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The occurrence of single and multiple organ dysfunction in pediatric electrical vs. other thermal burns

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Abstract

Background—Multiple organ failure (MOF) is a major contributor to morbidity and mortality in burned children. While various complications induced by electrical injuries have been described, the incidence and severity of single organ failure (SOF) and MOF associated with this type of injury are unknown. The study was undertaken to compare the incidence and severity of SOF and MOF as well as other complications between electrically and thermally burned children.

Patients and Methods—Between 2001 and 2016, two hundred eighty-eight pediatric patients with electrical burns (EB, N=96) or thermal burns (CTR, N=192) were analyzed in this study. Demographic data, length of hospitalization, number and type of operations, amputations, and complications were statistically analyzed. Incidence of SOF and MOF was assessed using the DENVER2 classification in an additive mixed model over time. Compound scores and organ-specific scores for lung, heart, kidney, and liver were analyzed. Serum cytokine expression profiles of both groups were also compared over time. Significance was accepted at $p<0.05$.

Results—Both groups were comparable in age (CTR 11±5 years vs. EB 11±5 years), percent total body surface area burned (CTR 33±25% vs. EB 32±25%), and length of hospitalization (CTR 18±26 days vs. EB 18±21 days). The percentage of high voltage injury in the EB group was 64%. The incidence of MOF was lower in the EB group (2/96, 2.1%) than the CTR group (20/192, 10.4%; $p<0.05$). The incidence of single organ failure was comparable between groups. Incidence

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All authors made substantial contributions to the conception or design of the work or to the acquisition, analysis, and interpretation of data as well as drafting the manuscript or revising it critically for important intellectual content.

of pulmonary failure was comparable in both groups, but incidence of inhalation injury was significantly higher in the CTR group (p<0.0001). Patients in the EB group had more amputations (p<0.001), major amputations (p=0.001), and combined major amputations (p<0.01). Mortality was comparable between the groups. Serum cytokine expression profiles were also comparable between groups.

Conclusions—In pediatric patients, electrical injury is associated with a lower incidence of MOF than other thermal burns. Early and radical debridement of nonviable tissue is crucial to improve outcomes in the electrical burn patient population.

Keywords

electrical burn; organ failure

Background

Electrical burn injury has a total incidence of approximately 6,000 cases in the U.S. per year, accounting for 3.2% of all burn accidents (1). The populations most prone to electrical injury are young children, teenagers, and adults exposed to occupational electrical hazards (1,2). Although overall mortality from high-voltage (HV) electrical injury is low, this type of injury is associated with particularly high morbidity, leading to the need for more surgical procedures and amputations as well as cardiac and renal complications (3–5). While single and multiple organ failure (MOF) significantly contribute to complications and death (6), their incidence in the pediatric population with electrical burn injury has not been comprehensively compared to those associated with thermal burns. Scoring systems such as the DENVER2 classification for SOF and MOF provides a standardized scoring tool to evaluate organ dysfunction following trauma and burns (7,8). Here we used this scoring system to determine the incidence and outcomes of single and MOF in the pediatric patient population affected by electrical versus flame or scald burns.

Patients and Methods

Patients

This study was approved by the Institutional Review Board at the University of Texas Medical Branch (Galveston, TX). We identified 198 patients who were admitted to our facility with electrical burn injury from 2001 to 2015. After excluding all patients aged 19 years or older and those that were admitted more than 72 h after injury, 96 patients were included in the analysis. They were matched to a comparison group of 192 patients with flame or scald burns. SAS 9.2 was used to match cases and controls, in a blinded fashion, at a 1:2 ratio based on the closest matching propensity score. Case-cohort matching was performed using the following as predictors: percent total body surface area (TBSA) burned, percent TBSA third-degree burns, age at burn, year admitted. The quality of the matching was analyzed in all cases. P<0.05 was accepted as significant. Length of hospital stay (LOS) as well as the number and type of operations were recorded for each patient; days of mechanical ventilation were recorded where applicable. Comorbidities and complications such as inhalation injury and renal failure requiring dialysis were recorded. Causes of death were confirmed through autopsy.

