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A voltage-based analysis of fluid delivery and outcomes in burn patients with electrical injuries over a 6-year period

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ABSTRACT

Introduction: Electrical injuries are associated with significant morbidity for affected patients. While cardiac and surgical interventions have been extensively reported, no practice guidelines or studies have specifically addressed fluid delivery and associated outcomes of patients with electrical injuries. The study objective was to evaluate the differences in fluid delivery in patients with high (≥1000 V) and low (<1000 V) voltage electrical injuries.
Methods: This retrospective, observational study included adult electrical injury patients admitted for acute care. Patients with reported voltages were classified into high and low voltage subgroups. Primary outcomes of fluid administration and urine output over the first 24 h after injury were assessed between subgroups. Secondary outcomes included renal, cardiac, surgical, and additional complications such as mortality, cost, and length of stay.
Results: Data were analyzed in 36 patients with reported voltages, including 26 patients in the high and 10 patients in the low voltage subgroups. Patients in the high voltage subgroup had a statistically significant higher median (IQR) total IV fluid given [46.6 (22.4–61.9) vs. 22.5 (8.3–31.4) mL/kg, p=0.033] in the first 24 h to achieve a similar urine output to the low voltage subgroup. The high voltage patients had higher rates of myoglobinuria, rhabdomyolysis, and creatinine kinase elevation. Patients in the high voltage vs. low voltage group had significantly longer median (IQR) length of stay (days) [11 (2–19) vs. 1 (1–6); p=0.015] and higher cost of hospital stay [$124,608 (19,486–296,991) vs. $16,165 (12,409–69,659); p=0.033].
Conclusions: These results reinforce the importance of assessing electrical injuries and obtaining a voltage to provide patient-specific care, as high voltage electrical injuries receive more fluid than estimated maintenance rates. This study is the first of its kind to characterize fluid given for high and low voltage electrical injuries and effects on patient outcomes.

Abbreviations: %TBSA, percentage of total body surface area; ABLS, Advanced Burn Life Support; AKI, acute kidney injury; CK, creatinine kinase; HV, high voltage; IV, intravenous; LV, low voltage; OSH, outside hospital; SCr, serum creatinine.

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1. Introduction

Although a relatively rare injury sustained by burn patients, electrical injury is a potentially devastating event associated with both short-term and long-term consequences [1]. The 2017 American Burn Association's National Burn Repository Annual Report states electrical injuries represented approximately three percent of all cases reported from 2008 through 2017. Of these, 59% were work-related, mostly occurring in middle-aged, white, males, with additional causes including other accidents and suspected self-inflicted injuries [2].

There are three factors involved that determine the nature of an electrical injury: current, voltage, and resistance. Ohm's Law defines the relationship of these three factors, where current is directly proportional to voltage and inversely related to resistance. Voltage has been divided into high [≥1000 V (HV)] and low [<1000 V (LV)] subgroups in the literature and in practice. High voltage injuries have been known to be associated with deep underlying tissue damage resembling crush injury, while low voltage injuries are generally localized to the immediate surrounding area. Additionally, the type of current (alternating vs. direct) and path of current flow can influence the acuity of electrical injury. The duration and resistance at the point of contact are also important factors. Different tissues within the human body have varying properties, and the following are listed from lowest to highest resistance: nerves, blood vessels, muscle, skin, tendon, fat, and bone. Once the skin resistance is overcome, the path is unpredictable and the damage is ultimately a reflection of the interaction of electricity within the tissues [2,3].

Due to the fact that these injuries are generally uncommon, the literature is limited related to patient-specific recommendations upon presentation for initial assessment and resuscitation, specifically regarding medical management, fluid delivery and goal urine output, resuscitation period, and endpoints. There is a paucity of data in regards to fluid delivery patient-specific calculations, and associated clinical outcomes, especially when stratifying patients based on voltage incurred. Available guideline recommendations are lacking in these areas for managing electrical injury patients as well [4–6]. Previous studies have addressed surgical outcomes such as rates of escharotomies, fasciotomies, amputations, and mortality, but are lacking in medical management strategies and outcomes [7–9]. The objective of this study was to evaluate the differences in fluid delivery in patients with HV versus LV electrical injuries.

