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Severe And Fatal Electrical Injuries In Babil, Iraq: A Retrospective Clinical-Forensic Reappraisal Of 41 Cases

Thamir M. Kadhim
Department of Pathology, College of Medicine, AL-Qadisiyah University

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Abstract

Overview: Electrical injuries are among the major causes of sudden death, severe physiological disturbances, and preventable accidents, making them a significant forensic and public health concern. Hence, it is essential to understand the epidemiological characteristics of electrical injury and the underlying injury mechanisms for better prevention strategies and forensic investigations.

Problem Background: Fatal electrocution has remained a challenge in areas with poorly integrated clinical documentation, electrical exposure assessment, and forensic investigations despite the advances in electrical safety and emergency medicine. Iraq provides valuable evidence of scenarios where inconsistencies in reported findings, limited sample sizes, and incomplete exposure information restrict scientific interpretation and generalizability of findings.

Research Contribution: This study critically re-examines all the reported electrical injury cases in the Babylon governorate, Iraq and revises the historical studies with regard to findings from epidemiological studies, pointing out inconsistencies; the study also proposes an integrated framework involving a forensic–clinical assessment that focuses on the systematic correlations of electrical exposure characteristics, physiological injury mechanisms, clinical outcomes, and post-mortem evidence.

Research Methodology: Data from 41 cases of severe electrical injury from May 2014 to May 2015 were aggregated for the retrospective descriptive reappraisal in this study. Reported frequencies and percentages were checked for consistency and correlated against relevant forensic research conducted between 2022 and 2026. A total of 28 males (68.29 %) and 13 females (31.71 %) were reported in the historical dataset. Thirty-seven cases (90.24 %) were exposed to low voltage, while 38 persons died (92.68%). The proposed framework was conceptually developed, as no predictive model was implemented or validated.

Conclusion: The predominance of reported low-voltage exposure was demonstrated within the selected severe-injury cohort; the study highlights the importance of standardised multidisciplinary forensic assessment. However, it is important that future studies improve data reliability, strengthen mortality assessment, and support evidence-based electrical injury prevention via implementation of multicenter investigations that integrate clinical, forensic, and electrical engineering evidence.

Keywords: Electrocution; Electrical injury; Forensic epidemiology; Mortality; Forensic pathology; Electrical safety; Iraq.

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1. Introduction

1.1 Overview

Electrical injuries continue to be a global preventable cause of morbidity and mortality with major public health, emergency medicine, and forensic pathology implications. Exposure to electricity can lead to several defects, ranging from mild burns and transient neurological responses to moderate and exacerbated tissue damage, cardiac arrhythmias, respiratory arrest, and death. The severity of these injuries is mostly predicted by factors such as voltage, current, exposure time, current pathway, tissue resistance, and environment [1][2]; thus, the effects of contact with electricity on a patient cannot be ascertained just by knowing the voltage or the nature of external apparent damage [3]. Electrical accidents can happen in a household, workplace, or industrial setting; electrical shock can cause severe thermal injuries, in addition to electrolyte system involvement. It is pertinent to note that even low voltage can cause fatal physiological effects on patients, especially if it passes through the thoracic region. Lightning injury is another type of electric trauma that involves high energy exposure for a very short time, and may be serious with cardiovascular and neurologic effects. Hence, it is important to consider the type of electrical contact and the physiological mechanism of the exposure when determining severity, and not just define the injury by voltage [4][5].

Cases of death from electrocution are mostly difficult to establish through forensic studies; electrical contact marks may provide important diagnostic evidence in such cases, but their appearance varies, and may sometimes be absent in fatal cases. Hence, accurate forensic interpretation in cases of electrocution requires the integration of incident circumstances, clinical documentation, external and internal postmortem findings, and supplementary investigations [6][7]; such multidisciplinary assessment is essential for distinguishing electrical fatalities from other causes of sudden death and improving the reliability of medicolegal conclusions.

1.2 Problem Background

The need to consider geographical, environmental and occupational background when investigating electrical injuries has become necessary considering that electrical injury vary in fatality level across cases and geographical regions. For instance, in Türkiye, an autopsy-based study of 386 electrocution fatalities reported that most of the cases involved male victims mostly due to the nature of their occupation [1]. Another study in Saudi Arabia revealed that the occupational hazards remains an important factor in electrocution-related deaths [2]. The role of multi-disciplinary investigation into cases of electrocution fatalities has also been emphasized; for instance, the applicability of forensic engineering in the study of electrical mortality was reported by Alqassim et al. [6], whereas Askar et al. [7] discussed suit-ups for further forensic diagnostic techniques in the postmortem stage of suspected electrocution death. Evidently, medical and technical evidence might provide useful information for a more accurate reconstruction and interpretation of an electrical incident; however, in local communities, like Babil province Iraq, historical investigations might be a reliable source of information for evaluating electrical injuries. For example, a study carried out between May 2014 and May 2015 in Babil province found a total of 41 severe electrical injuries, 68.29 %, encompassing males and 31.71 % females. The number of reported cases was 37, 2, and 2 for low voltage, high voltage, and lightning cases, respectively, in 90.24 % of the cases; 38 deaths and three survivors were also noted, suggesting a significant concentration of fatal outcomes within the selected area. However, these findings require careful interpretation as the source case series primarily included severe and fatal electrical injuries, meaning that the observed case-fatality proportion does not represent the mortality risk among all electrically exposed individuals. Furthermore, discrepancies between reported percentages and case counts, together with incomplete exposure documentation, limit the reliability of certain descriptive findings. Hence, a critical scientific reappraisal using contemporary principles of forensic epidemiology and evidence-based interpretation remains a necessity.

1.3 Problem Statement

While the advancement of forensic medicine and electrical injury research has improved understanding of the mechanisms of fatal electrical exposures, some physiological, methodological and diagnostic limitations still hinder accurate interpretation. Medical and forensic records are often used for non-standardised epidemiological studies and research, and are frequently used in retrospective investigations; therefore, the actual current, the contact, the time of contact, the electrical pathway, and the characteristics of the equipment and the environment may not be available or documented. These are portrayed in the instances of cases in Babil where data may be useful and descriptive, but there is still concern

with data consistency within the study, evidenced by inconsistencies in data reported as regards the proportion of low-voltage injuries, seasonal incidents, and the proportion of electrical contact marks.