Patient Management

Upon admission, patients in both groups were resuscitated with lactated Ringer's solution administered in increments over the first 24 h and thereafter dependent on sufficient urinary output of 0.5ml/kg/h in the flame and scald group and 1ml/kg/h in the electrical injury group. Within the first 48 h of admission, all patients with full-thickness burns underwent wound excision and coverage with autograft. Any open areas that remained were then covered with homograft. This procedure was repeated until all open wounds were covered with autologous skin. Upon admission for electrical injury, patients underwent exploratory fasciotomy as soon as possible, and nonviable parts of affected extremities were resected within the first 48 h. Twenty-four hours following debridement, a second look procedure was performed to assess possible progression of muscle damage. If no further resection was performed, creatinine kinase and myoglobin levels in the blood were monitored until normalization.

Organ Failure Assessment

Organ failure was prospectively assessed during acute hospitalization using DENVER2 definitions as previously published (7). Specific organ functions were evaluated continuously during hospitalization through quantification of biomarkers, clinical markers, and administered medication as described in Table 2. MOF was defined as a total DENVER2 score >3 (out of 12 maximum points) for two or more organs for a minimum of 2 consecutive days. The worst daily value was counted if more than one were calculated per day. Single organ failure was defined as a daily average organ DENVER2 score >2 points (out of 3 maximum points).

Protein and Cytokine Profile

Blood samples were collected from burn patients at admission, pre-operatively, and every 5 days postoperatively for 4 weeks for cytokine analysis. Blood was transferred to serum-separator collection tubes and centrifuged for 10 min at 1320 rpm. The resulting serum was removed and stored at −70°C until analysis. We used the Bio-Plex Human Cytokine 17-Plex panel with the Bio-Plex Suspension Array System (Bio-Rad, Hercules, CA) to quantify 17 inflammatory mediators as described elsewhere (6).

Statistical Analysis

Patient data were prospectively collected and recorded by physicians, nurses, and support staff using the clinical information system Emtek. Data were processed and analyzed with Microsoft Access® and Excel® (Microsoft Corporation Inc., Redmond, WA, USA). Normally-distributed data are presented as mean ± standard deviation or standard error of the mean and non-normally distributed data as median ± median absolute deviation. Chi squared test, Fisher's exact test, student's t-test, analysis of variance, and Mann-Whitney rank sum test were used where appropriate. DENVER2 scores were modeled by a generalized additive mixed model with relation to study group and time post burn, adjusting for covariates age at burn and burn size, with a penalized spline to compensate for the non-linear relation between the Denver2 score and time from admission and controlled for repeated measures per subject. Statistical significance was accepted at $p<0.05$.

Results

Patient Characteristics

Analysis of matching quality revealed no significant differences between the EB (N=96) and CTR (N=192) groups, indicating a successful match. As shown in Table 1, the groups were comparable in mean age at the time of burn, the percentage of TBSA burned, and the percentage of full-thickness burned TBSA. The average time between burn and admission was 30±24 h for both groups. LOS was, on average, 18 days for both groups (p=0.92). However, the electrical burn group had a longer duration of hospitalization per percent of TBSA burned (EB 0.96 d/%TBSA vs. CTR 0.47 d/%TBSA, p<0.01) and per % TBSA full-thickness burn (EB 1.64 d/%TBSA3rd vs. CTR 0.97d/%TBSA 3^{rd}, p<0.01). Mortality was comparable in the EB group (3.13%) and CTR group (4.17%, p=0.652). Causes of death are shown in Table 4.