2. Methods

2.1. Study setting, design, and participants

This retrospective, observational, chart review was conducted at a 315-bed safety-net (serving all patients regardless of payor status), academic medical center in Indianapolis, IN. The study institution is a Level 1 Trauma Center and Regional Burn Center with 15 inpatient beds within the burn center. Approval was granted by the Indiana University Institutional Review Board prior to initiating data collection. Data were collected from adult patients admitted within 48 h of electrical injury between January 1, 2010 and December 31, 2015. Patients who were pregnant, incarcerated, admitted for a follow-up surgical procedure, and/or left against medical advice were excluded from the analysis. Of the patients who met inclusion criteria, those who had a documented voltage were categorized into HV (≥1000 V) and LV (<1000 V) subgroups for comparison.

2.2. Data collection

Data were collected from the electronic medical record and analyzed retrospectively. Patient demographic information included age, gender, race, weight, height, percentage of total body surface area (%TBSA) involvement, whether the patient was transferred from an outside hospital (OSH), voltage, presence of thermal injury and/or inhalation injury, documented loss of consciousness during injury, and presence of concomitant trauma. Patient complications and outcomes data included presence of cardiac history and/or history of neuropathy, positive urine myoglobin and number of days to resolution, admission creatinine kinase (CK), peak CK, last CK checked, documented rhabdomyolysis and number of days to resolution, admission serum creatinine (SCr), presence of acute kidney injury (AKI) during hospital stay, documented compartment syndrome, whether an initial ECG was obtained, presence of arrhythmias during hospital stay, positive troponins, documented ocular injury and/or neuropathy, initial escharotomy or fasciotomy performed intravenous (IV) fluid delivery over the first 48 h after injury, urine output in the first 48 h after injury, length of hospital stay, cost of hospital stay, and mortality.

2.3. Outcomes

The primary outcome was the difference in IV fluid given and urine output (mL/kg/h) in the first 24 h after injury (defined as the initial resuscitation period) between the HV and LV subgroups. Fluid delivery included the initial rate of fluid (mL/h), maximum rate of fluid (mL/h), total IV fluid given (mL/kg), and ratio of total IV fluid received to Holliday–Segar fluid calculation (mL) in the first 24 h [10].

Secondary outcomes can be divided into four categories: renal outcomes, surgical interventions, cardiac outcomes, and additional complications compared between the HV and LV subgroups. Renal outcomes included comparison of CK values (admission, peak, and final CK checked), presence of myoglobinuria, rhabdomyolysis, and/or acute kidney injury. The presence of compartment syndrome and patients who underwent escharotomies, fasciotomies, and/or amputations were included as surgical interventions. Cardiac outcomes included whether an initial ECG was obtained as part of the study institution's electrical injury protocol, presence of any arrhythmia during hospital admission, and presence of positive troponins. Finally, additional complications included documented ocular injury and/or neuropathy, as well as mortality, length of hospital stay, and cost of hospital stay.

2.4. Statistical analysis

Statistical tests were performed using Minitab® 16 statistical software (Minitab Inc., State College, PA). Normally distributed

data were reported with mean (SD), whereas non-parametric data were reported with median (interquartile range [IQR]). Normality was tested using the Anderson–Darling normality test. The Student's *t*-test was used to detect differences between normally distributed, continuous data. For non-parametric, continuous data, a Mann–Whitney *U* test was used to detect potential differences. The Fisher's Exact or χ^2 tests were used to detect differences in nominal data. The significance level (alpha) was predetermined to be less than 0.05. An a priori power calculation was not performed as this was a convenience sample of all patients meeting inclusion criteria during the define study period. Pearson correlation coefficient (r) was calculated to determine the degree of association between variables.

3. Results

3.1. Patients

A total of 48 patients with electrical injury were identified during the study time period, 42 of which met inclusion criteria. The most common reason for exclusion was patients presenting for follow-up clinic appointments or surgical procedures. The included patients were then further stratified into subgroups of HV and LV, and of the 42 total patients, 36 had voltages reported with 26 in the HV and 10 in the LV subgroups.

