence immunohistochemistry was suggested. An experimental study on animal samples about c-fos expression showed significant differences in immunostaining especially between the groups with antemortem electric injury and groups of postmortem injury, suggesting that the analysis can be useful both in identifying electrical injury and distinguishing antemortem from postmortem electric shock.[19] With regard to the heart immunohistochemical investigation, a study was performed on a rat's sample, where fatal electrocution was observed to be associated to both reduced expression of connexin 43 and increased expression of angiotensin II and endothelin 1.[20] Further, myocardial damage can be documented by biochemical analysis as was done in our case in which histological myocardial necrosis was also highlighted by the increase of cardiac blood CK-MB and cTnI. A study on the biochemical analysis suggests a possible relationship between the pathological and biochemical findings in autopsy cases with postmortem interval >24 h and, particularly, the relation between myocardial injury and CK-MB and cTnI elevations or between prolonged hypoxia/skeletal muscle injury and serum uric acid, creatinine and pulmonary surfactant elevations.[21] There were findings about the serum heart-type fatty acid binding protein levels that may be a better indicator than those of cTnI to reflect the myocardial damage in the early period of the electrocution,[22] and these biochemical markers of myocardial injury as well as myoglobin (Mb) can be evaluated in pericardial and cerebrospinal fluids.[23]

Other researchers have evaluated some biomarkers in connection with the cause of death and postmortem interval, highlighting that the cardiac biomarkers are higher in electrocution cases after 12 h postmortem.[24] Interpretation of the postmortem biochemistry results should take into account the influence of postmortem intervals on the breakdown of proteins and in cases of electrocution should be checked for cardiac troponin T within the first 50 h.[25] All these factors suggest that elevated cardiac biomarkers observed in our case study can be signs of myocardial injury due to current passage.

Finally, our reported case confirmed the usefulness of the SEM to detect pulmonary artery endothelium damage from electric current flow, like electroporations. In fact, some studies highlighted the presence of pores on the surface of endothelial cells of the aorta and pulmonary arteries by SEM in victims of electrocution and electrified rabbits, suggesting it as a useful marker to identify electrocution for the cases without a detectable current mark on the skin.[26,27]

Taken together, the findings of the forensic investigations performed in this case report clearly suggest that the man died from electrocution and summarises the forensic tools that can be useful and key investigations where there is no current mark. There is a need for further forensic research with further studies or reports to provide a larger sample demonstrating the effectiveness of auxiliary tests such as biochemical analysis and SEM for endothelial cells damage.

Declaration of conflicting interests

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