ORIGINAL ARTICLE
Turk J Surg 2026;42(3):339-349

Clinical characteristics, treatment strategies, and amputation outcomes in electrical burn patients: A single-center experience

Ahmet Yavuz[1], Ahmet Eray Sarı[2], Ali Emre Akgün[3], Merve Akın[3]

[1]Department of General Surgery, University of Health Sciences Türkiye, Gülhane Training and Research Hospital, Ankara, Türkiye
[2]Department of General Surgery, University of Health Sciences Türkiye, Ankara Bilkent City Hospital, Ankara, Türkiye
[3]Burn Treatment Unit, Department of General Surgery, University of Health Sciences Türkiye, Ankara Bilkent City Hospital, Ankara, Türkiye

ABSTRACT

Objective: Electrical burns are associated with deep tissue damage and a high risk of limb loss. Early identification of patients at risk for amputation remains challenging, as traditional predictors such as voltage level and total body surface area (TBSA) may not adequately reflect tissue injury. This study aimed to evaluate clinical, laboratory, and treatment-related factors associated with amputation in adult patients with electrical burns, with a focus on biomarker-based risk prediction.

Material and Methods: This single-center retrospective cohort study included adult patients hospitalized for electrical burns between February 2019 and October 2025. Patients with incomplete records or hospital stays <7 days were excluded. Demographic data, burn characteristics, electrocardiographic findings, surgical interventions, and laboratory parameters at admission and day 7 were recorded. Univariate and multivariate logistic regression analyses were performed to identify factors associated with amputation. Discriminative ability was assessed using receiver operating characteristic (ROC) curve analysis.

Results: A total of 83 patients were included (91.6% male; median age 32 years), with 75.9% exposed to high voltage. Amputation was required in 22.9%, and mortality was 2.4%. Compared with patients who did not undergo amputation, those requiring amputation had significantly higher admission levels of creatine kinase (CK), CK-MB, aspartate aminotransferase, alanine aminotransferase (ALT), lactate dehydrogenase (LDH), C-reactive protein, neutrophils, and neutrophil/lymphocyte ratio, whereas albumin, lymphocyte count, and HALP score were significantly lower. No significant differences were observed between the amputation and non-amputation groups with respect to voltage level or TBSA. In multivariable analysis, none of the evaluated variables remained independently associated with amputation; however, LDH (odds ratio=1.001, p=0.074) and HALP score (odds ratio=0.683, p=0.056) showed borderline associations. ROC analysis showed good performance for HALP, ALT, and LDH (area under the curve: 0.76-0.77).

Conclusion: Amputation risk in electrical burns is more closely related to biomarkers of muscle injury and inflammation than to voltage or TBSA. Although no independent predictors were identified in multivariable analysis, admission LDH and HALP score showed borderline associations with amputation risk, and several laboratory biomarkers demonstrated meaningful discriminatory performance. Early laboratory assessment may therefore contribute to risk stratification and support limb-preserving strategies. Prospective multicenter studies are needed for validation.

Keywords: Electrical burn, amputation, HALP score

INTRODUCTION

Electrical burns account for a significant proportion of burn injuries worldwide. While electrical burns constitute approximately 4-5% of all burn cases in the general population, this rate can reach as high as 27% in developing countries (1-3). A notable demographic feature of electrical injuries is that the majority of cases involve young and middle-aged male patients (particularly those injured in occupational accidents) (4). The damage caused by electric current in the body can be more complex and deeper than ordinary thermal burns; extensive areas of necrosis may be found even under injuries that appear limited on the skin surface (5). Therefore, it can be difficult to determine the true extent of the damage in electrical injuries during the initial assessment, and these patients may initially develop a multiple organ failure syndrome with an intense inflammatory response (6).

Electrical burns can lead to high morbidity and mortality rates, as well as serious long-term sequelae. Complications such as cardiac arrhythmia, acute renal failure, and neurological deficits are common in the acute phase; compartment syndrome developing in the limbs and subsequent amputation are considered one of the

Cite this article as: Yavuz A, Sarı AE, Akgün AE, Akın M. Clinical characteristics, treatment strategies, and amputation outcomes in electrical burn patients: a single-center experience. *Turk J Surg.* 2026;42(3):339-349

Corresponding Author
Ahmet Yavuz

E-mail: ayavuz.95@gmail.com
ORCID ID: orcid.org/0009-0008-1039-1478

Received: 27.04.2026
Accepted: 24.08.2026
Epub: 31.08.2026
Publication Date: 07.09.2026

DOI: 10.47717/turkjsurg.2026.2026-4-27

Available at **www.turkjsurg.com**

most severe consequences of electrical burns (7). Amputation is also not uncommon in adult patients exposed to electrical injury: For example, a large-scale database analysis showed that approximately 30% of patients hospitalized for electrical burns required at least one amputation (8). In contrast, the amputation rate is significantly lower (~6-7%) in non-electrical burn etiologies (8). Patients with electrical burns who experience limb loss suffer from serious psychosocial problems in addition to permanent loss of working capacity and physical disadvantages. In these individuals, the lifelong limitations brought about by amputation, social stigmatization, difficulties returning to work, and psychological problems such as depression and post-traumatic stress disorder are markedly increased (8). Consequently, amputation is the complication of electrical burns with the most devastating effects on both the patient and society; therefore, its prevention, risk reduction, and accurate prediction should be among the most critical goals.

Identifying risk factors leading to amputation after an electrical burn is critical for recognizing high-risk patients early and enabling appropriate interventions. The literature reports that factors such as high voltage exposure, direct passage of electrical current through the body (contact burn), and the presence of deep tissue damage increase the risk of amputation (1,9). However, comprehensive studies on this subject, particularly those based on single-center experience, are limited. To fill this gap, we retrospectively examined the clinical determinants affecting the development of amputation in adult patients treated for electrical burns at our center using a cohort design. The findings of our study were interpreted in light of the existing literature and our center's experience.

MATERIAL and METHODS

Ethical Statement

The study was conducted with the approval of the Local Ethics Committee of University of Health Sciences Türkiye, Ankara Bilkent City Hospital (approval no: TABED 2-25-1618, date: 12.11.2025) and was carried out in accordance with the principles of the Declaration of Helsinki. Due to the retrospective design of the study and the use of anonymized patient data, the requirement for informed consent was waived by the local ethics committee.