Patient demographics are listed in Table 1. The overall cohort, HV, and LV subgroups were well-matched and there were no statistical differences found regarding baseline characteristics. Most patients in the overall cohort were white, middle-aged males, which is consistent with what is reported for electrical injuries in the 2017 American Burn Association's National Burn Repository [2]. Details regarding patient injuries are also found in Table 1. The only difference between the HV and LV subgroups was the HV subgroup had a significantly larger median (IQR) %TBSA when compared to the LV subgroup [5% (2–14) vs. 1% (0.5–3); (p=0.029)]. However, the overall difference in %TBSA was not regarded to be clinically significant by the authors and would have no effect on resuscitation in clinical practice as these patients would be placed on maintenance fluids rather than receive full resuscitation based on their %TBSA. A strong positive correlation was found between voltage and %TBSA (r=0.813; $p<0.001$). All other injury details, such as additional thermal injury, inhalation injury, loss of consciousness during injury event, and concomitant trauma, were well-matched between groups.

3.2. Primary outcomes: fluid delivery and urine output in the first 24 h after injury

Baseline fluid characteristics in the resuscitation period, defined as the first 24 h after injury, were compared between groups and are located in Table 2. Almost all patients in the HV and LV subgroups initially received IV fluids, and the majority of these patients who received IV fluids were initially treated with Lactated Ringer's [18 (81.8%) vs. 5 (55.6%); (p=0.185)]. The study institution's electrical injury protocol dictates the addition of sodium bicarbonate to the resuscitation fluid in the setting of a positive urine myoglobin, and there were no significant differences in the rate of sodium bicarbonate

Table 1 – Patient demographics.

Parameter	Overall (N=42)	High voltage (n=26)	Low voltage (n=10)	P
Background information				
Male, n (%)	41 (97.6)	26 (100.0)	9 (90.0)	0.278
Caucasian, n (%)	39 (92.9)	24 (92.3)	8 (80.0)	0.305
Mean age, years (SD)	43 (13)	42 (12)	49 (14)	0.220
Median weight, kg (IQR)	94.9 (78.7–106.1)	98.8 (87.7–108.5)	83.9 (75.6–112.4)[a]	0.428
Transferred from OSH, n (%)	24 (57.1)	15 (57.7)	5 (50.0)	0.722
Median admission SCr, mg/dL (IQR)	0.99 (0.84–1)	0.99 (0.8–1.0)	1.00 (0.9–1.1)	0.157
Injury details				
Median %TBSA[b], n (IQR)	3 (1–10)	5 (2–14)	1 (0.5–3)	0.029
Additional thermal injury, n (%)	22 (52.4)	14 (53.8)	3 (30.0)	0.274
Inhalation injury, n (%)	3 (7.1)	3 (11.5)	0 (0.0)	0.545
Loss of consciousness, n (%)	15 (35.7)	11 (42.3)	3 (30.0)	0.706
Concomitant trauma, n (%)	3 (7.1)	2 (7.7)	1 (10.0)	1.000

OSH, outside hospital; SCr, serum creatinine; %TBSA, percentage of total body surface area involvement.
[a] n=9.
[b] n=24 for high voltage and n=7 for low voltage.

Table 2 – Fluid characteristics.

Parameter	High voltage	n	Low voltage	n	P
Received IV fluids, n (%)	22 (84.6)	26	9 (90.0)	10	1.000
IV fluid was Lactated Ringer's, n (%)	18 (81.8)	22	5 (55.6)	9	0.185
Sodium bicarbonate was added to fluid, n (%)	8 (36.4)	22	1 (11.1)	9	0.220

utilization between the HV and LV subgroups. This rate also correlated with the number of patients who experienced myoglobinuria, discussed below.