Furthermore, there is a lack of detailed individual-level clinical and forensic data to consider the associations of exposure characteristics, injury severity, emergency treatment and survival. Another restriction is the interpretation of death; there are only 41 selected cases, of which three survived; so, this data is not sufficient for building a reliable multivariable mortality prediction model. Again, the high death rate is a consequence of the kinds of injuries that were sampled, not a true reflection of the overall death rate due to electrical exposure in the population of the entire country. A lack of understanding between these terms can result in misconceptions about electrical injury hazards [8].

Regarding forensic diagnosis, the electrical contact lesions can be non-existent, non-specific, or ambiguous in determining the circumstances through direct examination of the lesion, and this is a serious limitation [6, 7]. So, isolated clinical or postmortem findings alone may not provide a sufficient explanation of the relationship between exposure to electricity and the outcome. Therefore, the central research problem is the limited consistency and integration of epidemiological, clinical, electrical exposure, and forensic information in the assessment of severe and fatal electrical injuries.

1.4 Research Aim

The clinical, forensic, and epidemiological features of severe electrical injury records in Babil Governorate, Iraq are re-evaluated in this study in a bid to develop an integrated forensic–clinical framework for aligning/streamlining the outcome of investigations of electrical injuries in the studied region.

Specifically, the study aims to:

Discuss demographic profiles, voltage classifications, anatomical injury distribution, time trends and clinical outcomes reported in the source case series.

Detect numerical inconsistencies and methodological flaws, ascertain verifiable results from information under further confirmation, and contextualise historical observations employing appropriate sources in the forensic field published in the period 2022-2026.

Establish a conceptual framework to connect all the components of electrical exposure characteristics, mechanisms of physiological injury, clinical presentation, post-mortem findings, and documented outcomes; the proposed process is a continuation of the multidisciplinary principles of recent forensic investigations and forensic engineering diagnostic studies.

Identify priorities for future multicenter research, including standardised electrical injury registries, improved integration of emergency and forensic records, and the potential application of explainable artificial intelligence when sufficiently large and representative datasets become available.

Note that the proposed framework is conceptual, as neither clinical validation nor predictive model development is claimed as a completed component of the present study.

2. PROPOSED METHODOLOGY

2.1. Research Design and Methodological Overview

This research is a retrospective descriptive and methodological study, aimed at reassessing the past electrical injury observations in terms of mortality and severity in Babil Governorate; the study further builds a structured framework that integrates clinical, forensic and electrical-engineering evidence. The methodology includes two main steps: i) secondary quantitative evaluation of reported aggregate observations, and ii) conceptualisation of an integrated forensic–clinical evaluation framework. The empirical component is composed of 41 case-severity cases of electrical injury collected from May 1, 2014 to May 1, 2015; frequencies are extracted, percentages are calculated separately, and inconsistencies are noted. The conceptual aspect introduces five stages of evidence assessment. No new patient-level data, laboratory measurements, or validated predictive models are claimed. Reporting principles for observational research are considered [9].

The research is a secondary audit of published historical aggregate case series and a different proposal of a conceptual framework; the reporting unit is a published category count, not an independently observed patient. Hence, this study does not estimate incidence, exposure-specific risk, causal effects, or diagnostic performance; the proposed framework was not applied to individual cases.

2.2 Study Setting, Population, and Data Sources

The historical investigation used observations from Babil Governorate, Iraq, Al-Hilla Teaching Hospitals, and the Babil Health Directorate, Department of Forensic Medicine. According to the source syndromic series, there were 41 severe electrical injury cases reported, and 38 of these were fatal; these included clinical observations, descriptionss of exposure to electricity, external lesions, autopsy information, and some laboratory studies. The present reappraisal relies exclusively on the historical source report as a a source of empirical data; no individual records or electrical measurements were available, nor were there detailed laboratory data orcross-tabulations. Thus, the unit of analysis is the reported aggregate series,, and there is no estimation of fatality risk at the population level nor of incidence at the level of one population member. From the accessible source, it was not possible to determine the historical sampling frame, case ascertainment procedure, referral pathway and complete inclusion and exclusion criteria. In fact, the 41 cases should be considered as a selected series (or selected population-representative) rather than a consecutive or population-representative set. No unreported eligibility criteria are inferred.

2.3 Data Extraction and Variable Organisation

A structured extraction sheet is used to categorise variables into five categories:

Demographics (sex, age group, occupational circumstance as stated);

Electrical exposure (voltage class, lightning, circumstances involved);

Anatomical and forensic findings (sites of contact marks: for mostly exposed patients only the locations of contact marks are listed; in the absence of contact marks only the electronic unconscious state of the body can be described categorically; associated injuries, including injuries to the body which are not caused by the electrical exposure; autopsy observations, including the absence of any contact marks or anticipated findings;

Temporal and environmental characteristics (season, time of day);

Clinical outcomes (resuscitation, need for hospitalisation, survival, and death).

The frequency, percentage, denominator and manuscript location are shown for every variable. When classification is made by the source, the categories are maintained instead of being re-categorised in an after-the-fact fashion. What is most important is that each category will be kept, as will the source section, the literal category label, the reported numerator, explicit or inferred denominator (indicated as such), the reported percentage, the recomputed percentage, and the audit disposition. These denominators are only used when the source is clearly a classification at the individual case standing level (e.g., 41 cases of patients), and subgroup denominators (individual patients receiving hospital care) are kept separate.

When a source statement contradicts others, it is coded “unresolved contradiction” (not zero), not when one statement contradicts another. “Unresolved contradiction” is coded to a source statement when a source statement contradicts other statements, rather than another source statement (not zero). The supplementary audit register providing count-level checks has been provided in the Appendix. Note that no independent duplicate extraction was carried out.

2.4 Descriptive Statistical Analysis

The proportion of category *i* expressed as a percentage is computed as:

$$P_{\mathrm{i}} = \frac{n_{\mathrm{i}}}{N_{\mathrm{i}}} \times 100, \quad (1)$$

Where

n_i = the reported count in category *i*

N_i = its applicable denominator.

Count consistency is examined for mutually exclusive and collectively exhaustive classifications through:

$$\sum_{\mathrm{i}=1}^{\mathrm{k}} n_{\mathrm{i}} = N, \quad (2)$$

Where

k = the number of categories

N = the classification total.