Study Design

This study is a single-center, retrospective observational cohort study analyzing the medical records of patients hospitalized and treated for electrical burns at a tertiary burn center between February 2019 and October 2025. The study was designed and reported in accordance with the STROBE Statement guidelines.

Since our burn unit serves adult patients, pediatric cases were excluded. Initially, 99 patients were evaluated; 10 patients were excluded because of incomplete clinical data and 6 patients were excluded because they were discharged within the first 7 days. None of the patients excluded due to early discharge died or underwent major amputation within the first 6 days. Patients with a hospital stay shorter than 7 days were excluded because adequate follow-up assessment of temporal laboratory changes could not be performed. A total of 83 patients with complete clinical records were included in the final analysis. Patients with thermal, chemical, or radiation burns other than electrical burns were also excluded.

Data Collection

Demographic characteristics, burn etiology, electrical voltage (high/low), burn depth and total body surface area, affected anatomical regions, length of hospital stay, and surgical interventions (escharotomy, fasciotomy, grafting, amputation, etc.) were recorded.

Laboratory parameters at admission and on the 7th day of treatment were collected, including creatinine, blood urea nitrogen (BUN), aspartate aminotransferase (AST), alanine aminotransferase (ALT), lactate dehydrogenase (LDH), white blood cell (WBC), neutrophil/lymphocyte ratio (NLR), hemoglobin (Hb), platelet (PLT), C-reactive protein (CRP), creatine kinase (CK), CK-MB, myoglobin, and HALP score.

All data were obtained retrospectively from the hospital electronic archive system. The HALP score was calculated using the standard formula reported in the literature (Hb × albumin × lymphocyte / PLT) and used as an indicator of systemic inflammatory status.

Statistical Analysis

All statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). The distribution of continuous variables was assessed using the Kolmogorov-Smirnov test. Since most variables were not normally distributed, data are presented as median (minimum-maximum).

Comparisons between admission and day 7 laboratory values were performed using the Wilcoxon signed-rank test. Differences between patients with and without amputation were evaluated using the Mann-Whitney U test for continuous variables and the chi-square test for categorical variables.

Univariate logistic regression analysis was performed to identify factors associated with amputation, and odds ratios (ORs) with 95% confidence intervals (CIs) were reported. Given the limited number of amputation events, a parsimonious multivariable logistic regression model was established using three clinically meaningful variables selected according to univariate analysis results and clinical relevance.

Receiver operating characteristic (ROC) curve analysis was used to evaluate the predictive performance of clinical and laboratory markers. The area under the curve (AUC), optimal cut-off values, sensitivity, and specificity were calculated. A p-value <0.05 was considered statistically significant.

Due to the retrospective design, potential limitations such as measurement bias, variability in laboratory timing, and incomplete documentation may exist. Efforts were made to minimize bias by excluding incomplete or inconsistent data. No a priori sample size calculation was performed.

RESULTS

A total of 83 patients hospitalized due to electrical burns were included in the study. The median age was 32 years (18-66), and the majority were male (91.6%, n=76). Most injuries resulted from occupational accidents (80.7%), and high-voltage contact was reported in 75.9% of cases. Comorbidities were uncommon: Diabetes mellitus was present in 3.6% of patients, coronary artery disease in 2.4%, and no patient had chronic kidney disease. The overall mortality rate was 2.4% (n=2). Multitrauma associated with electrical injury was identified in 19.3% of patients.

Regarding burn distribution, the most frequently affected region was the upper extremity (94%), followed by the lower extremity (68.7%) and the trunk (37.3%). Joint involvement was observed in 78.3% of the cohort. The median total body surface area (TBSA) burned was 8% (1-47), with second- and third-degree burns predominating. The median length of hospital stay was 25 days (7-98), and the median number of surgical procedures was 4 (0-29). Cardiac involvement during hospitalization was assessed: 84.3% had a normal electrocardiography (ECG), while arrhythmias were detected in 13.3%, atrioventricular block in 1.2%, and repolarization abnormalities in 1.2%.

Laboratory parameters demonstrated marked elevations in muscle injury markers, including CK [700 (31-148.906) U/L], myoglobin [472 (13-1000) μg/L], and CK-MB [9.62 (0.23-300) μg/L]. The median troponin level, indicative of potential cardiac involvement, was 9 ng/L (1-12.087) (Table 1).

The majority of patients required surgical debridement, with escharectomy performed in 96.4%, grafting in 63.9%, fasciotomy in 28.9%, and escharotomy in 25.3%. As regenerative treatment, scaffold application was performed in 26.5% of cases, and stem cell therapy in 7.2%. Amputation was performed in a total of 19 patients (22.9%) (Table 1).

The average time to amputation in patients who underwent amputation was 15.58±7.56 days after the burn, and the most common sites of amputation were below the knee (n=5) and the toes. The revision amputation rate was 36.8%, indicating continued advanced tissue necrosis (Table 1).

When laboratory parameters at admission and on day 7 were compared, significant changes were observed in several biochemical, inflammatory, and hematological markers. Among

Table 1. Clinical, demographic, laboratory, treatment, and amputation-related characteristics of patients

Age (years)	32 (18-66)
Gender	
Male	76 (91.6%)
Female	7 (8.4%)
DM status	
Present	3 (3.6%)
Absent	80 (96.4%)
CAD status	
Present	2 (2.4%)
Absent	81 (97.6%)
CKD status	
Absent	83 (100%)
Mortality	
Survived	81 (97.6%)
Died	2 (2.4%)
Length of stay (days)	25 (7-98)
Upper extremity burn	
Present	78 (94%)
Absent	5 (6%)
Lower extremity burn	
Present	57 (68.7%)
Absent	26 (31.3%)
Head, neck burn	
Present	11 (13.3%)
Absent	72 (86.7)
Facial burn	
Present	15 (18.1%)
Absent	68 (81.9%)
Body burn	
Present	31 (37.3%)
Absent	52 (62.7%)
Perineal burn	
Present	8 (9.6%)
Absent	75 (90.4%)
Burns in the joint areas	
Present	65 (78.3%)
Absent	18 (21.7%)
Electrical voltage	
High voltage	63 (75.9%)
Low voltage	20 (24.1%)
Work accident situation	
Work accident	67 (80.7%)
Not a work accident	16 (19.3%)