Operations and Amputations

The number of operations in the EB group (4±3) and CTR group (3±4) did not significantly differ. However, amputations were significantly more common in the EB group (25% vs. 7% for CTR, p<0.001). Major amputations above the wrist or ankle were performed in 19.8% of patients in the EB group and 3.2% of patients in the CTR group (p=0.001). The percentage of patients undergoing a combination of two or more major amputations was 6.2% in the EB group and 0.5% in the CTR group (p<0.01).

Complications

The incidence of inhalation injury was significantly higher in the CTR group (18.4%) than in the EB group (2.0%, p<0.001). The average number of days of mechanical ventilation was comparable between groups (p=0.26). The incidence of renal failure requiring hemodialysis was 3.2% in the EB and 5.8% in the CTR group (p=0.333).

Organ failure

The incidence of MOF according to DENVER 2 criteria was 2.1% (2/96) in the EB group and 10.4% (20/192) in the CTR group (p=0.013). Mortality in the subgroup of patients with MOF was similar between groups. In the EB group, both patients (100%) with MOF died, while 7 out of 20 patients with MOF died in the CTR group (35%, p=0.075). Mean compound DENVER2 scores modelled over time as a continuous variable were significantly lower in the EB group than in the CTR group during the first 3 days post admission but not significantly different thereafter (Fig. 1).

There was no statistically significant difference in the incidence of single organ failure between the two groups. Results are shown in Table 3.

DENVER2 sub-scores for individual cardiac organ failure modelled over time as a continuous variable were significantly elevated in the CTR group during the first 3 days post burn ($p<0.05$, Fig. 2). DENVER2 sub-scores for individual pulmonary, hepatic, and renal organ failure modelled over time as a continuous variable were not significantly different between the groups during hospitalization.

Cytokine Profile

A comparative analysis of 499 individual measurements in the CTR group and 384 individual measurements in the EB group did not reveal any statistically significant differences between the groups in levels of IL-2, IL-4, IL-6, IL-7, IL-8, IL-10, IL-12, IL-13, IL-17, GM-CSF, IFN-γ, TNF-α, IL-1b, G-CSF, or MCP-1 at 0–2, 3–7, 8–14, 15–21, or 22–66 days post burn. In contrast, during the first 48 h post burn, IL-5 levels were higher in the EB group (1.9 pg/ml) than the CTR group (0.9 pg/ml; n=26; $p<0.05$).

Discussion

Although various smaller case series and retrospective reviews have been published, no comprehensive study of a large patient group has evaluated the incidence of multiple and single organ failure in pediatric electrical burn patients. In this comparative study of electrical and other thermal burns, we were able to show, for the first time, the specific incidence of single and MOF in the pediatric population affected by electrical injury. Electricity has several detrimental effects on the human body: obvious to visual inspection, dermal and sub-dermal structures are destroyed through thermal energy, while obscure and extensive damage to deep muscle compartments can occur secondary to the electricity passing through the body (9,10). Electrical injury can be further sub-classified into HV injury (>1,000 V; HV) or low-voltage injury (<1,000 V), which is an arbitrary classification and only correlates to a degree with injury severity (3,11,12). In our pediatric patient population, the percentage of HV injury was 64%, a rate that is at the high end of the range reported by others (13–67%) (9,13). The wide range of HV injuries described across the literature can be attributed to the fact that a large portion of HV injuries are occupational and thus not common in children, although there also exists an epidemiological accumulation during adolescence.

MOF is one of the leading causes of death in pediatric burn patients (14) and results from a complex cascade of metabolic, inflammatory, and infectious dysregulations that are currently under investigation (6). Here we were able to show that our electrical injury group had a significantly lower incidence of MOF and significantly lower total DENVER2 scores during the first 3 days post burn than a thermal burn control group. This finding may seem contradictory to the notion that electricity inflicts greater damage and more severe morbidity per percent TBSA burned. It is likewise not related to a less severe profile of injury, as mean burn size and the percentage of HV injury are higher in our study group than in most comparable published case series and retrospective reviews (9,10,15). We hypothesize that the reduced incidence of MOF may be attributed, in part, to the early and aggressive debridement of nonviable tissue—often through major amputation of unsalvageable extremities. This approach, as summarized by George et al. (16), may shorten and dampen the inflammatory response that contributes to MOF. Unfortunately, we were not able to show a significant effect of reduced MOF on overall mortality in our study group.