The selected-sample case-fatality proportion (CFP) is defined by:

$$CFP = \frac{D}{N} \times 100, \quad (3)$$

Where

D = deaths

N = all selected cases.

Applied to the historical series:

$$CFP = \frac{38}{41} \times 100 = 92.68\%. \quad (4)$$

The CFP is a descriptive proportion within a selected severe-injury series, not a population mortality rate or probability of death following exposure. There is no inferential hypothesis testing or multivariable analysis because of the unavailability of individual-level predictors and outcome cross-tabulations.

2.5 Numerical Consistency and Data Quality Verification

The computation of the reported and independently recalculated percentages is performed using the absolute percentage-point discrepancy:

$$\Delta_i = |P_i^{(\text{reported})} - P_i^{(\text{calculated})}|. \quad (5)$$

Where discrepancies greater than the precision attributable to rounding are flagged; for instance, 37/41 low-voltage cases correspond to 90.24 %, and 34/41 summer cases correspond to 82.93 %. A tolerance level of 0.05 is allowed for percentages reported in one decimal place, while for percentages displayed in two decimal places, differences of at most 0.005 percentage points are rounded to the nearest hundredth. The aggregate-data extraction and consistency verification scheme is represented in Algorithm 1.

Algorithm 1. Aggregate-Data Extraction and Consistency Verification

Input: historical manuscript; reported frequencies, percentages, and denominators. Output: verified descriptive table and discrepancy register.

1. Identify each reported categorical variable and locate its source statement.

2. Extract category frequencies, percentages, and applicable denominators.

3. Recalculate percentages using (1) and check exhaustive totals using (2).

4. Compute discrepancies using (5); flag differences beyond rounding precision.

5. Record contradictory counts, missing denominators, and unclear definitions.

6. Preserve unresolved discrepancies; do not reconstruct unavailable patient records.

7. Export the audited descriptive table and discrepancy register.

2.6 Proposed Integrated Forensic–Clinical Assessment Framework

Five evidence domains are combined in a sequential but iterative assessment process in this framework; the aim is to organise multidisciplinary findings and document uncertainty, not replace forensic judgment or professional clinical judgment.

Stage I: Electrical Exposure Characterisation: The suspected electrical source, voltage classification, current type, contact duration, potential current pathway, equipment characteristics, and environmental circumstances are recorded in this stage; voltage alone does not establish body current or physiological severity.

Stage II: Physiological Injury Assessment: Assessment of the cardiac, neurological, respiratory, thermal, and mechanical injury mechanisms is performed in this stage. No mechanical explanations are provided here unless based on clinical, technical, or pathological evidence.

Stage III: Clinical Presentation and Outcome Assessment

Consciousness, cardiovascular and respiratory status, initial rhythm where documented, resuscitative intervention, hospitalisation, and outcome are organised at this stage; any missing observation is explicitly identified.

Stage IV: Forensic and Engineering Investigation: Scene information, autopsy, histopathology, external examination, toxicology, and electrical-equipment assessment are integrated in this stage when available. Possible electrocution is not excluded only based the absence of a visible electrical mark [6] [7].

Stage V: Evidence Reconciliation and Uncertainty Assessment: The available information (clinical, forensic, and engineering) is evaluated to produce a reliable multidisciplinary interpretation.