Table 1. Continued	
1st-degree burn (%)	0 (0-15)
2nd-degree burn (%)	5 (0-45)
3rd-degree burn (%)	1 (0-20)
4th-degree burn (%)	0 (0-7)
Total burn surface area (%)	8 (1-47)
Total number of operations	4 (0-29)
Presence of multiple trauma	
Present	16 (19.3%)
Absent	67 (80.7)
ECG change	
Absent	70 (84.3%)
Rhythm disorder	11 (13.3%)
AV block	1 (1.2%)
Repolarization problem	1 (1.2%)
Admission CK (U/L)	700 (31-148906)
Admission CK-MB (μg/L)	9.62 (0.23-300)
Admission myoglobin (μg/L)	472 (13-1000)
Admission troponin (ng/L)	9 (1-12087)
Stem cell therapy	
Present	6 (7.2%)
Absent	77 (92.8%)
Scaffold treatment	
Present	22 (26.5%)
Absent	61 (73.5%)
Escarectomy	
Present	80 (96.4%)
Absent	3 (3.6%)
Graft application	
Present	53 (63.9)
Absent	30 (36.1)
Escharotomy	
Present	21 (25.3%)
Absent	62 (74.7%)
Fasciotomy	
Present	24 (28.9%)
Absent	59 (71.1%)
Amputation	
Present	19 (22.9%)
Absent	64 (77.1%)
Days after burn to amputation (days)	15.58±7.56
Amputation sites (n=19)	
Right below-knee	3 (15.8%)
Right foot first toe	3 (15.8%)
Left below-knee	2 (10.5%)
Right foot	2 (10.5%)
Right fifth toe	2 (10.5%)
Right forearm	2 (10.5%)
Left foot	1 (5.3%)
Left foot toes	1 (5.3%)
Right foot toes	1 (5.3%)
Left forearm	1 (5.3%)
Left hand	1 (5.3%)
Revision amputation required	
Present	7 (36.8%)
Absent	12 (63.2%)

DM: Diabetes mellitus, CAD: Coronary artery disease, CKD: Chronic kidney disease, ECG: Electrocardiography, AV: Atrioventricular, CK: Creatine kinase.

renal function parameters, median creatinine levels decreased from 0.80 mg/dL at admission to 0.67 mg/dL on day 7, and this reduction was statistically significant (p=0.001). Similarly, median albumin levels decreased from 41 g/L to 37 g/L (p=0.001), while median BUN levels decreased from 14.93 mg/dL to 12.13 mg/dL during follow-up (p=0.007).

Markers of tissue injury demonstrated significant improvement over time. Median AST levels decreased from 90 U/L at admission to 43 U/L on day 7, median ALT levels decreased from 64 U/L to 53 U/L, and median LDH levels decreased from 432 U/L to 247 U/L (all p=0.001).

Inflammatory markers also showed significant changes during hospitalization. Median WBC count decreased from 14.06×10^9/L to 9.06×10^9/L, median neutrophil count decreased from 11.81×10^9/L to 5.60×10^9/L, and median NLR decreased from 6.95 to 3.95 (all p=0.001). In contrast, median lymphocyte count remained relatively stable (1.59×10^9/L vs. 1.63×10^9/L, p=0.906). Among hematological parameters, median Hb levels decreased from 15.0 g/dL at admission to 12.3 g/dL on day 7 (p=0.001), whereas median PLT count increased from 272×10^9/L to 300×10^9/L (p=0.008). Median CRP levels increased from 25 mg/L to 50 mg/L; however, this difference did not reach statistical significance (p=0.149). Finally, median HALP score significantly decreased from 3.10 at admission to 1.88 on day 7 (p=0.001) (Table 2).

Significant elevation in muscle and cardiac injury markers was observed in patients with ECG changes. CK (p=0.022), CK-MB (p=0.042), and troponin (p=0.017) levels were markedly elevated in the group with ECG changes, indicating the effect of electrical current on the cardiac conduction system. No significant relationship was observed between electrical voltage and ECG changes (p=0.725) (Table 3).

Table 2. Patients' admission and day 7 laboratory values						
Variables	**Mean**	**Standard deviation**	**Median**	**Minimum**	**Maximum**	***p-value**
Admission creatinine (mg/dL)	0.79	0.15	0.8	0.5	1.15	**0.001**
7th-day creatinine (mg/dL)	0.71	0.38	0.67	0.35	3.81	
Admission albumin (g/L)	39.96	6.12	41	26	51	**0.001**
7th-day albumin (g/L)	36.55	7.84	37	19	50	
Admission BUN (mg/dL)	15.31	5.11	14.93	7	34.07	**0.007**
7th-day BUN (mg/dL)	13.9	8.25	12.13	6.07	79.80	
Admission AST (U/L)	324.28	630.638	90	10	4877	**0.001**
7th-day AST (U/L)	64.17	67.99	43	10	404	
Admission ALT (U/L)	125.46	153.15	64	11	818	**0.001**
7th-day ALT (U/L)	76.42	67.31	53	8	381	
Admission LDH (U/L)	723.70	961.41	432	144	7784	**0.001**
7th-day LDH (U/L)	278.81	103.84	247	129	576	
Admission WBC ($x10^9$/L)	15.24	6.26	14.06	4.57	35.24	**0.001**
7th-day WBC ($x10^9$/L)	10.14	4.33	9.06	3.23	23.9	
Admission neutrophil ($x10^9$/L)	12.38	6.4	11.81	2.87	32.42	**0.001**
7th-day neutrophil ($x10^9$/L)	7.47	4.43	5.6	1.76	21.66	
Admission lymphocyte ($x10^9$/L)	1.79	1.06	1.59	0.16	6.02	0.906
7th-day lymphocyte ($x10^9$/L)	1.64	0.76	1.63	0.29	3.8	
Admission NLR	12.15	15.54	6.95	0.94	97.81	**0.001**
7th-day NLR	6.39	6.26	3.95	1.25	31.05	
Admission Hb (g/dL)	14.66	2.18	15	7.9	19.6	**0.001**
7th-day Hb (g/dL)	12.23	2.41	12.3	7.7	16.9	
Admission PLT ($x10^9$/L)	281.34	107.54	272	101	905	**0.008**
7th-day PLT ($x10^9$/L)	317.39	110.74	300	87	585	
Admission CRP (mg/L)	59.55	71.77	25	1	296	0.149
7th-day CRP (mg/L)	87.84	91.65	50	1	350	
Admission HALP	4.35	3.6	3.1	0.45	22.29	**0.001**
7th-day HALP	2.85	2.26	1.88	0.37	9.01	

*: Wilcoxon signed-rank test, BUN: Blood urea nitrogen, AST: Aspartate aminotransferase, ALT: Alanine aminotransferase, LDH: Lactate dehydrogenase, WBC: White blood cell, NLR: Neutrophil-to-lymphocyte ratio, Hb: Hemoglobin, PLT: Platelet, CRP: C-reactive protein, HALP score: Hemoglobin (g/dL) × albumin (g/L) × lymphocyte count ($\times 10^9$/L)/platelet count ($\times 10^9$/L).