Pulmonary failure was the most common single organ dysfunction, and its incidence was comparable between the two groups, despite the fact that inhalation injury was significantly less often diagnosed in the electrical burn group. One possible explanation for this phenomenon could be under-diagnosis of inhalation injury in the electrical injury group. However, our institution's protocol is to perform diagnostic bronchoscopy upon admission of a burn of any etiology when slight suspicion for inhalation injury is present, making sampling bias an unlikely systematic error. Possible reasons for pulmonary dysfunction following electrical burns may be direct damage to lung parenchyma via the electrical current itself (17) or blunt lung trauma through a shockwave and muscle contraction, as described by Hartford et al. (18). Further research is warranted to identify the specific effects of electricity on pulmonary tissue integrity and function.

In our study population, we diagnosed significantly fewer incidents of cardiac failure, as indicated by the DENVER2 classification, in the electrical burn group during the first 3 days post burn. Although arrhythmia and other cardiac dysfunction are frequently a complication of electrical injury, only a low incidence of cardiac complications has been described during first 24 h in electrically injured adults (19,20). Pediatric patients demonstrate virtually no serious cardiac complications that are relatable to the electric current according to published reviews (3,21).

Renal failure following electrical injury is rare and commonly attributed to extensive muscular destruction and release of myoglobin into the circulation (22). We found no difference in the incidence of renal failure, as indicated by DENVER2 score or need for dialysis. This finding may be attributable to early and radical excision of damaged muscle and other nonviable tissue within the first 48 h post burn.

We also encountered no hepatic failure in the electrically injured subgroup of our study population. This finding is in line with the existing literature on pediatric or adult electrical injury, which provides no specific descriptions of hepatic complications.

On average, our electrically injured patients were hospitalized twice as long per percent TBSA burned as their counterparts with other thermal burns. Prolonged length of stay after electrical injury has been linked to an increased number of surgical procedures, major amputations, and concomitant traumatic injury (9,23,24). We assessed whether single or MOF may contribute to this phenomenon but conclude that there is no specific influence of single or MOF on length of hospitalization in our patient population. The number and types of operations that our patients underwent are in accordance with the findings of others (3,9,20). Unfortunately, major extremity amputation remains a common procedure after electrical injury, especially HV injury.

As we previously described, burn injury entails a systemic inflammatory, hypermetabolic, and catabolic response that can be evaluated through the measurement of cytokine and protein biomarkers over time post burn (6,25). In this study, we conclude that there are no characteristic differences in the cytokine profiles of electrical and other thermal burns.

Limitations and Future Directions

One limitation of this study is its retrospective design; a prospective approach may have yielded even more focused data sets for analysis. Furthermore, the question remains as to what the best way to classify and stratify the severity and prognosis of electrical injury would be. Further research is warranted to determine whether a method of classifying injury severity exists that is more accurate than TBSA burned and high- versus low-voltage injury. The current finding that electrical injury in pediatric patients is associated with a lower incidence of organ dysfunction should not hide the fact that morbidity in this specific patient population arises from various factors other than single and MOF. The high frequency of major amputations poses its own challenge in the rehabilitation of these young patients and beyond.