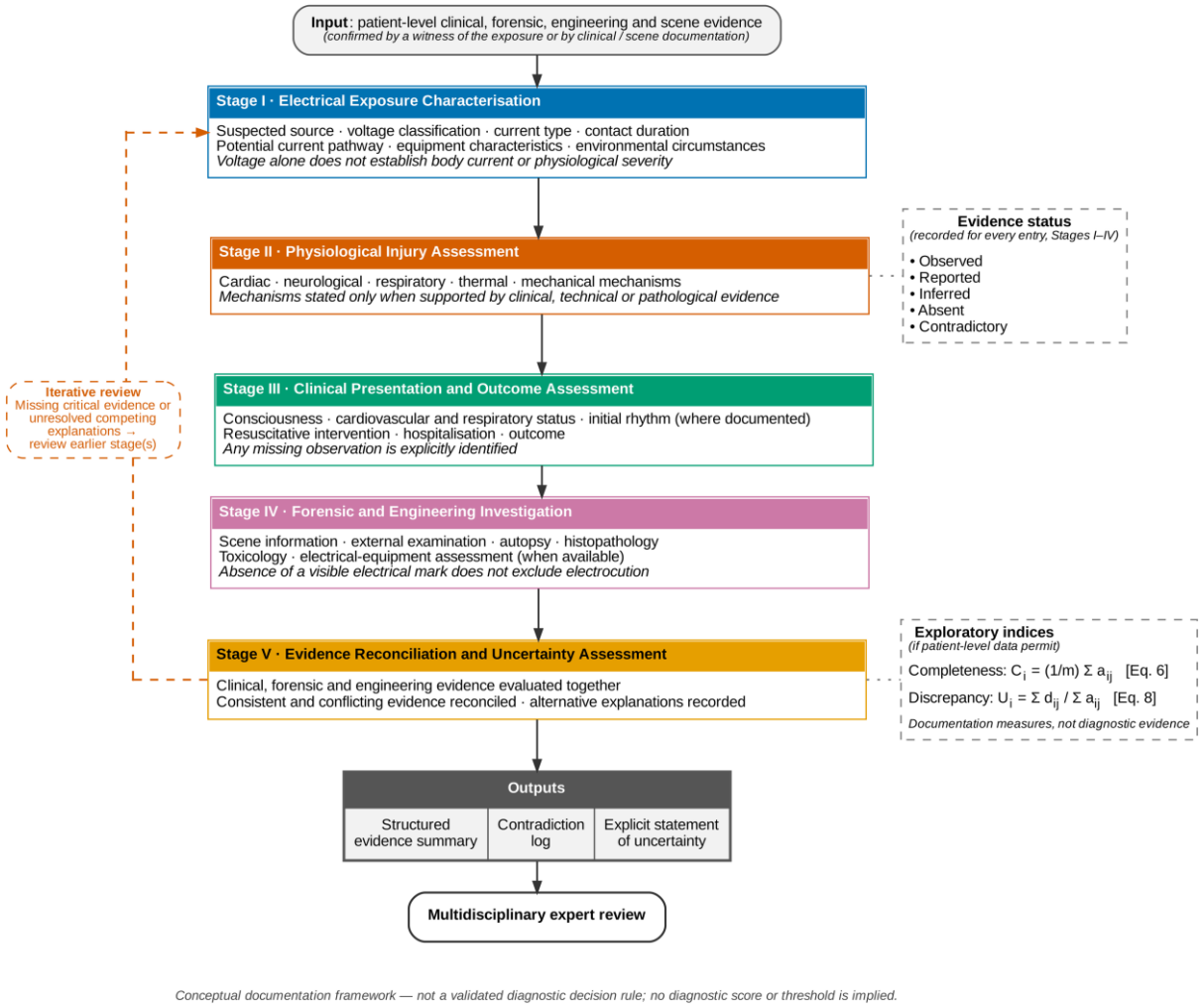


Figure 1. Proposed integrated forensic–clinical assessment framework

Framework status and workflow rules:

The proposed framework is not a validated decision rule to diagnose the electrical exposure but only a proposed documentation process with five steps; entries are based on confirmation from either a party that witnessed the exposure, or recorded documentation in the clinical or scene setting. Evidence is noted as observed, reported, inferred, absent, or contradictory; cases of missing critical evidence or unresolved competing explanations demands review of earlier stage(s). No diagnostic score or required decision threshold are claimed, only a structured evidence summary, a contradiction log, and a clear statement of uncertainty.

2.7 Proposed Quantitative Assessment of Evidence Completeness and Consistency

For potential patient-level implementation, a binary evidence-availability indicator a_{ij} is defined for item j in case I; an exploratory evidence-completeness index is:

$$C_i = \frac{1}{m} \sum_{j=1}^{m} a_{ij}, \quad a_{ij} \in \{0, 1\}, \quad (6)$$

Where

m = the number of prespecified evidence items,

$a_{ij} = 1$ indicates available documentation,

$a_{ij} = 0$ indicates unavailable documentation.

Therefore,

$$0 \leq C_i \leq 1. \quad (7)$$

A proposed discrepancy index to quantify identified inconsistencies among available evidence is defined as:

$$U_i = \frac{\sum_{j=1}^{m} d_{ij}}{\sum_{j=1}^{m} a_{ij}}, \quad \sum_{j=1}^{m} a_{ij} > 0, \quad (8)$$

Where

$d_{ij} = 1$ denotes a predefined inconsistency in an available item

$d_{ij} = 0$ otherwise, subject to $0 \leq d_{ij} \leq a_{ij}$.

Thus,

$0 \leq U_i \leq 1$.

These indices quantify the completeness of documentation and identified inconsistency, not diagnostic evidence. These indices were not computed for the historical cases due to unavailability of patient-level evidence inventories. The indices presented below are only for illustrative specifications and for future protocol development; a minimum evidence-item dictionary, assessor instructions, applicability rules, and a list of mutually exclusive contradiction conditions must be specified by the investigators before implementation, and non-applicable items must be removed from the denominator, not scored as missing. Assessment of discrepancy must only occur when relevant evidence is available and comparable, no index is to be interpreted as a probability of correct diagnosis, prospective testing must be done for item weighting, interrater reliability, and clinical utility.

2.8 Proposed Explainable Artificial Intelligence Extension

If there is a large and representative patient level dataset, an explainable predictive extension may be considered based on predictors like demographics, electrical exposure, clinical findings, resuscitation information, and forensic observations. A generic model is represented as:

$$\hat{p}_i = f\theta(x_i), \quad (9)$$

Where

x_i = the predictor vector,

θ = model parameters,

$\hat{p}_i$ = predicted probability of a prespecified binary outcome.

An interpretable logistic regression baseline is given as:

$$\hat{p}_i = \frac{1}{1 + exp[-(\beta_0 + \beta^T x_i)]}. \quad (10)$$

Ridge-penalised binary cross-entropy may be minimised for a dataset of *n* independent observations as follows:

$$\beta = arg\ min\beta_0, \beta \{ -\frac{1}{n} \sum_{i=1}^{n} [y_i\ ln(\hat{p}_i) + (1 - y_i) ln(1 - \hat{p}_i)] + \lambda \|\beta\|^2_2 \}. \quad (11)$$

Where

$y_i \in \{0,1\}$ = outcome status,

β_0 = unpenalized intercept,

β = coefficient vector,

$\lambda \geq 0$ controls regularisation.

Adequate sample-size justification, missing-data management, leakage prevention, calibration assessment, and external validation would be required in future studies, with reporting guided by TRIPOD+AI [10]. For this historical dataset, no model training, predictive accuracy, or validation metrics are claimed [11] [12]. The logistic formulation is not a novel algorithm; rather, it is a conventional illustrative baseline. The considered dataset (41 aggregate cases; three survivors) is not enough to fit a model, estimate outcome discrimination, or perform external validation; a pre-specified outcome and prediction time point may be needed for future models [13].

2.9 Proposed Research Workflow

As presented in the proposed workflow, completed secondary reappraisal is differentiated from future, conceptual and validation activities, which yield descriptive reappraisal results in terms of literature contextualization and the proposed integrated framework **(see Figure 2)**.