Table 3. Effect of laboratory and stress on predicting ECG changes				
Variables		**ECG change detected (n=13, 15.7%)**	**No ECG changes (n=70, 84.3%)**	**p-value**
Admission CK (U/L)		1512 (330-148906)	588.5 (31-82900)	***0.022**
Admission CK-MB (µg/L)		20.2 (1.37-300)	8.55 (0.23-300)	***0.042**
Admission myoglobin (µg/L)		800 (30-1000)	401 (13-1000)	*0.166
Admission troponin (ng/L)		30 (2-12087)	7.5 (1-2145)	***0.017**
Electrical voltage	**High voltage**	11 (17.5%)	52 (82.5%)	**0.725
	Low voltage	2 (10%)	18 (90%)	

*: Mann-Whitney U test, **: Chi-square test, CK: Creatine kinase, ECG: Electrocardiography.

Among patients who underwent amputation (n=19), the median length of hospital stay was 50 days (15-98), which was significantly longer than in the non-amputation group [15.5 days (7-77); p=0.001]. The total number of surgical interventions was also substantially higher in the amputation cohort [11 procedures (3-29)] compared with patients who did not require amputation [3 procedures (0-20); p=0.001]. The TBSA burned was 12% (2-47) in the amputation group and 7% (1-45) in the non-amputation group; however, this difference did not reach statistical significance (p=0.114).

Admission laboratory parameters demonstrated notable differences between groups. Median albumin levels were significantly lower in the amputation group (35 g/L) compared with the non-amputation group (42 g/L; p=0.001). Likewise, the admission HALP score was significantly reduced in patients requiring amputation (2.18 vs. 3.81; p=0.001).

Markers of muscle injury were markedly elevated among amputated patients. CK levels were significantly higher in the amputation group (11.720 U/L) than in the non-amputation group (480.5 U/L; p=0.007). Similarly, CK-MB levels (30.2 vs. 5.57 μg/L; p=0.005), AST (442 vs. 75.5 U/L; p=0.002), ALT (173 vs. 50.5 U/L; p=0.001), and LDH (819 vs. 365 U/L; p=0.001) were all significantly increased in the amputation cohort.

Inflammatory markers also differed significantly between groups. WBC counts were higher in the amputation group (17.95×10^9/L vs. 13.16×10^9/L; p=0.023), as were neutrophil counts (15.15×10^9/L vs. 10.5×10^9/L; p=0.013). Conversely, lymphocyte levels were lower among amputated patients (1.2×10^9/L vs. 1.7×10^9/L; p=0.004). The NLR demonstrated a significant disparity, with values of 10 in the amputation group and 5.7 in the non-amputation group (p=0.003).

CRP levels were substantially higher in patients who underwent amputation (90 mg/L) compared with those who did not (21 mg/L; p=0.015). Myoglobin levels were also elevated (1000 vs. 376 μg/L; p=0.047), and troponin concentrations were significantly increased in the amputation cohort (21 vs. 7.5 ng/L; p=0.008).

Regarding clinical variables, amputation was significantly more frequent in patients with lower-extremity burns (31.6%) than in those without lower-extremity burns (3.8%; p=0.012). Fasciotomy was significantly associated with amputation, with an amputation rate of 54.2% among patients who underwent the procedure compared with 10.2% in those without fasciotomy (p=0.001). No significant associations were observed between amputation and sex, electrical voltage exposure, upper-extremity burns, or joint involvement (all p>0.05) (Table 4).

In the univariate logistic regression analysis performed to identify parameters associated with the development of amputation, length of hospital stay, total number of operations, albumin, CK, AST, ALT, LDH, WBC count, neutrophil count, lymphocyte count, NLR, Hb, PLT count, CRP, and the HALP score were found to be significantly associated with amputation. In addition, lower extremity burn and fasciotomy status were significantly associated with amputation in the univariate analysis (Table 5).

When variables that were significant in the univariate analysis together with clinically relevant parameters were included in the multivariable logistic regression model, none of the variables remained independently associated with amputation risk. However, admission LDH levels [odds ratio (OR) =1.001, p=0.074] and admission HALP score (OR =0.683, p=0.056) demonstrated borderline associations with amputation in the adjusted analysis. Similarly, fasciotomy status showed a trend toward significance but did not remain an independent predictor after adjustment (OR =0.319, p=0.118) (Table 5).

According to ROC analysis, the parameter with the highest AUC value for predicting amputation was the HALP score, with an AUC value of 0.772 (p=0.001) and a cut-off point of 2.67; at this threshold, sensitivity was determined to be 68.4% and specificity 68.8%. For ALT levels, the AUC was 0.766 (p=0.001), with a cut-off value of 96 U/L; sensitivity was determined to be 68.4% and specificity 67.2%.

The AUC value for predicting amputation based on LDH level was 0.761 (p=0.001), with a cut-off value of 570.5 U/L, sensitivity of 73.7%, and specificity of 73.4%. The AUC value for AST was 0.736 (p=0.002, cut-off: 147.5 U/L), for CK it was 0.705 (p=0.007, cut-off: 1031.5 U/L), and for CK-MB, the AUC was 0.711 (p=0.006, cut-off: 12.25 μg/L).

The AUC value for NLR, an inflammatory response marker, was 0.725 (p=0.003), and the cut-off value was determined as 9.23, with a sensitivity of 63.2% and specificity of 68.8% at this value (Table 6, Figure 1).