Table 3 displays results for fluid given and urine output over the first 24h after injury. HV patients received a median (IQR) of 46.6mL/kg/day (22.4–61.9) and LV patients received a median (IQR) of 22.5mL/kg/day (8.3–31.4) (p=0.033). The ratio of total IV fluid received compared to the Holliday–Segar fluid calculation (mL) is also reported, with patients in the HV subgroup receiving a mean (SD) of 1.3 (0.60) times and patients in the LV subgroup receiving a mean (SD) of 0.6 (0.30) times the Holliday–Segar estimation (p=0.004). Additionally, patients in the HV subgroup had higher median initial and maximum rates of fluid in the first 24h after injury.

3.3. *Secondary outcomes*

Secondary outcomes are reported in Table 4. In addition to the first 24h after injury, fluid delivery was also assessed in the second 24h after injury, but yielded no statistical difference. In regard to renal outcomes, the HV subgroup had significantly higher rates of reported rhabdomyolysis and myoglobinuria. Fig. 1 shows creatinine kinase outcomes specifically. The HV subgroup had significantly higher admission and peak CK levels but returned to a CK level similar to that of the LV subgroup. There were no statistical differences in the rates of AKI within 48h or at any point during hospitalization. Looking at surgical outcomes, there was no statistical difference in the rates of compartment syndrome, escharotomies, fasciotomies, or amputations; however, no patients in the LV subgroup experienced any of these events. The study institution's electrical injury protocol dictates all patients should receive an initial ECG upon admission, and this was found to be consistent in all patients. There were no statistical differences found in cardiac outcomes such as initial arrhythmias, any arrhythmia during hospitalization, or rates of positive troponins. Finally, there was no difference in the rates of mortality,

Table 3 – Primary outcomes.

Parameter	High voltage	n	Low voltage	n	P
Median initial rate of fluid, mL/h (IQR)	206 (150-294)	22	125 (100-150)	8	0.004
Median maximum rate of fluid, mL/h (IQR)	286 (150-348)	22	125 (100-150)	8	0.001
Median total IV fluid in first 24h, mL/kg (IQR)	46.6 (22.4-61.9)	19	22.5 (8.3-31.4)	5	0.033
Mean ratio of total IV fluid received to Holliday-Segar fluid calculation, mL (SD)	1.3 (0.60)	19	0.6 (0.30)	5	0.004
Mean urine output rate in first 24h, mL/kg/h (SD)	1.09 (0.60)	21	1.03 (0.98)	5	0.904

Table 4 – Secondary outcomes.

Parameter	High voltage (n=26)	Low voltage (n=10)	P
Fluid status (second 24h after injury)			
Median total IV fluid, mL/kg (SD)[a]	32.1 (17.5-43.5)	22.7 (7.0-38.4)	0.475
Renal outcomes			
Myoglobinuria, n (%)	10 (38.5)	0 (0.0)	0.035
Rhabdomyolysis, n (%)	12 (46.2)	0 (0.0)	0.015
AKI within 48h, n (%)	4 (15.4)	0 (0.0)	0.559
AKI at any point during hospitalization, n (%)	6 (23.1)	0 (0.0)	0.157
Surgical interventions			
Compartment syndrome, n (%)	7 (26.9)	0 (0.0)	0.157
Initial escharotomy, n (%)	3 (11.5)	0 (0.0)	0.545
Initial fasciotomy, n (%)	7 (26.9)	0 (0.0)	0.155
Amputations, n (%)	3 (11.5)	0 (0.0)	0.545
Cardiac outcomes			
Initial ECG obtained, n (%)	26 (100.0)	10 (100.0)	1.000
Arrhythmia on initial assessment, n (%)	2 (7.7)	1 (10.0)	1.000
Any arrhythmia during hospital stay, n (%)	6 (23.1)	1 (10.0)	0.645
Positive troponins, n (%)	11 (50.0)	1 (20.0)	0.342
Additional complications			
Documented ocular injury, n (%)	4 (14.4)	1 (10.0)	1.000
Documented neuropathy, n (%)	4 (14.4)	2 (20.0)	1.000
Mortality, n (%)	0 (0.0)	0 (0.0)	1.000
Median length of stay, days (IQR)	11 (2-19)	1 (1-6)	0.015
Median cost, dollars (IQR)	124,608 (19,486-296,991)	16,165 (12,409-69,659)	0.033

AKI, acute kidney injury; ECG, electrocardiogram.
[a] n=14 for high voltage and n=2 for low voltage.