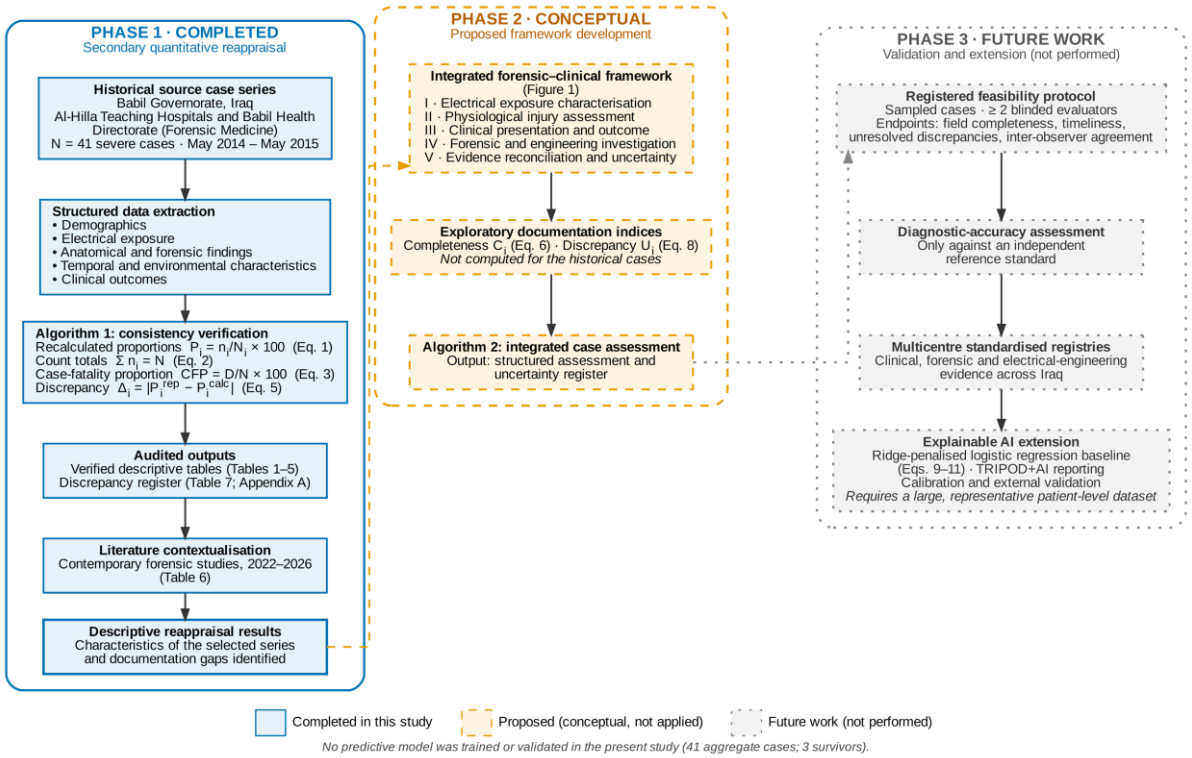


Figure 2. Overall research methodology workflow; proposed validation remains future work.

Algorithm 2. Proposed Integrated Case Assessment Procedure

Input: patient-level clinical, forensic, engineering, and scene evidence. Output: structured assessment and uncertainty register.

1. Register exposure circumstances and electrical-source characteristics.

2. Identify plausible physiological mechanisms without assuming causation.

3. Document clinical presentation, interventions, and outcome.

4. Compile forensic, pathological, and engineering findings.

5. Identify missing evidence and calculate C_i using (6), if data permit.

6. Apply prespecified discrepancy criteria and calculate U_i using (8), if defined.

7. Reconcile consistent and conflicting evidence; record alternative explanations.

8. Produce an integrated assessment for multidisciplinary expert review.

2.10 Proposed Framework Validation Strategy

Cases from both clinical, forensic, and engineering institutions are needed for future validation efforts; they are also needed to pre-specify evidence variables and operational definitions, to validate inter-observer agreement and feasibility, and to determine if the framework will enhance documentation and consistency of expert evaluation. Diagnostic performance should not be assessed without an appropriate independent reference standard; a new protocol for validation is needed for any predictive-model development [14].

The future validation of the framework should start with a registered feasibility protocol which is carried out using sampled cases and at least 2 blinded evaluators. Completion and timeliness of required fields, frequency of unresolved discrepancies, as well as inter-observer agreement, should be included in the primary feasibility endpoints. An independent reference standard, on which to defend the diagnosis, is necessary for any diagnostic accuracy study; without an independent reference standard, process outcomes only should be reported. Thresholds for acceptable agreement/completeness need

to be set prospectively, not inferred from reviewing the outcomes.

2.11 Ethical Considerations, Limitations, and Reproducibility

In this reappraisal, already published observations are aggregated and used without involving patient records or recruitment of participants that can be identified; there is no ethics approval identifier for the historical source report, and no ethics approval for this report is claimed. The major limitation is that patient-level data is not available, as well as variable definition differences and varying historical statements. Count extraction, denominator definitions, re-calculated percentages and discrepancy records are maintained to ensure reproducibility. The conceptual framework and indices, and the AI extension, are not validated.

3. RESULTS AND DISCUSSION

3.1 Demographic Characteristics of Electrical Injury Cases

The retrospective descriptive reappraisal in this study included 41 cases of severe electrical injuries recorded in Babil Governorate, Iraq from May 2014 to May 2015; this data on demographic variables is summarized in Table 1, where the number of males was 28 (68.29 %) and that of females was 13 (31.71 %), giving a male-to-female ratio of 2.15:1. The age distribution of the population ranged from < 12 years to 52 years, and most of the people (75.61 %) aged between 12 and 52 years. The source case series did not contain information to further stratify by individual age or individual type of exposure, or detailed enough on occupation to allow for further stratification.

Table 1. Demographic characteristics of the historical electrical injury cases (N = 41).

Characteristic	Number	Percentage (%)
Male	28	68.29
Female	13	31.71
Age below 12 years	10	24.39
Age 12–52 years	31	75.61
Total	41	100.00

It is expected that male gender will predominate cases of electrocution deaths possibly due to occupational risks [1][2]; however, in Babil, there are more reports of female cases (almost a third of the selected population), suggesting that the characterization of electrical injury prevention as a working condition for men only, needs to be revisited. It is also noteworthy that childhood electrical exposures may have been a significant component of the historical series as a quarter of case patients were under 12 years of age. Potential domestic hazards, such as electrical equipment that is not safe, electrical outlets that are easily accessible, and exposed wiring, offer plausible areas for prevention. However, the data aggregated to date are insufficient to define exposure circumstances of these children and develop a specific mechanism for household exposure from available data. These demographic results should be interpreted as characteristics of the selected severe-injury series rather than estimates of electrical injury incidence within the general population.

3.2 Electrical Injury Characteristics

The classification of electrical injuries based on source case into low-voltage exposure, high-voltage exposure, and lightning-related injury is presented in Table 2, together with their respective frequencies and recalculated percentages.

Table 2. Distribution of electrical injury cases by exposure classification (N = 41).