DISCUSSION

Electrical burns predominantly affect young male individuals and are most commonly associated with occupational accidents (9,10). Large series reported in the literature indicate that the vast majority of patients sustaining electrical burn injuries are working-age men, often belonging to high-risk occupational groups. For instance, a study from China demonstrated that 93.8% of patients with high-voltage electrical burns were male, and 73.5% were between 19 and 50 years of age (10). The mean age and sex distribution observed in our cohort are consistent with these findings and reflect the typical demographic pattern of electrical burn injuries. Although comorbidities are generally less prevalent in younger populations, their presence may exacerbate clinical severity; however, data specifically addressing comorbidities in electrical burn patients remain limited. Overall mortality rates are reported to be low, ranging

Table 4. Effect of laboratory and clinical variables on amputation prediction

Variables		Amputation present (n=19)	No amputation (n=64)	p-value
Age (years)		32 (19-59)	33 (18-66)	*0.700
Length of stay (days)		50 (15-98)	15.5 (7-77)	***0.001**
Total burn surface area (%)		12 (2-47)	7 (1-45)	*0.114
Total number of operations		11 (3-29)	3 (0-20)	***0.001**
Admission creatinine (mg/dL)		0.73 (0.5-1.01)	0.82 (0.52-1.15)	*0.081
Admission albumin (g/L)		35 (28-46)	42 (26-51)	***0.001**
Admission BUN (mg/dL)		14.47 (7.93-28)	14.93 (7-34.07)	*0.457
Admission CK (U/L)		11720 (31-148906)	480.5 (32-56558)	***0.007**
Admission AST (U/L)		442 (15-4877)	75.5 (10-1290)	***0.002**
Admission ALT (U/L)		173 (11-818)	50.5 (12-781)	***0.001**
Admission LDH (U/L)		819 (144-7784)	365 (164-1878)	***0.001**
Admission CK-MB (μg/L)		30.2 (1.52-300)	5.57 (0.23-300)	***0.005**
Admission myoglobin (μg/L)		1000 (100-1000)	376 (13-1000)	***0.047**
Admission troponin (ng/L)		21 (5-2030)	7.5 (1-12087)	***0.008**
Admission WBC (x10^9/L)		17.95 (6.34-35.24)	13.16 (4.57-35.05)	***0.023**
Admission neutrophil (x10^9/L)		15.15 (3.88-32.42)	10.5 (2.87-31.43)	***0.013**
Admission lymphocyte (x10^9/L)		1.2 (0.16-2.72)	1.7 (0.27-6.02)	***0.004**
Admission NLR		10 (2.3-97.81)	5.7 (0.94-48.59)	***0.003**
Admission Hb (g/dL)		14.6 (7.9-19.6)	15.1 (8.1-18.9)	*0.725
Admission PLT (x10^9/L)		274 (101-905)	270.5 (133-474)	*0.422
Admission CRP (mg/L)		90 (1-274)	21 (1-296)	***0.015**
Admission HALP		2.18 (0.53-6.32)	3.81 (0.45-22.29)	***0.001**
Gender	**Female**	1 (14.3%)	6 (85.7%)	**0.493
	Male	18 (23.7%)	58 (76.3%)	
Upper extremity burn	**Present**	16 (20.5%)	62 (79.5%)	**0.076
	Absent	3 (60%)	2 (40%)	
Lower extremity burn	**Present**	18 (31.6%)	39 (68.4%)	****0.012**
	Absent	1 (3.8%)	25 (96.2%)	
Burns in the joint areas	**Present**	17 (26.2%)	48 (73.8%)	**0.221
	Absent	2 (11.1%)	16 (88.9%)	
Electrical voltage	**Low voltage**	4 (20%)	16 (80%)	**0.493
	High voltage	15 (23.8%)	48 (76.2%)	
Fasciotomy status	**Present**	13 (54.2%)	11 (45.8%)	****0.001**
	Absent	6 (10.2%)	53 (89.8%)	

*: Mann-Whitney U test, **: Chi-square test, BUN: Blood urea nitrogen, CK: Creatine kinase, AST: Aspartate aminotransferase, ALT: Alanine aminotransferase, LDH: Lactate dehydrogenase, WBC: White blood cell, NLR: Neutrophil-to-lymphocyte ratio, Hb: Hemoglobin, PLT: Platelet, CRP: C-reactive protein, HALP score: hemoglobin (g/dL) × albumin (g/L) × lymphocyte count (×10^9/L) / platelet count (×10^9/L).

between 0.2% and 0.5% in large cohorts (9,10). The mortality rate of 2.4% observed in our study may be attributable to the severity of cases managed at a tertiary referral center.

In electrical burns, the anatomical regions most commonly affected are the extremities, with current entry and exit points frequently located in distal segments. Previous studies have reported that a substantial proportion of amputations involve the hand and upper extremities; in a large series, 43.9% of amputations affected the hand and 39.3% involved the upper extremity (10). These findings support the propensity of electrical current to cause profound deep tissue injury at contact points. Similarly, the distribution of affected body regions in our study was consistent with the existing literature.

