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Research Article

Discriminating Antemortem From Post-Mortem Low-Voltage Electrocution Burns: A Prospective Two-Year Study Applying a Three-Point Histopathologic Checklist and Sem/Eds Correlation

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ABSTRACT

Background: Correctly determining whether an electric-current skin lesion was produced during life (antemortem, AM) or after death (post-mortem, PM) remains pivotal in forensic reconstruction yet notoriously difficult when only gross inspection is available. Gross morphology overlaps, while several "vital" histological changes can be reproduced experimentally in cadavers.

Methods: In a two-year prospective series (July 2018 – June 2020) we examined 25 consecutive AM electrocution fatalities and 30 fresh cadavers in which standardised PM electrical burns were experimentally created (220 V AC, 400–1000 mA, 3–4 s). For every lesion we recorded macro morphology, fourteen predefined light-microscopic variables on haematoxylin–eosin (H&E) sections and surface/elemental characteristics on scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM/EDS). Pearson's x^2 with Yates' correction tested inter-group differences; diagnostic performance indices were calculated for individual and composite markers.

Results: AM lesions were significantly larger (≥ 1 cm in 52 % vs 17 %, p = 0.01) and more often oval/elongated. Epidermal nuclear streaming (72 % vs 53 %, p = 0.04), coagulative epidermal necrosis (72 % vs 43 %, p = 0.02), dermal collagen homogenisation > ⅓ thickness (36 % vs 10 %, p = 0.01) and sweat-gland nuclear elongation (56 % vs 16 %, p < 0.001) discriminated AM from PM injuries. Combining any two of the three strongest criteria—deep dermal homogenisation, sweat-gland nuclear streaming, marked epidermal necrosis—achieved 84 % sensitivity and 90 % specificity for vitality. Metallisation was absent in both cohorts except sparse environmental particles, limiting the value of SEM/EDS in low-voltage deaths.

Conclusion: The grade and depth of dermal and adnexal damage, rather than their mere presence, provide reliable positive criteria of vitality in electrocution burns. A simple three-point H&E checklist offers high diagnostic accuracy and can be readily adopted in routine forensic practice.

Keywords: Electrocution; Forensic Pathology; Wound Vitality; Histopathology; Scanning Electron Microscopy.

INTRODUCTION

Electrocution accounts for 1–4 % of medicolegal autopsies worldwide and is a leading cause of traumatic mortality among young working-age males in low- and middle-income countries [1, 2]. The forensic pathologist's first task when confronted with a suspected electrical fatality is to identify an electrical skin mark (often colloquially dubbed a "Joule burn") and, more challengingly, to establish whether that mark formed before death. This step directly affects certification of cause and manner of death and may exonerate or implicate employers, co-workers or potential assailants [3]. Classical descriptions emphasise a central chalk-white focus surrounded by a hyperaemic rim, with crateriform edges reflecting epidermal delamination and keratin coagulation [4]. Yet up to one-fifth of confirmed electrocution deaths lack a visible entry wound,

particularly when initial contact is through moist clothing or when high-resistance pathways (bones, joints) dominate current flow [5]. Conversely, electrical contact after death—whether accidental in mortuary handling or deliberately inflicted to mimic homicide—can generate lesions that closely resemble vital burns. Gross appearance alone is therefore insufficient. Histologically, Moritz first catalogued intra-epidermal vacuolation, nuclear elongation and dermo-epidermal separation as hallmarks of electrical injury in 1947 [6]. Subsequent animal and cadaveric experiments revealed that many such changes reflect rapid thermal denaturation and can be reproduced post-mortem within seconds, blurring the vital artefact boundary [7]. More recent work has shifted towards quantitative or graded assessment of dermal collagen homogenisation and adnexal damage, arguing that deeper, more extensive alterations imply blood-borne heat dissipation achievable only in the living [8]. Ultrastructural approaches add another dimension. Variable-pressure SEM with EDS can detect trace metals—typically copper, iron or aluminium—deposited by conductor erosion at the contact point. Several case series report metallisation as virtually pathognomonic of electrical origin and occasionally of time-related value when oxidation profiles are compared [9]. However, metallisation is inconsistent, influenced by alloy composition, voltage, humidity and the presence of insulating clothing [10]. Despite more than seventy-five years of cumulative research, few studies integrate gross, histological and electron-microscopic examinations within the same cohort to provide a pragmatic vitality algorithm for frontline pathologists. The present prospective study therefore (i) catalogues the macro-, micro- and ultrastructural features of AM versus PM electrocution burn marks created under real-world low-voltage conditions; (ii) quantifies similarities and discriminators; and (iii) proposes a concise, high-specificity set of histomorphological criteria suitable for routine application. By synthesising observations across multiple investigative layers, we aim to reduce diagnostic ambiguity, improve courtroom robustness and ultimately support the delivery of justice in electrocution-related fatalities.