Conclusions

Electrical injury in pediatric patients is associated with a lower incidence of MOF than other thermal burns. We recommend early and radical excision of nonviable tissue as a mainstay of therapy in electrical injury to improve outcomes after this type of injury. The comparable incidence of pulmonary failure between patients with electrical and thermal burns despite a significantly lower prevalence of inhalation injury in the electrically burned warrants further research into the specific effects of electricity on lung parenchyma.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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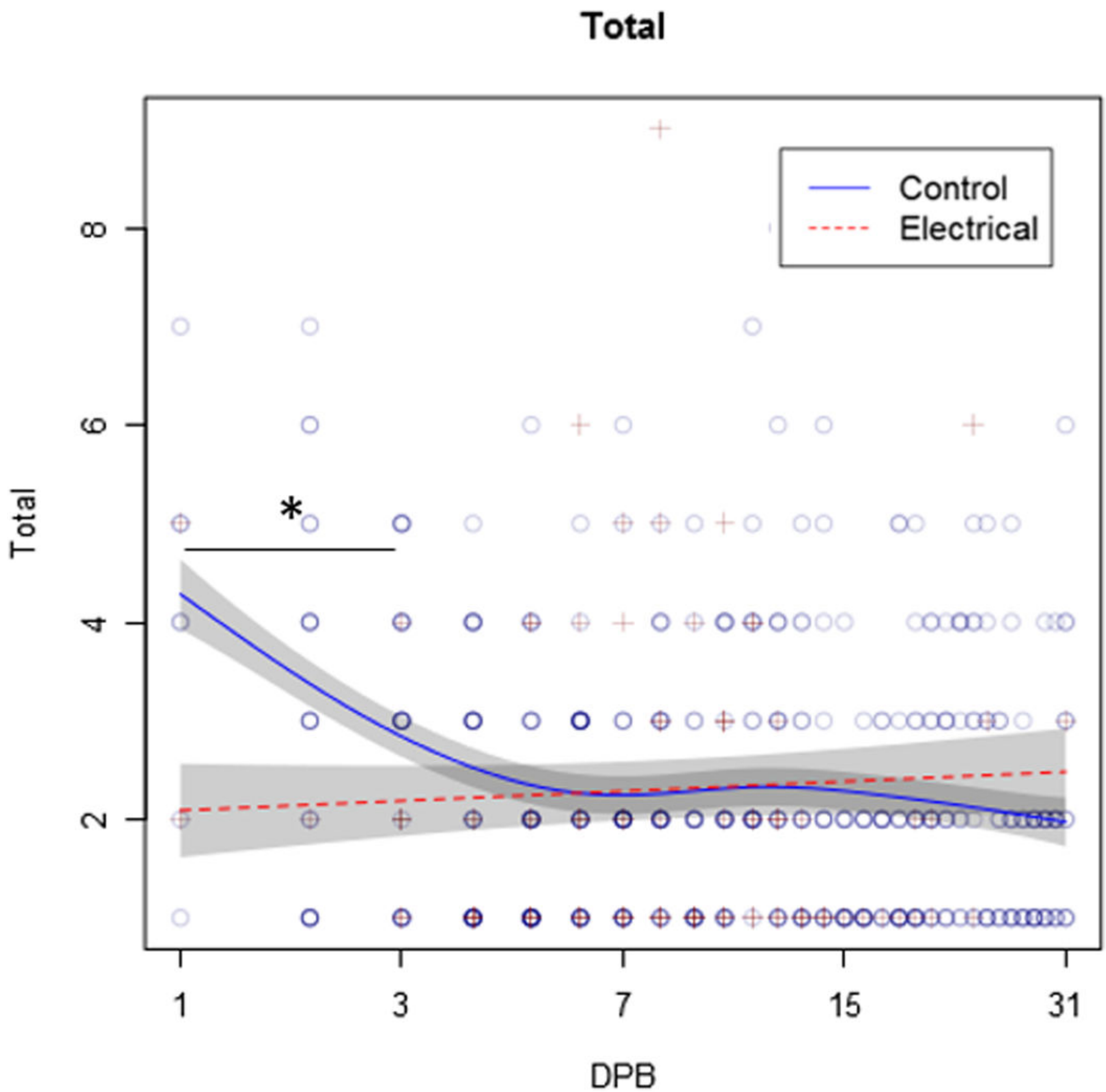

Fig. 1.