Table 5. Univariate and multivariable logistic regression analyses for predictors of amputation						
Variables	**Univariate analysis**			**Multivariate analysis**		
	B	**p**	**OR (95% CI)**	**B**	**p**	**OR (95% CI)**
Age (years)	-0.004	0.872	0.996 (0.953-1.041)			
Length of stay (days)	0.054	**0.001**	1.056 (1.028-1.084)			
Total burn surface area (%)	0.027	0.240	1.027 (0.982-1.074)			
Total number of operations	0.257	**0.001**	1.293 (1.143-1.464)			
Admission creatinine (mg/dL)	-2.945	0.103	0.053 (0.002-1.821)			
Admission albumin (g/L)	-0.171	**0.001**	0.842 (0.763-0.930)			
Admission BUN (mg/dL)	0.031	0.540	1.031 (0.935-1.137)			
Admission CK (U/L)	0.001	**0.013**	1.000 (1.000-1.000)			
Admission AST (U/L)	0.002	**0.004**	1.002 (1.001-1.003)			
Admission ALT (U/L)	0.004	**0.016**	1.004 (1.001-1.008)			
Admission LDH (U/L)	0.002	**0.001**	1.002 (1.001-1.003)	0.001	0.074	1.001 (1.000-1.002)
Admission CK-MB (μg/L)	0.004	0.054	1.004 (1.000-1.009)			
Admission myoglobin (μg/L)	0.001	0.085	1.001 (1.000-1.003)			
Admission troponin (ng/L)	0.001	0.814	1.000 (1.000-1.000)			
Admission WBC (x10^9/L)	0.097	**0.021**	1.101 (1.015-1.195)			
Admission neutrophil (x10^9/L)	0.104	**0.013**	1.109 (1.022-1.204)			
Admission lymphocyte (x10^9/L)	-1.090	**0.008**	0.336 (0.150-0.754)			
Admission NLR	0.057	**0.008**	1.059 (1.015-1.105)			
Admission Hb (g/dL)	-0.522	**0.001**	0.593 (0.444-0.793)			
Admission PLT (x10^9/L)	0.006	**0.025**	1.006 (1.001-1.010)			
Admission CRP (mg/L)	0.007	**0.010**	1.007 (1.002-1.013)			
Admission HALP	-0.509	**0.005**	0.601 (0.423-0.854)	-0.381	0.056	0.683 (0.462-1.010)
Gender	-0.622	0.577	0.537 (0.061-4.761)			
Upper extremity burn	-1.760	0.065	0.172 (0.026-1.118)			
Lower extremity burn	-2.446	**0.021**	0.087 (0.011-0.690)			
Burns in the joint areas	-1.041	0.194	0.353 (0.073-1.698)			
Electrical voltage	-0.223	0.724	0.800 (0.232-2.763)			
Fasciotomy status	-2.346	**0.001**	0.096 (0.030-0.307)	-1.141	0.118	0.319 (0.076-1.335)
Constant				-0.794	0.333	

*: Amputation was coded as 1 and absence of amputation as 0. For categorical predictors, the last category was used as the reference category (simple contrast): Male for gender, present for upper extremity burn, lower extremity burn, burns in the joint areas, and fasciotomy status, and high voltage for electrical voltage. Therefore, ORs represent the odds of amputation for the non-reference category relative to the reference category. Odds ratios (Ors) >1 indicate increased odds of amputation, whereas ORs <1 indicate decreased odds of amputation relative to the reference category. BUN: Blood urea nitrogen, CK: Creatine kinase, AST: Aspartate aminotransferase, ALT: Alanine aminotransferase, LDH: Lactate dehydrogenase, WBC: White blood cell count, NLR: Neutrophil-to-lymphocyte ratio, Hb: Hemoglobin, PLT: Platelet count, CRP: C-reactive protein, HALP score: Hemoglobin (g/dL) × albumin (g/L) × lymphocyte count (×10^9/L) / platelet count (×10^9/L).

Aggressive surgical management in the early phase is a cornerstone of electrical burn treatment. Rapid debridement, escharotomy, and fasciotomy are critical interventions aimed at reducing compartment pressure and limiting progressive necrosis. In one series, escharotomy was performed in 40.5% of patients and fasciotomy in 24.7%, with most procedures undertaken on the day of admission (11). Following surgical excision of full-thickness necrosis, wound closure is commonly achieved using split-thickness skin grafts or flap reconstructions. A large cohort study reported the use of skin grafts in 83.2%

Table 6. ROC curve for amputation					
Risk factor(s)	**AUC (95% CI)**	**Cut-off**	**p**	**Sensitivity (%) (95% CI)**	**Specificity (%) (95% CI)**
Admission CK (U/L)	0.705 (0.560-0.850)	1031.5	**0.007**	63.2% (38.4-83.7)	64.1% (51.1-75.7)
Admission AST (U/L)	0.736 (0.604-0.867)	147.5	**0.002**	68.4% (43.4-87.4)	68.8% (55.9-79.8)
Admission ALT (U/L)	0.766 (0.637-0.894)	96	**0.001**	68.4% (43.4-87.4)	67.2% (54.3-78.4)
Admission LDH (U/L)	0.761 (0.613-0.909)	570.5	**0.001**	73.7% (48.8-90.9)	73.4% (60.9-83.7)
Admission CK-MB (μg/L)	0.711 (0.590-0.831)	12.25	**0.006**	63.2% (38.4-83.7)	62.5% (49.5-74.3)
Admission NLR	0.725 (0.596-0.855)	9.23	**0.003**	63.2% (38.4-83.7)	68.8% (55.9-79.8)
Admission HALP	0.772 (0.656-0.888)	2.67	**0.001**	68.4% (43.4-87.4)	68.8% (55.9-79.8)

*: Sensitivity and specificity are presented with exact binomial 95% confidence intervals (Clopper-Pearson method), CK: Creatine kinase, AST: Aspartate aminotransferase, ALT: Alanine aminotransferase, LDH: Lactate dehydrogenase, NLR: Neutrophil-to-lymphocyte ratio, CI: Confidence interval, ROC: Receiver operating characteristic, AUC: Area under the curve, HALP score: Hemoglobin (g/dL) × albumin (g/L) × lymphocyte count ($\times 10^9$/L) / platelet count ($\times 10^9$/L).

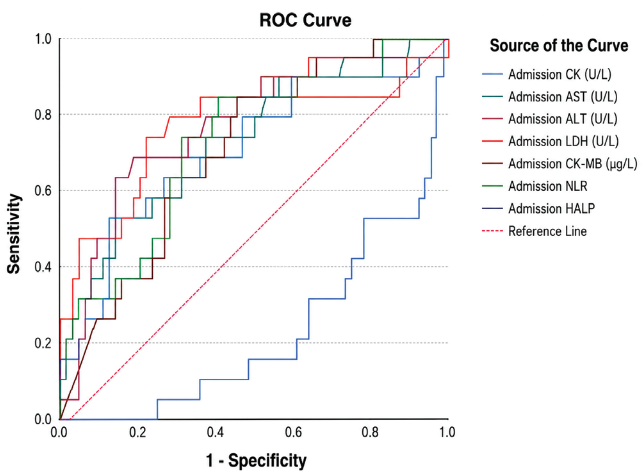

Figure 1. ROC curves of admission biomarkers for predicting amputation.