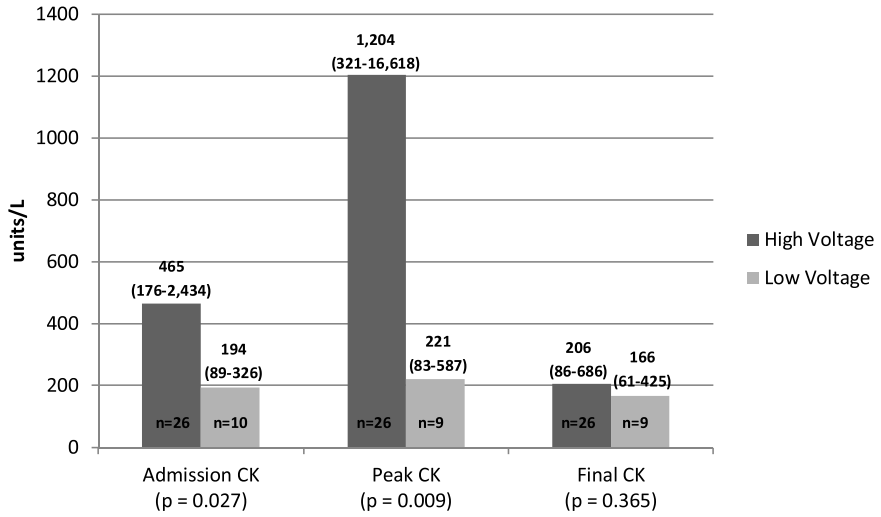

Fig. 1 – Creatinine kinase outcomes.
All values are reported as median (IQR); CK, creatinine kinase.

ocular injury, or reported neuropathy. Of note, all patients who experienced neuropathy were managed with gabapentin. The HV patients had a significantly longer median (IQR) length of stay compared to the LV patients [11 days (2–19) vs. 1 day (1–6); p=0.015]. There was a moderate positive correlation between voltage and length of stay (r=0.549; p=0.007). The HV patients also had significantly higher cost associated with their hospital stay, with a median (IQR) of $124,608 (19,486–296,991) vs. $16,165 (12,409–69,659) in the LV subgroup (p=0.033).

4. Discussion

Guideline recommendations describing electrical injuries are relatively limited. The 2001 American Burn Association Practice Guidelines for Burn Care do not address the management of electrical injuries specifically and have not been updated [4]. In 2006, the *Journal of Burn Care and Research* Practice Guidelines for the Management of Electrical Injuries gave recommendations regarding cardiac monitoring and surgical management, but failed to provide specific recommendations regarding medical management or fluid delivery [5]. The most recent and specific recommendations for the medical management of electrical injuries can be found in the 2016 Advanced Burn Life Support (ABLS) Providers Manual [6]. In the setting of electrical injury, ABLS recommends initial fluid resuscitation with Lactated Ringer's at 4 mL/kg/% TBSA titrated to maintain a urine output of 30-50 mL/h. This fluid resuscitation strategy is often used for major burns (≥20% TBSA), expanding upon the original work of Baxter and Shires [11]. This approach would be inaccurate for patients with electrical injury since most have a %TBSA that would not warrant full resuscitation. This finding was confirmed by a recent meta-analysis of 5485 electrical injury patients with an average % TBSA on admission of 14.0% [12]. Other ABLS recommendations include urine output goals in the setting of myoglobinuria, cardiac monitoring guidance, and a statement that medications for pain and anxiety should be administered [6]. Overall, guideline-based recommendations for medical management are lacking, and there are no voltage-based interventions based on whether a patient sustained a HV or LV electrical injury.