Mean DENVER2 compound scores with continuous confidence intervals over time as a continuous variable. DPB: days post burn. *p<0.05, control vs. electrical.

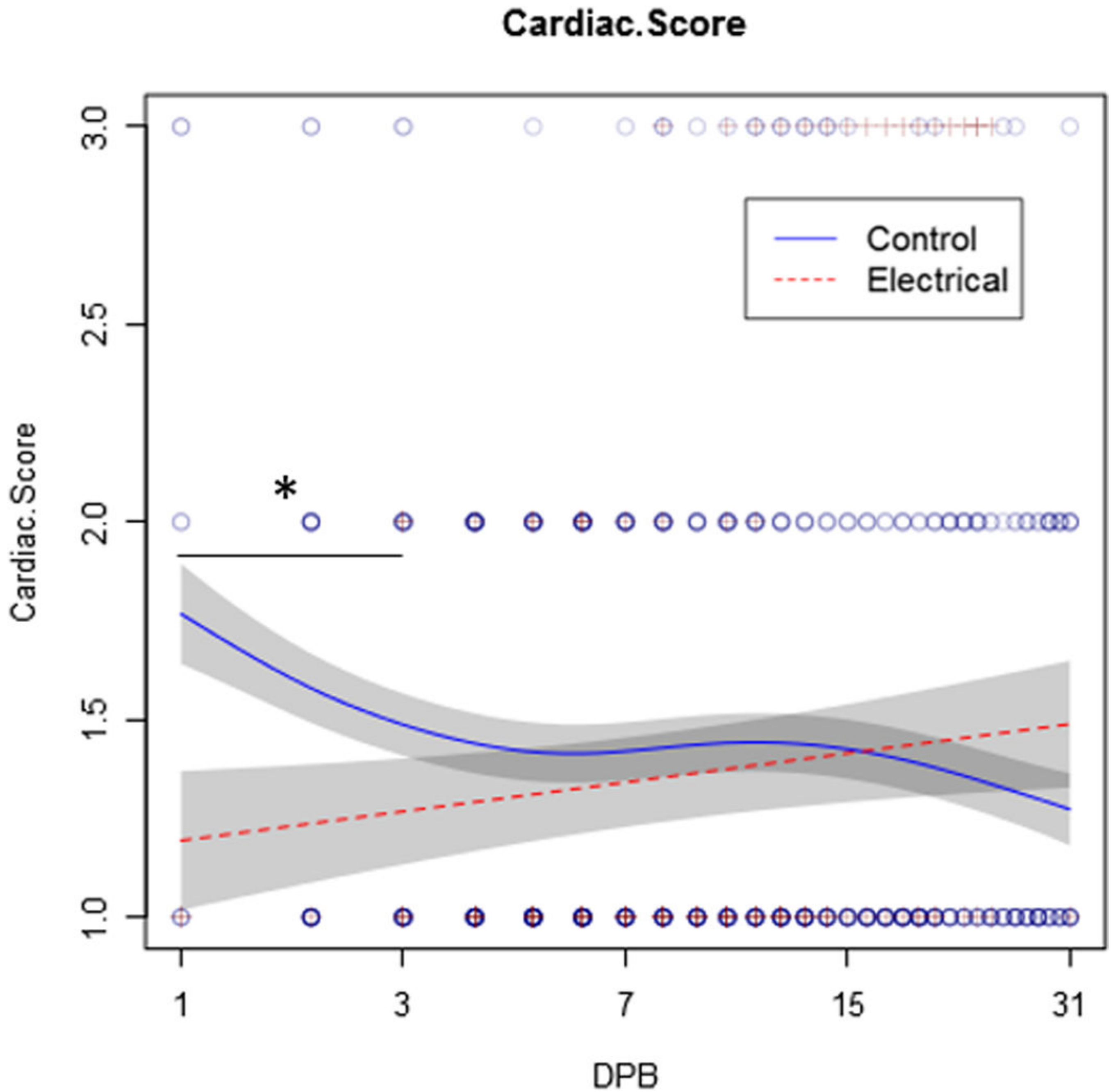

Fig. 2.
Mean DENVER2 cardiac scores with continuous confidence intervals over time as a continuous variable. DPB: days post burn. *p<0.05, control vs. electrical for the first 72 h.