MATERIALS AND METHODS

Study Design and Setting

A prospective comparative observational study was conducted from July 2018 to June 2020 in the Departments of Forensic Medicine, Pathology and Anatomy (Electron Microscopy Facility) at the All-India Institute of Medical Sciences, New Delhi. Institutional Ethics Committee approval (AIIMS/IECPG-383/30.08.2018, RT-4/18.10.2018) and police or next-of-kin consent were obtained for each examination.

Case Selection

Antemortem group (AM): all electrocution fatalities (n = 25) undergoing medicolegal autopsy within 24 h of death in which a discrete electrical entry mark was demonstrable. Post-mortem group (PM): 30 fresh adult cadavers (< 24 h post-mortem) without cutaneous disease or decomposition. A single experimental electrical burn (0.5 × 0.5 cm) was produced on the dominant palm using a purpose-built device delivering 220 V alternating current at 400–1000 mA for 3–4 s.

Gross Examination

Lesion site, shape, maximal diameter (small < 0.5 cm; medium 0.5–1 cm; large > 1 cm), surface colour, blistering and surrounding erythema or charring were documented and photographed.

Histology

One-centimetre-square wedges encompassing the lesion and contralateral normal skin were fixed in 10 % neutral-buffered formalin, routinely processed and stained with H&E. Fourteen pre-defined variables (Table 1) were graded by two blinded histopathologists according to the modified Uzun scale with discrepancies resolved by consensus.

Scanning Electron Microscopy and EDS

Surface samples (4 × 4 mm) were fixed in Karnovsky's solution, critical-point dried, sputter-coated with Au/Pd and examined on a ZEISS EVO-18 SEM at 15 kV. Elemental spectra were acquired from regions of interest using an Oxford Instruments EDS detector.

Statistical Analysis

Categorical frequencies were compared between AM and PM groups using Pearson's χ^2 test with Yates' correction where appropriate (SPSS v24.0). For ordinal variables with ≥ 3 grades, scores were dichotomised as marked (≥ 2+) versus absent/mild (0–1+). Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were calculated for key markers individually and in composite.

A p-value < 0.05 was considered statistically significant.