There have been several previously published studies describing the surgical management of electrical injuries; however, there is little guidance on the medical management, specifically fluid given [7–9,12–16]. Hussman et al. [7] evaluated surgical outcomes in high (n=38) and low (n=91) voltage electrical injuries over a 13-year period. While the authors described surgical interventions, amputations, neurological deficits, and other complications among HV and LV subgroups, fluid delivery and medical management were not addressed. Cheema examined the management of electrical versus non-electrical burn injuries and stated fluid resuscitation was initiated, but did not provide any specifics beyond this [13]. Chudasama et al. evaluated length of stay, renal failure, death, and rates of fasciotomy and amputation which were similar to the rates seen in our study, but fluid management or medical interventions were not discussed [16]. Finally, fluid administration and associated outcomes are entirely absent in the recent meta-analysis published by Shih et al., further enforcing the need for our study [12].

Furthermore, those studies that do address fluid management in electrical injury patients do not provide any outcomes-related data or voltage-based recommendations [8,9,17–20]. Arnoldo et al. [8] compared outcomes between HV (n=263) and LV (n=143) subgroups over a 20-year period with a total of 700 electrical injury admissions. The results of this review demonstrated higher rates of fasciotomies, amputations, arrhythmias, and mortality in the HV subgroup (p-values not reported). This review discussed methods related to cardiovascular, surgical, and myoglobinuria-related outcomes. The authors state grossly pigmented urine was treated by immediate administration of 25 g of mannitol and

two ampules of sodium bicarbonate, followed by Lactated Ringer's at a rate to achieve gross clearing of the urine, but the specific rate and duration of IV fluids was not further defined. Furthermore, differences in fluid given and resuscitation outcomes between HV and LV subgroups were not compared. Another study by Cancio et al. evaluated risk factors associated with the need for fasciotomy and amputation in 195 patients with HV electrical injury. Due to the retrospective nature of this study, despite using the Brooke Army Hospital Formula for all patients, the authors report an inability to determine causality between fluid management and clinical outcomes [17]. Finally, Luz et al. [9] evaluated electrical injuries retrospectively over a five-year period. The HV subgroup (n=52) had higher rates of fasciotomies, amputations, acute renal failure, and mortality compared to the LV subgroup (n=17) [p-values not reported]. This review also included information related to cardiovascular, fluid resuscitation, surgical, and topical therapies. For fluid resuscitation, the Brooke Army Hospital formula was used in the initial 24 h after injury with a goal urine output of 30–50 mL/h in the absence of myoglobinuria, but recommendations for type of fluid were not provided. However, fluid given to maintain the goal urine output were not compared or reported between HV and LV subgroups. Overall, the literature does not provide weight-based fluid recommendations, a consistent urine output goal, voltage-based treatment goals, or a definitive duration for fluid resuscitation, nor is there guidance on if electrical injury patients receive full resuscitation. Our study addressed each of these many gaps.

4.1. *Summary of key findings*

In our study, there was a statistically significant difference in the primary outcome of fluid delivery in the first 24 h after injury. The results demonstrate HV patients received more than twice the volume of fluid in terms of their total weight-based amount received and had higher maximum fluid rates in the first 24 h to achieve the same goal urine output as the LV patients. In the initial burn resuscitation period, the amount of fluid needed is often determined by targeting a urine output goal of 0.5–1 mL/kg/h, which patients in both the HV and LV subgroups were able to maintain [21]. As recent data have confirmed, the average electrical injury patient would not be an appropriate candidate for full Parkland or Brooke Army resuscitation calculations. Thus, an alternative method for estimating fluid recommendations in this population is needed.

There are several methods for estimating both maintenance and resuscitative fluid volumes utilized in practice. A quick, useful way to estimate maintenance fluid volumes in clinical practice is to target 30–35 mL/kg/day in each patient, with burn patients often receiving more than this estimation in the initial resuscitation period [22]. Our study demonstrated HV patients received more than this maintenance fluid estimation (46.6 mL/kg/day), while the LV patients received significantly less than this estimation would predict (22.5 mL/kg/day). Additionally, the Holliday–Segar formula is another well-known method for predicting maintenance fluid delivery [10]. During the resuscitative period for burn patients with <20% TBSA, a common strategy for predicting initial fluid delivery is to target 1.5–2 times the predicted maintenance estimations. Our study population showed that patients in the HV subgroup received approximately 1.3–1.5 times their maintenance fluid prediction, while the LV patients received less than their maintenance fluid calculation would predict. In addition, HV patients received higher initial rates and higher maximum rates of fluid during the resuscitative period. This implies if electrical injury patients were resuscitated with their predicted maintenance fluid estimations, regardless of method of prediction, the HV patients would likely be under-resuscitated and the LV patients would likely be over-resuscitated.