Table 1

Patient characteristics.

Characteristic	Control N=192		Electrical N=96		
	Mean	SD	Mean	SD	p-value
Age at burn, years	11	5	11.0	5	0.84
Sex F:M	63:129	N/A	26:70	N/A	0.32
TBSA burn, %	33	25	32	25	0.65
TBSA third degree burn, %	22	22	21	22	0.81
Burn to admit, days	1	1	1	1	0.83
Length of stay, days	18	26	18	21	0.92

Data presented as mean ± standard deviation or count.

TBSA: total body surface area.

Tables 2

DENVER2 scoring system(7)

Component	Measurement	Score			
		0	1	2	3
Pulmonary	PaO2/FiO2	≥250	175–249	100–174	<100
Renal	Creatinine	≤1.8	>1.8 – 2.5	>2.5 – 5.0	> 5.0
Hepatic	Bilirubin	≤2.0	>2.0 – 4.0	>4.0 – 8.0	> 8.0
Cardiac	Inotrope Medication	none	S	M	L

Patient receives 0 inotrope agents: score = 0

Patient receives 1 agent:

Dose size	S	M	L
Cardiac score	1	2	3

Patient receives 2 agents:

Dose sizes	S,S	S,M	M,M	L,any
Cardiac score	2	2	3	3

Patient receives 3 or more agents: score = 3

Agent	Small Dose	Moderate Dose	Large dose	Units
Dopamine	< 6	6–15	>15	μg/Kg/min
Dobutamine	< 6	6–16	>15	μg/Kg/min
Epinephrine	< 0.06	0.06 – 0.25	> 0.25	μg/Kg/min
Norepinephrine	< 0.11	0.11 – 0.50	>0.50	μg/Kg/min
Phenylephrine	< 0.6	0.6 – 3.0	> 3.0	μg/Kg/min
Milrinone	< 0.4	0.4 – 0.7	> 0.7	μg/Kg/min
Vasopressin	< 0.03	0.03 – 0.07	> 0.07	units/min

Cardiac score is calculated by combination dosage and number of inotrope agents administered.

none= no agents administered; S= small dose; M=moderate dose; L=large dose

Table 3

Incidences of SOF and multiple organ failure.

Organ Failure	Incidence								
	Control (CTR) n=192		Electrical (EB) n=96		p	Kraft et al. n=821[Ⱡ]		p	
	n	%	n	%		n	%	vs. EB	
MOF	20	10.4	2	2.1	**0.017**	157	19.1	< **0.0001**	
Pulmonary	78	40.6	37	38.5	0.73	230	28.0	0.03	
Cardiac	13	6.8	3	3.1	0.2	77	9.4	0.04	
Renal	6	3.1	4	4.2	0.65	16	1.9	0.159	
Hepatic	6	3.1	0	0.0	0.08	23	2.8	0.09	

[Ⱡ]: incidences by Kraft et al (7) for comparison

Table 4

Causes of death, type of electrical injury, and multiple organ failure.

Burn Type	Cause of Death	HV	MOF
Electrical			
1	Sepsis	X	X
2	Sepsis		
3	Renal failure		X
Control			
1	Sepsis		X
2	Sepsis		X
3	Sepsis		X
4	Sepsis		X
5	Sepsis		X
6	Sepsis		X
7	Cerebral infarction		
8	MOF		X

MOF: multiple organ failure; HV: high voltage electrical injury