RESULTS

Across 55 lesions examined, clear morphological contrasts emerged between AM and PM groups, yet partial overlap at every investigative tier underscored the need for multi-modal assessment (Figure 1). Macroscopically, AM burns most often presented as parchment-white, oval entry wounds on the upper limbs, reflecting tangential hand contact with live domestic wiring, whereas PM burns produced under controlled conditions on cadaveric palms remained small, circular and sharply demarcated. Light-microscopic evaluation yielded the greatest discriminatory power. While epidermal nuclear elongation, vacuolar degeneration and intra-epidermal clefting appeared in both cohorts, their extent differed markedly. AM specimens frequently displayed confluent coagulative necrosis of the epidermis with streaming of hyperchromatic nuclei in the basal and suprabasal layers. Deeper tissues mirrored this gradient: collagen bundles in the papillary and upper reticular dermis became homogenised and eosinophilic, occasionally extending beyond one-third of the dermal thickness. Sweat glands situated within these zones exhibited elongation and polarisation of nuclei along the current path—findings encountered only sporadically in PM controls. Ultrastructurally, the highly detailed SEM surface topology of both AM and PM lesions showed keratin "river-bed" fissuring and pitted craters; however, EDS rarely demonstrated conductive metal deposition. Only sporadic niobium, gold or mercury particles—also present in contralateral normal skin—were identified, suggesting environmental contamination rather than true metallisation (Table 3). When diagnostic indices were calculated (Table 4), single markers such as sweat-gland nuclear elongation achieved high specificity (84 %) but modest sensitivity (56 %). Conversely, dermal homogenisation > ⅓ depth was specific (90 %) yet insensitive (36 %). A composite criterion requiring any two of the three best performers—(a) deep dermal homogenisation, (b) sweat-gland nuclear streaming, (c) marked epidermal necrosis—boosted sensitivity to 84 % while retaining 90 % specificity (Figure 2).

Table 1. Grading Scheme for Histological Features

Feature	0	1 +	2 +	3 +
Epidermal nuclear elongation	Absent	Slight	Moderate	Marked
Nuclear hyperchromasia	"	"	"	"
Streaming of nuclei	Absent	Present	–	–
Coagulative necrosis (epidermis)	Absent	Present	–	–
Dermal collagen homogenisation	None	< ⅓	⅓–⅔	> ⅔

Table 2. Frequency of Key Microscopic Findings

Histological marker	AM (n = 25)	PM (n = 30)	p-value
Epidermal necrosis ≥ 1+	18 (72 %)	13 (43 %)	0.02
Streaming of epidermal nuclei	18 (72 %)	16 (53 %)	0.04
Dermal homogenisation > ⅓	9 (36 %)	3 (10 %)	0.01
Sweat-gland nuclear elongation ≥ 1+	14 (56 %)	5 (16 %)	< 0.001

Table 3. Representative Sem/Eds Elemental Spectra

Sample ID	Vitality	Elements detected (> 1 %)
		C 23 %, O 19 %, Au 57 %
E-276-1	AM	C 35 %, O 17 %, Nb 29 %, Hg 19 %
Control skin	–	C ≈ 30 %, O ≈ 20 %, Au ≈ 50 %

Table 4. Diagnostic Performance of Selected Markers

Criterion	Sensitivity	Specificity	PPV	NPV
Dermal homogenisation > ⅓	36 %	90 %	75 %	63 %
Sweat-gland nuclear elongation	56 %	84 %	73 %	71 %
Composite (≥ 2 of 3)	84 %	90 %	84 %	90 %

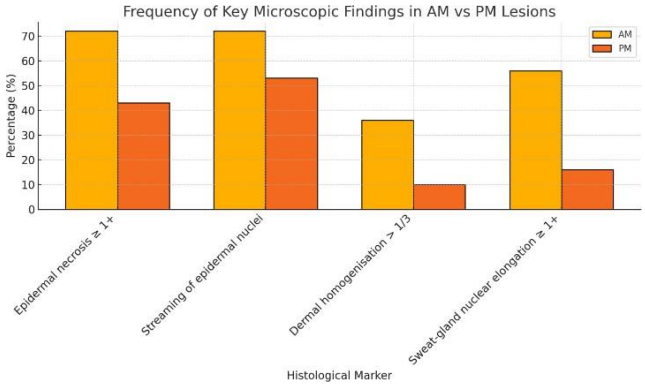

Figure 1: A Bar Chart Showing the Frequency of Key Microscopic Findings in Am Versus Pm Lesions