We were also able to demonstrate patients with HV electrical injuries had significantly higher admission and peak CK levels, rates of myoglobinuria, and rhabdomyolysis. However, these patients returned to a CK level similar to the LV patients, and there were no differences in the rates of acute kidney injury. This is indicative that our resuscitation was effective in both the HV and LV subgroups, further confirming that HV patients have higher fluid requirements to prevent these undesirable outcomes. Although we were not powered to detect a difference in escharotomies, fasciotomies, amputations, or other interventions, there was a noticeable trend of higher rates in the HV subgroup.

Finally, patients with HV injuries had a significantly longer length of hospital stay and higher cost of hospital stay, further supporting the hypothesis HV injuries are more severe than LV injuries. The HV patients were admitted for a median of 10 days longer than the LV patients. At our burn center, the majority of LV patients are maintained under observation status in the emergency department and are discharged for follow-up in clinic without requiring admission. The difference in median cost of hospital stay between the HV and LV subgroups was $108,443. The median cost of hospital stay per patient in our overall cohort was $36,543 with an absolute range of $4761–$619,088. Previous literature, although limited, has described a difference in average length of stay ranging from 8 to 27 days between HV and LV electrical injuries with mean cost of hospitalization $14,901 and an overall range of $900–$120,000 (of note, this data has not been adjusted for inflation) [7,16]. Our study adds to the available literature regarding the cost of hospitalization for patients with electrical injury, as published data is lacking in these regards.

4.2. *Strengths and limitations*

Noted strengths of this study include the six-year study period with HV and LV subgroups well-matched at baseline. Specifically, there were no differences in patient weights, rates of transfer from an outside hospital, or admission SCr values, all of which could have been potential confounders in the amount of fluids the patients received. Our study was the first to directly address fluid estimations and effect outcomes to our knowledge. We were also able to demonstrate patient-specific, weight-based fluid estimations based on voltage to maintain the same urine output goal in HV and LV electrical injury patients.

The major limitations of our study include the retrospective, single-center study design, and a small sample size. However, the small sample size is consistent with previously reported literature and low rates of electrical injury reported

nationally in the 2017 American Burn Association's National Burn Repository [2]. This small sample size may have contributed to the lack of statistical significance in many of our secondary outcomes, although this was beyond the scope of our study aims. There were also charting inconsistencies due to the retrospective study design, primarily with respect to recorded voltages. A total of six patients could not be stratified into the HV and LV subgroups due to lack of reported voltage associated with their injuries. While this limits our overall sample size, this does not affect data analyzed in our subgroups with reported voltage. Finally, our study is limited because it is unable to demonstrate causality due to its retrospective nature. While we are unable to directly account for patient outcomes due to fluid resuscitation methods, this likely had a significant effect. With a lack of clear, standardized treatment guidelines, there is no way to do a prospective, randomized study in this patient population.

5. Conclusions

Results from this study indicate it is important to obtain an accurate voltage to properly assess electrical injuries to provide patient-specific care. A standardized, systematic approach utilizing targeted interventions is indicated to care for electrical injury patients. Similar to what has been previously demonstrated with surgical management, a varied approach is needed in the medical management between HV and LV electrical injuries. Patients with HV electrical injuries need approximately 45-50 mL/kg/day (approximately 1.3-1.5 times maintenance fluid estimations), while those with LV electrical injuries receive approximately 30-35 mL/kg/day (normal maintenance fluid estimations) to maintain adequate urine output during resuscitation based on the results of this study. Future studies warrant a prospective evaluation of an electrical injury protocol which provides patient-specific fluid recommendations based on voltage type in addition to surgical management. Additionally, future studies could consider a longer study period or a multi-center approach to target a larger patient population.

Conflicts of interest and source of funding

None declared.

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