ROC: Receiver operating characteristic, CK: Creatine kinase, AST: Aspartate aminotransferase, ALT: Alanine aminotransferase, LDH: Lactate dehydrogenase, NLR: Neutrophil-to-lymphocyte ratio.

and flap reconstruction in 49.3% of cases (10). In addition, experimental approaches involving stem cell-based therapies, cell-derived products, and biomaterial scaffolds have demonstrated significant improvements in wound healing in preclinical studies (12). Although these techniques have not yet entered routine clinical practice, they represent promising strategies for addressing the severe tissue loss associated with electrical burns. In the future, such regenerative approaches may also contribute to reducing amputation rates by improving tissue viability and supporting early reconstruction in severe electrical burn injuries. In our series, rates of escharotomy, fasciotomy, and grafting were comparable to those reported in the literature.

Amputation surgery is often an unavoidable component of treatment in electrical burn injuries. Pedrazzi et al. (11) reported an amputation rate of 13.5% in their cohort. The amputation rate of 22.9% observed in our study is consistent with values reported in the literature. For example, a tertiary referral center in another country reported an amputation rate of approximately 22% among electrical burn patients (1), whereas a large cohort from India documented rates as high as 38% (8). These findings suggest that limb loss following electrical injury constitutes a comparable clinical burden across different geographic regions.

Delayed demarcation resulting from microvascular thrombosis and progressive tissue necrosis in electrical injuries increases the likelihood of revision amputations following initial surgery (13). Dash et al. (8) reported a revision amputation rate of 23.9% in a series of 209 patients. This trend aligns with studies emphasizing the need for staged debridement in electrical burns and highlighting the failure of early reconstruction or closure due to ongoing necrosis (14). In our cohort, revision amputations were required in 36.8% of cases. The timing and recurrence of amputations are closely related to the unique pathophysiology of progressive tissue loss in electrical injuries (15). Although large database studies have reported overall amputation rates of approximately 30% in electrical burn patients, the temporal distribution of amputations has rarely been detailed (6). In our series, the mean time to first amputation was 15.58 days, further supporting the concept of delayed tissue demarcation.

Laboratory parameters provide valuable insight into the pathophysiology of electrical burns. Markers of muscle injury, such as CK, CK-MB, myoglobin, and LDH, rise markedly in the early phase due to rhabdomyolysis and deep muscle necrosis. In a prospective study of high-voltage electrical contact burns, Babu et al. (16) demonstrated that CK, CK-MB, and LDH levels were significantly higher in patients requiring amputation, supporting the prognostic value of muscle injury biomarkers in this setting. Inflammatory markers, including CRP and WBC count, typically rise early after burn injury; however, persistently elevated values beyond the first week often suggest secondary infection or systemic inflammation. A meta-analysis of burn patients demonstrated that elevated CRP and neutrophil levels were associated with sepsis and mortality (17). In our study, higher WBC and CRP levels in the amputation group were consistent with these findings and support a contributory role of systemic inflammation and infection in amputation risk.

Cardiac involvement in electrical burns is generally mild and transient. In a series of 480 patients reported by Pilecky et al. (18), the most common electrocardiographic findings were sinus bradycardia (10.4%) and sinus tachycardia (4.4%), while severe arrhythmias were rare. Similarly, Ahmed et al. (19). reported ECG abnormalities in 18% of patients following electrical injury, whereas no serious arrhythmias were detected. In our cohort, ECG abnormalities were predominantly benign and showed no significant association with voltage level. Moreover, significant associations were observed between ECG changes and CK, CK-MB, and troponin levels. These findings suggest that voltage exposure alone is not a reliable predictor of clinically relevant cardiac injury.

An important observation in our study was the lack of a linear relationship between TBSA and amputation risk. Even when a limited skin area is affected in high-voltage injuries, severe deep tissue damage may necessitate amputation. Conversely, limb preservation may be possible in low-voltage injuries involving larger surface areas. Dash et al. (8) similarly reported higher amputation rates in electrical burn patients with TBSA <25% compared with those with TBSA >25%. These findings indicate that, in electrical burns, deep tissue injury rather than surface area involvement is a more critical determinant of prognosis.

Although high-voltage exposure has traditionally been considered a major risk factor for amputation (20), we did not observe a statistically significant association between voltage level and amputation in our cohort. Instead, muscle injury enzymes (CK, CK-MB, LDH), liver enzymes (AST, ALT), inflammatory markers (CRP, WBC), and composite indices such as the HALP score and neutrophil-to-lymphocyte ratio (NLR) were significantly associated with amputation risk. In a similar study, patients undergoing amputation after high-voltage electrical injury exhibited significantly higher CK, CK-MB, and LDH levels (16). In our analysis, ROC curves demonstrated meaningful discriminatory power of these parameters for predicting amputation. However, none of the variables remained independent predictors in the multivariable analysis, which may be related to the limited number of amputation events and the restricted statistical power of the study. Although the HALP score demonstrated significant discriminatory performance in ROC analysis and was associated with amputation risk in univariate analysis, it did not remain an independent predictor in the multivariable model. Additionally, in our study, the observed association between fasciotomy and amputation should not be interpreted as a causal relationship. Fasciotomy is generally performed in the setting of severe compartment syndrome and extensive ischemic tissue injury; therefore, its association with amputation likely reflects the severity of the underlying injury rather than an independent adverse effect of the procedure itself. Similarly, variables such as length of hospital stay and total number of operations may reflect the clinical consequences of severe injury and amputation rather than direct causal predictors. Therefore, these findings should be interpreted with caution.

The originality of this study lies in emphasizing a biomarker-based approach for prognostic assessment in electrical burn patients. While previous studies have primarily focused on clinical parameters such as voltage level and TBSA, our findings suggest that simple, readily available laboratory markers may facilitate early risk stratification. This approach may enable timely identification of patients at high risk for amputation and support the early implementation of more aggressive therapeutic strategies. Given the multisystem involvement characteristic of electrical burns, a multidisciplinary approach incorporating surgery, intensive care, nephrology, rehabilitation, and psychosocial support is likely to improve patient outcomes.

Study Limitations

This study has several limitations. Its retrospective and single-center design limits control over patient selection and treatment heterogeneity, and the relatively small sample size may restrict generalizability. In addition, the limited number of amputation events (n=19) constrained the number of variables that could be included in the multivariable logistic regression model and increased the risk of overfitting. Therefore, the loss of statistical significance observed in the multivariable analysis may partly reflect limited statistical power and a potential type II error, and borderline associations should be interpreted with caution. Consequently, multicenter prospective studies are warranted to validate these findings. In conclusion, biochemical and hematological parameters in adult electrical burn patients are significantly associated with the development of amputation, and early assessment of these biomarkers may provide substantial support to clinical decision-making processes.