Electrical exposure	Number	Percentage (%)
Low voltage	37	90.24
High voltage	2	4.88

Lightning	2	4.88
Total	41	100.00

Low voltage exposure was the largest category of exposures, with 37 cases, or 90.24 %; two cases involved high voltage (4.88 %) and lightning (4.88 %) injuries. The high occurrence of low-voltage exposure is an important descriptive observation as it indicates that severe and fatal outcomes were documented in association with sources classified as low voltage. However, this does not suggest that low-voltage exposure is as critical as high-voltage exposure, nor does it prove that the risk from low-voltage exposure is greater than that from high-voltage exposure; exposure-specific population denominators, standardised injury definitions, and detailed clinical outcomes would be needed to make such conclusions. The historical source report did not provide the measured current intensity during the contact, the duration of contact, the electrical pathway, or detailed information on the conductivity of the environment; thus, reliable reconstruction of physiological mechanisms leading to individual effects is impossible. There are multiple factors that influence the severity of electrical injury, including electrical source characteristics, tissue resistance, duration of exposure and current pathway.

Forensic research has recently emphasised the combination of pathological and technical evidence during evaluation of electrical fatalities rather than relying exclusively on voltage classification [6] [7][15]. A further issue concerns the numerical inconsistency between the source report's abstract and results; although the abstract reported 95.12 % low-voltage exposure, the results section documented 37 cases among 41 individuals, giving a recalculated percentage of 90.24 %; this discrepancy is addressed as part of the data-quality assessment in Section 3.8 (Table 7).

3.3 Anatomical Distribution of Electrical Contact Sites

The source case series reported electrical injury locations involving the upper extremities, lower extremities, chest, and head, together with cases in which no visible electrical lesion was recorded (see Table 3).

Table 3. Anatomical distribution of reported electrical injury sites (N = 41).

Anatomical location	Number	Percentage (%)
Upper extremities	20	48.78
Lower extremities	9	21.95
Chest	6	14.63
Head	4	9.76
No visible lesion	2	4.88
Total	41	100.00

The most common anatomical category observed was upper extremity (20 cases, 48.78 %); nine injuries (21.95 %) occurred in the lower extremities, six (14.63 %) involved the chest, and four (9.76 %) involved the head. The distribution is consistent with the possibility that a significant number of incidents were caused by direct hand-to-hand contact with energised electrical equipment. However, it was not possible to establish from the source case series the exact mode/way of contact or direction of electrical flow. Chest and head lesions are clinically and forensically relevant as these anatomical sites can have potentially important physiological consequences. The location of a lesion on the body, however, does not necessarily indicate the existence of the current lesion, or the mechanism of death. Two cases (4.88 %) were classified in the anatomical distribution of the source report as having no visible electrical lesion; this finding corroborates the forensic concept that the absence of any of the signs or marks of an external origin does not rule out electrical injury. Forensic analysis of electrical contact injuries often focuses not only on the incident circumstances, scene findings, autopsy observations, and

technical analysis, but also combines all these aspects [6], [7]; it is also noteworthy that the results section of the source report highlighted electrical absence in only a single instance while the anatomical distribution and discussion sections reported electrical absence in two instances. The discrepancy will need to be addressed by checking the original records; thus, the reported number from the anatomical table is two.

3.4 Temporal and Environmental Patterns

The historical study documented substantial seasonal and daytime concentrations of electrical injury cases; of the 41 reported incidents, 34 occurred during summer (82.93 %), whereas seven occurred outside the summer category (17.07 %). The source-reported results described these seven incidents as occurring in winter, without presenting a complete four-season classification. Thirty incidents (73.17 %) occurred during daytime, while the remaining 11 (26.83 %) occurred outside the daytime category (see Table 4).

Table 4. Seasonal and temporal distribution of electrical injury cases (N = 41).

Characteristic	Number	Percentage (%)
Summer	34	82.93
Other reported season	7	17.07
Daytime	30	73.17
Non-daytime	11	26.83

One of the most significant findings was the number of incidents in the summer, the spring-summer transition period; several possible environmental factors could have contributed, such as more use of electrical equipment, exposure to cooling systems, and more contact with the electrical infrastructure at high temperatures. The power source investigators also discussed potential hazards and risks presented by alternate electric power sources; the historical data, however, failed to have measurements at the case level that characterise the interruption in electricity supply, exposure to generators, or environmental conditions. Therefore, these explanations are only hypotheses for the observed seasonal distribution and do not constitute causative explanations. Additionally, the high number of daytime events may be associated with the higher likelihood of exposure during routine household and/or work activities; however, the conclusion of an increased risk of injury during the day may need some basic information regarding the amount of time spent in activities and the number of people exposed. Nevertheless, without detailed information on the time spent in different activities or the number of individuals exposed, the observed distribution cannot establish a higher daytime injury risk.

The source report's abstract reported that 92.68 % of incidents occurred during summer, whereas the results section documented 34 cases, corresponding to 82.93 %; the latter percentage is arithmetically consistent with the reported count and denominator. Hence, there is a need to consider location, activity, and electrical source information in any future electrical injury surveillance system, especially if seasonality or time is also included.

3.5 Clinical Outcomes, Hospitalisation, and Resuscitation

The historical investigation revealed that of 41 selected severe electrical injury cases, 38 (92.68 %) were deaths and three were survivors; there are five hospitalized, of these three are survivors and two later died; the remaining 36 died at the scene or on hospital arrival (see Table 5).

Table 5. Clinical outcomes of the historical severe electrical injury cases.

Outcome	Number	Percentage (%)
Deaths	38	92.68
Survivors	3	7.32
Hospitalized	5	12.20

Not hospitalised / dead before admission	36	87.80
Deaths among hospitalised patients	2 of 5	40.00
Survivors among hospitalised patients	3 of 5	60.00
Received resuscitative measures	15	36.59

When interpreted without considering the influence of the sampling characteristics of a particular study, the overall case fatality ratio is unusually high in the present instance, but the present case series concerned only electrocution injuries of the severe type, involving many deaths before admission to the hospital. Thus, the observed proportion represents a considerable selection towards fatal outcomes. No inferences should be made as to the risk of death with electrical exposure in the broader community, or that the 2 cohorts from emergency departments with lower-level injuries would have the same survival rates. Observed mortality proportion in hospitalized group is 40.00 % (n=5), which is not a reliable estimation of prognosis for the hospitalized group. Furthermore, historical source reports lack detailed information on initial physiological status and severity of the injury, electrocardiographic findings, treatment time, and associated comorbidities. There were reported 15 cases (36.59 %) where resuscitative measures were used, but those cases did not appear on the aggregated data, so could not be aggregated by survivor or non-survivor status. Therefore, conclusions on 'curso-relationship' (resuscitation being associated with better survival) cannot be drawn, nor can differences in treatment timing be attributed to the recorded outcome. The historical findings, however, do confirm that emergency response documentation is an important priority for future research; additional future investigations would be clinically beneficial if the interval between exposure and initial medical contact, initial cardiac rhythm, resuscitation time and response to treatment were recorded [16].