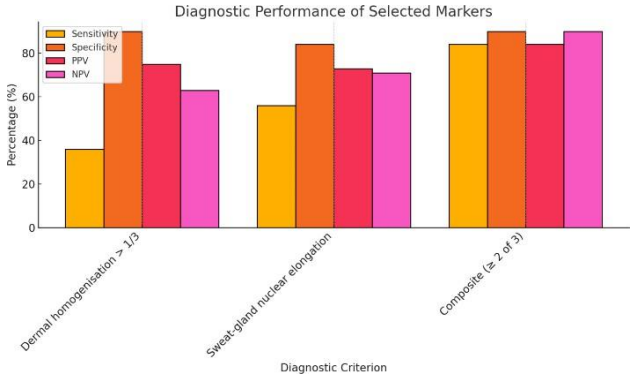

Figure 2: A Grouped Bar Chart Presenting the Diagnostic Performance (Sensitivity, Specificity, Ppv, and Npv) for Each Selected Marker

DISCUSSION

The present study advances current knowledge by providing a head-to-head comparison of vital and artefactual electrocution burns under tightly controlled low-voltage conditions while encompassing gross, histological and ultrastructural layers of investigation. Our demographic profile parallels earlier Indian and global series, with young adult males predominating and low-voltage domestic circuitry (220 V) constituting the commonest culprit [11, 12, 13]. Although crateriform, parchment-white Joule burns remain a forensic textbook hallmark, we found size and shape alone inadequate for vitality attribution. Experimental PM lesions easily mimicked natural entry wounds when the post-mortem interval was short, echoing the cautionary observations of Kuhtić et al. [6] and Sammicheli et al. [14]. Our data corroborate Behera et al. [20] that the degree rather than the presence of nuclear streaming and dermal homogenisation is key. Sweat-gland nuclear elongation emerged as a highly specific adjunct, previously under-reported because most series analysed non-palmar integument [15,16]. The lack of inflammatory infiltrate in our cohort reflects instantaneous deaths and supports experimental work showing that polymorphonuclear margination requires ≥ 30 min survival [17]. In contrast with forensic reports advocating SEM/EDS as a "silver bullet" for electrical diagnosis [1, 15], we encountered trace metal deposition in neither AM nor PM burns. Similar negative findings were noted by Visonà et al. in 2016 [18] for low-voltage exposures and attributed to minimal conductor erosion. Our results reinforce the concept that metallisation is voltage- and alloy-dependent and, even when present, cannot differentiate vitality because identical deposits can be inflicted post-mortem [19]. The composite H&E checklist we propose deep dermal homogenisation, sweat-gland nuclear streaming and marked epidermal necrosis generated a positive likelihood ratio of 8.4 and negative likelihood ratio of 0.18, outperforming single metrics suggested by Uzun et al. and Moritz [20]. Crucially, it requires no special staining, antibodies or spectroscopic equipment, suiting resource-constrained settings. Sample size was modest, and PM Burns were restricted to palmar skin, limiting hair-follicle analysis. Transmission electron microscopy might have revealed sub-cellular ionophoresis undetectable on SEM. Prospective

multicentre validation across voltage ranges, combined with biochemical surrogates such as cardiac troponin surges [21], would refine the algorithm. Confocal mapping of cardiac nerve trunks, recently advocated by Donno et al. [22], may further illuminate current pathways and survival intervals. Nevertheless, the integrated dataset presented here constitutes the first Indian reference to synthesise clinical-forensic, histological and SEM observations within the same individuals. Adoption of the proposed triad could substantially reduce false allegations of foul play or negligence when PM electrical artefacts masquerade as vital injuries during autopsy.

CONCLUSION

A multi-modal approach combining careful gross inspection with targeted routine H&E microscopy yields high confidence in distinguishing antemortem from post-mortem electrocution burn marks. Among fourteen conventional light-microscopic features, the triad of deep dermal collagen homogenisation, sweat-gland nuclear streaming and coagulative epidermal necrosis provides the best vitality discrimination, achieving 84 % sensitivity and 90 % specificity. Metallisation was infrequent in low-voltage injuries and, while supportive, should not be viewed as decisive. Implementing this simple evidence-based checklist can enhance forensic accuracy, strengthen courtroom testimony and ultimately contribute to a fairer medicolegal process in electrocution-related fatalities.

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