CONCLUSION

This study demonstrates the clinical value of a biomarker-based approach for predicting the development of amputation in adult patients with electrical burns. Voltage exposure alone was not a decisive determinant; rather, parameters reflecting muscle injury and systemic inflammation—including AST, ALT, LDH, CK, CK-MB, the HALP score, and NLR—were strongly associated with amputation risk. Although logistic regression and ROC curve analyses indicated meaningful predictive performance for these variables, none remained independently associated with amputation in multivariable analysis. Admission LDH levels and HALP score showed borderline associations with amputation risk in the multivariable analysis.

These findings underscore the importance of incorporating early biochemical and inflammatory markers, in addition to clinical assessment, into decision-making regarding amputation. Electrocardiographic abnormalities were generally benign and did not show a significant correlation with voltage level. Despite early escharotomy, fasciotomy, and appropriate reconstructive procedures, the frequent need for revision amputation highlights the progressive tissue injury characteristic of electrical burns.

Overall, within a multidisciplinary framework, early risk stratification based on admission laboratory data may facilitate timely identification of high-risk patients, support tissue-preserving strategies, and help prevent complications. Prospective, multicenter studies are warranted to further clarify the integration of these biomarkers into routine clinical practice.

Ethics

Ethics Committee Approval: The study was conducted with the approval of the Local Ethics Committee of University of Health Sciences Türkiye, Ankara Bilkent City Hospital (approval no: TABED 2-25-1618, date: 12.11.2025) and was carried out in accordance with the principles of the Declaration of Helsinki.

Informed Consent: Due to the retrospective design of the study and the use of anonymized patient data, the requirement for informed consent was waived by the local ethics committee.

Footnotes

Author Contributions

Concept - A.Y., A.E.S.; Design - A.Y., A.E.S.; Data Collection or Processing - A.Y., A.E.S.; Analysis or Interpretation - A.Y., M.A.; Literature Search - A.Y., A.E.A., M.A.; Writing - A.Y., A.E.A., M.A.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

REFERENCES

1. *Arumugam PK, Thakur P, Sarabahi S. Changing trends in electrical burns from a tertiary care centre - epidemiology and outcome analysis. Ann Burns Fire Disasters. 2021;34:351-359.*
2. *Bounds EJ, Khan M, Kok SJ. Electrical burns. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025. Available from: https://www.ncbi.nlm.nih.gov/books/NBK519514/*
3. *Shih JG, Shahrokhi S, Jeschke MG. Review of adult electrical burn injury outcomes worldwide: an analysis of low-voltage versus high-voltage electrical injury. J Burn Care Res. 2017;38:e293-e298.*
4. *Mobayen M, Sadeghi M. Prevalence and related factors of electrical burns in patients referred to Iranian medical centers: a systematic review and meta-analysis. World J Plast Surg. 2022;11:3-11.*
5. *Koumbourlis AC. Electrical injuries. Crit Care Med. 2002;30(Suppl 11):S424-S430.*
6. *Kim E, Wan B, Solis-Beach KJ, Kowalske K. Outcomes of patients with amputation following electrical burn injuries. Eur Burn J. 2023;4:318-329.*
7. *Králík D. Electrical burns in adults. Acta Chir Plast. 2023;65:66-69.*
8. *Dash S, Arumugam PK, Muthukumar V, Kumath M, Sharma S. Study of clinical pattern of limb loss in electrical burn injuries. Injury. 2021;52:1925-1933.*
9. *Ding H, Huang M, Li D, Lin Y, Qian W. Epidemiology of electrical burns: a 10-year retrospective analysis of 376 cases at a burn centre in South China. J Int Med Res. 2020;48:300060519891325.*
10. *Li H, Tan J, Zhou J, Yuan Z, Zhang J, Peng Y, et al. Wound management and outcome of 595 electrical burns in a major burn center. J Surg Res. 2017;214:182-189.*
11. *Pedrazzi N, Klein H, Gentzsch T, Kim BS, Waldner M, Giovanoli P, et al. Predictors for limb amputation and reconstructive management in electrical injuries. Burns. 2023;49:1103-1112.*
12. *Abdul Kareem N, Aijaz A, Jeschke MG. Stem cell therapy for burns: story so far. Biologics. 2021;15:379-397.*
13. *Jeschke MG, van Baar ME, Choudhry MA, Chung KK, Gibran NS, Logsetty S. Burn injury. Nat Rev Dis Primers. 2020;6:11.*
14. *Mene A, Biswas G, Parashar A, Bhattacharya A. Early debridement and delayed primary vascularized cover in forearm electrical burns: a prospective study. World J Crit Care Med. 2016;5:228-234.*
15. *Khor D, AlQasas T, Galet C, Barrash J, Granchi T, Bertellotti R, et al. Electrical injuries and outcomes: a retrospective review. Burns. 2023;49:1739-1744.*
16. *Babu VS, Sharma S, Manas RK, Kaur C, R R. Study of serum creatine kinase and lactate dehydrogenase levels and their correlation in high-voltage electric contact burns. Eur J Plast Surg. 2021;44:103-110.*
17. *Nourigheimasi S, Yazdani E, Ghaedi A, Khanzadeh M, Lucke-Wold B, Dioso E, et al. Association of inflammatory biomarkers with overall survival in burn patients: a systematic review and meta-analysis. BMC Emerg Med. 2024;24:76.*
18. *Pilecky D, Vamos M, Bogyi P, Muk B, Stauder D, Racz H, et al. Risk of cardiac arrhythmias after electrical accident: a single-center study of 480 patients. Clin Res Cardiol. 2019;108:901-908.*
19. *Ahmed J, Stenkula C, Omar S, Ghanima J, Bremtun FF, Bergan J, et al. Patient outcomes after electrical injury: a retrospective study. Scand J Trauma Resusc Emerg Med. 2021;29:114.*
20. *Arnoldo BD, Purdue GF, Kowalske K, Helm PA, Burris A, Hunt JL. Electrical injuries: a 20-year review. J Burn Care Rehabil. 2004;25:479-484.*