3.6 Forensic Findings and Interpretation of Fatal Outcomes

Cardiopulmonary arrest following electrical injury was reported as the direct cause of death in the source case series, and the reported fatalities were accidental. Cardiopulmonary arrest, in itself, is not forensically a diagnosis of the underlying physiological mechanism that caused the arrest. Severe thermal injury, cardiac rhythm disturbance, and respiratory compromise are potential lethal processes associated with electrical exposure. In the individual cases of death, however, the historical source report was not adequate to establish an individual mechanism, because of the absence of patient-level electrocardiographic and pathological data. Therefore, the present evaluation does not retrospectively classify deaths as ventricular fibrillation, asystole, respiratory paralysis, or another specific initiating event.

Additionally, no signs of the intake of alcohol or drugs was observed in the source cases of the individual cases analyzed; the presence of alcohol/drugs, however, does not control or establish the manner of death in itself. This classification should instead depend on a combination of the circumstances of the incident, scene investigation, medical information and post-mortem findings. The lack of electrical contact marks, which has led to conflicting findings, further underscores the significance of integrated forensic evaluation. Scene investigation and ruling out alternative causes are especially insightful when there are ambiguous or missing feature of the skin lesions. As per Alqassim et al. [6], forensic engineering has contributed significantly to the investigation of electrical death; Askar et al. [7] discussed supplementary diagnostic approaches; these studies support the rationale for a multidisciplinary interpretation of suspected electrocution deaths. However, the present historical reappraisal does not demonstrate the diagnostic performance of these approaches, but identifies deficiencies in the available documentation that the proposed framework intends to address.

3.7 Comparison with Contemporary Forensic Research

The demographic, occupational, and forensic characteristics of electrocution fatalities have been investigated recently; for instance, Doğan et al. [1] investigated an autopsy-based case involving 386 electrocution-related deaths in Türkiye; the study showcased the relevance of a substantially larger medicolegal dataset for such a study. Furthermore, Al Bayat et al. [2] examined electrocution-related fatalities in eastern Saudi Arabia over 24 years, covering a wider observation period than the historical Babil investigation. Alqassim et al. [6] and Askar et al. [7], on the other hand,

focused on forensic diagnostic and investigative approaches rather than population-level injury distributions (see Table 6 for a summary of these studies)

Table 6. Methodological comparison between the Babil reappraisal and selected contemporary studies.

Study	Setting and design	Main relevance to the present study
Present reappraisal	Iraq; 41 selected cases; historical aggregate-data assessment	Numerical verification and conceptual integration
Doğan et al. [1]	Türkiye; 386-case autopsy-based investigation	Larger forensic dataset and medicolegal characterization
Al Bayat et al. [2]	Saudi Arabia; 24-year retrospective autopsy study	Long-term epidemiological and forensic investigation
Alqassim et al. [6]	Forensic engineering case reports	Technical evidence in electrocution diagnosis
Askar et al. [7]	Forensic diagnostic case study	Supplementary approaches to diagnostic interpretation

Variations in the sampling frames, inclusion criteria, observation periods, and availability of clinical information prevented direct numerical comparisons of mortality, voltage distribution, and anatomical injury patterns. For instance, the autopsy-based studies focused on fatal cases, whereas the Babil series included both fatal cases and a small number of survivors. The proportions derived from these different study populations are therefore not directly interchangeable. However, the contemporary literature provides methodological support for improving the integration of clinical, forensic, and electrical engineering evidence.

3.8 Statistical Interpretation and Data Consistency

In this work, statistical reappraisal was only on the descriptive measures derived from the published aggregate findings; the available data permitted recalculation of percentages and assessment of numerical consistency. Meanwhile, relationships between electrical exposure, anatomical injury location, resuscitation, demographic characteristics, and survival cannot be tested due to lack of patient-level cross-tabulations (see Table 7).

Table 7. Numerical discrepancies identified in the historical source report.

Variable	Source-report abstract	Source-report results	Reappraisal
Low-voltage exposure	95.12 %	37/41	90.24 %; count-supported
Summer incidents	92.68 %	34/41	82.93 %; count-supported
Cases without electrical marks	Not specified	One case in diagnostic text; two in anatomical distribution	Requires author verification
Early-morning high-voltage cases	Not specified	Four mentioned, despite two total high-voltage cases	Requires author verification

It is evidently important to verify counts, denominators, and narrative statements before making conclusions based on historical data. Again, the reappraisal does not assume that all variations are only arithmetically rectifiable; for

instance, the corresponding percentage can be recalculated where the underlying count is clearly available, but where there are varying counts or definitions, only the original records can be referred for any corrections. No new inferential statistics, regression coefficients, confidence intervals, or machine-learning performance estimates were generated. Therefore, the results support descriptive characterization and identification of reporting limitations, but do not establish independent predictors of death or causal relationships between exposure features and clinical outcomes.

3.9 Interpretation of the Proposed Integrated Framework

The fragmented documentation identified during the historical reappraisal was addressed by the proposed integrated forensic–clinical framework described in Section 2.6 (Figure 1); there are five components of the proposed approach:

The first component emphasises systematic characterisation of electrical exposure. The importance of this stage is showcased by the absence of reliable measurements of current intensity, contact duration, and current pathway in the historical study.

The second component considered physiological injury mechanisms, as well as the need for clear separation between documented observations and plausible explanations.

The third component paid attention to clinical presentation and outcomes, including hospitalisation, initial cardiac rhythm, resuscitation, and survival; this responds to the limited treatment-related information available in the historical records.

The fourth component integrates forensic pathology and electrical engineering investigation; such integration is particularly relevant when electrical contact marks are absent or when scene evidence is necessary to establish the circumstances of exposure.

The fifth component reconciles findings across domains and explicitly documents uncertainty.

The proposed framework provides a structured approach for future investigations, but its effectiveness has not been tested in the present study; no improvement in diagnostic accuracy, interobserver agreement, clinical outcomes, or forensic decision-making can therefore be claimed. The contribution of the framework is merely conceptual and methodological; it identifies the categories of evidence that should be collected and evaluated together in future research.

3.10 Clinical, Forensic, and Public Health Implications

There are several implications for electrical injury investigation and prevention based on historical observations:

The predominance of low-voltage cases indicates that prevention programs should address electrical hazards beyond industrial high-voltage installations; domestic electrical safety, equipment maintenance, appropriate insulation, and public awareness are relevant areas for future intervention.

Case definitions must be standardized as there are many numerical discrepancies in the historical manuscript; data must be transparently reported and audit records must be accessible.

Most of the cases happened during summer, hence, there may be a need for seasonal surveillance; relationship between seasonal patterns and specific environmental or infrastructure-related hazards also demands further investigation

The proportion of children within the selected sample supports attention to age-appropriate electrical safety education and the prevention of accidental childhood exposure.

Pre-hospital emergency response requires review as there are many cases of pre-hospital admission deaths; available data lacks information on whether delayed transfer or inadequate resuscitation caused these deaths. Therefore, emergency response must be standardized and recorded for avoiding potentially preventable factors.

Forensic investigations must be multi-parameterized, combining external and internal examination, incident circumstances, and relevant technical evidence; this will address issues of relying on a single diagnostic parameter.

3.11 Discussion Summary

The results highlighted instances of male predominance, high number of children cases, common exposure to low voltage, upper limb involvement, seasonal exposure, and high mortality rate among the severe injury group. Numerical verification process also showed discrepancies with seasonal percentages, electrical contact marks, and voltage classification. Documented counts can be used to reconcile some of the percentage differences; some of the contradictory statements need to be checked against the

original records. The study results provide a descriptive value of the historical Babil study, as well as indications of its limitations in the aspects of exposure characterization, clinical documentation, statistical analysis and forensic interpretation.

To overcome these, the proposed integrated forensic-clinical framework combined evidence from the electrical, physiological, clinical and post-mortal aspects that facilitates a multidisciplinary assessment process; the framework, however, is purely conceptual and needs independent validation to establish its practical effectiveness.

4. LIMITATIONS

The secondary reappraisal is only based on the information obtained from the following accidents of electrical injury in a historical series of 41 severe and fatal injuries from an electric shock that occurred in Babil. The following limitations were noted:

It was not possible to assess the case selection procedure, referral mechanisms or the completeness of ascertainment, as these points are not documented. The percentage of 38 deaths in 41 cases should not be used to assess the incidence of the deaths, or the risk of mortality for a given exposure or to suggest an association between exposure and mortality rates.

No individual-level records, cross-tabulations, measured current, time of exposure, electrical pathways, original cardiac rhythms, therapy timing, or thorough autopsy or engineering documentation were available; as such, only the arithmetic consistency checks and descriptive reporting were possible, and no valid multivariable associations, causal estimates or predictive models were developed. The missing marks and any high voltage issues that may have happened in the early morning remain unanswered. Its source requires ethics approval and full bibliographic provenance to be confirmed.

Conceptual ideas/vectors (e.g., the five-stage framework), completeness and discrepancy indices, and the proposed extension to AI were not tested and/or validated for these cases; they are not established to increase the accuracy or reliability of diagnosis, or to influence outcomes or to make criminal or forensic decisions.

Historical observations were based on a small sample; hence, they were geographically restricted, and selection bias may have affected the observations.

When using a diagnostic study, validation at the patient level, standardised patient-level data, explicit definition of evidence, prospective assessment of patients through assessor testing, and an appropriate independent reference standard would be necessary for future validation.

5. CONCLUSION AND FUTURE DIRECTIONS

5.1 Conclusion

A retrospective descriptive reappraisal of 41 severe electrical injury cases documented in Babil Governorate, Iraq was presented in this study, collectively with a proposal of an integrated forensic-clinical assessment framework. The findings demonstrate:

A predominance of male victims (68.29 %), low-voltage exposure (90.24 %), and incidents occurring during summer (82.93 %).

A case-fatality rate of 92.68 % was noted, suggesting that severe and fatal cases were preferred rather than the mortality risk associated with electrical exposure in the general population.

Inconsistencies in the historical source reporting highlight the relevance of standardised documentation and transparent statistical verification.

The need to integrate electrical exposure characteristics, clinical observations, forensic evidence, and engineering investigations to strengthen the interpretation of electrical fatalities.

5.2 Future Directions

Documentation of electric injury cases must be standardized in terms of injury mechanisms, applied resuscitation procedures, and clinical outcomes; this will support more reliable forensic/ epidemiological analysis.

Multicenter studies are necessary across Iraq; such studies must use standardized, prospective electrical injury registries that integrate forensic examinations, emergency medical records, and electrical engineering assessments to arrive at a more reliable electric injury assessment model.

The feasibility, reproducibility, and diagnostic utility of the proposed model are yet to be validated.

Larger scale studies using bigger datasets are needed to drive the development of explainable AI models for predicting outcome of electrical injury.

The effectiveness of the existing pre-hospital emergency response processes during domestic and occupational electrical safety interventions must be evaluated; these will improve forensic practice, support evidence-based strategies for preventing electrical injuries and fatalities, and inform clinical management.

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APPENDIX

Supplementary Appendix A. Aggregate Audit Register

Variable	Reported count	Denominator	Recomputed %	Audit note
Male	28	41	68.29	Count-supported
Female	13	41	31.71	Count-supported

Low voltage	37	41	90.24	Abstract reports 95.12%; unresolved source discrepancy
High voltage	2	41	4.88	Narrative mentions four early-morning cases; contradictory
Lightning	2	41	4.88	Count-supported
Summer	34	41	82.93	Abstract reports 92.68%; discrepancy
Deaths	38	41	92.68	Selected-case proportion only
Survivors	3	41	7.32	Count-supported
No visible mark	2	41	4.88	Another narrative says one; unresolved
Resuscitation	15	41	36.59	Outcome cross-tabulation unavailable