Results of microbiological surveillance in patients with high-voltage eletrical injuries: A 10-year single center experience

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ABSTRACT

Background and Aim: High voltage electrotrauma is one of the most serious injuries we can encounter in modern medicine, often associated with multiple disabilities and high susceptibility to infectious complications. These patients are admitted to specialized burn centers and require extensive multidisciplinary collaboration. In this study, we aim to uncover the prevalence, types and characteristics of microbial infections that develop in the aftermath of high voltage electrotrauma and to identify risk factors that may contribute to patients' susceptibility to infections.

Material and Methods: For the purposes of this publication, data of all 37 patients hospitalized in the intensive care unit of the Department of Burns and Plastic Surgery of the University Hospital in Brno with a diagnosis of high-voltage electrical injury between 2006–2016 were processed. Imprints and swaps from exfoliated areas were repeatedly taken for microbial analysis, together with tracheobronchial aspirate fluid, sputum, or bronchoalveolar lavage, urine and peripheral blood. The obtained data were analysed retrospectively.

Results: Among the 37 patients, the median age was 31.9, with an average hospital stay of 44.3 days and a mortality rate of 8.1%. A total of 28 individuals were dependent on artificial lung ventilation. The incidence of infectious complications varies during the hospitalization period according to the location of sampling cultivation and time spent at the hospital. 97.3% of patients developed infection in at least one body compartment. In 88.8% of cases, it was multipathogenic and in 41.6% a septic condition developed. In our study cohort, G+ dominated over G- strains. Most common representatives from G+ spectrum were Coagulase negative *Staphylococci* (97%), *Staphylococcus aureus* (57%), *Enterococcus fecalis et faecium* (51%). In G- spectrum, the order was as followed: *Klebsiella pneumoniae* (46%), *Pseudomonas aeruginosa* (41%), *Escherichia coli* (35%) and *Acinetobacter baumannii* (18.9%). The most common infection observed was burn wound infection (BWI), followed by bloodstream infections (BSI), lower respiratory tract infections (LRTI), and urinary tract infections (UTI), primarily caused by G+ pathogens. Notably, an increased hospital stay duration was associated with a rising prevalence of G- pathogens, particularly *K. pneumoniae P. aeruginosa* and *A. baumannii* which exhibited a high degree of antimicrobial resistance.

Conclusion: This study provides a detailed insight into the occurrence and consequences of high-voltage electrical injuries in Moravia over a decade. Factors significantly impacting survival and severity of outcomes included total burn surface area, full-thickness burns, inhalation injury, and the need for tracheostomy. However, the study is limited by its relatively small sample size, long data collection period with potential changes in clinical practice, and single-center design, which may affect the generalizability of the findings. Further multicentric studies are needed to validate these results and refine infection prevention strategies in this patient population.

KEY WORDS

eletrical burn injury – microbiological surveillance – ICU care – burn wound – nosocomial infection – *Pseudomonas aeruginosa*

SOUHRN

Váňa V., Lipový B., Cvanová M., Hanslianová M., Holoubek J.: Výsledky mikrobiologického šetření u pacientů s úrazy elektrickým proudem: 10letá zkušenost v jediném centru

Cíl: Úraz elektrickým proudem z vysokého napětí je jedním z nejzávažnějších úrazů, se kterými se můžeme v moderní medicíně setkat. Často bývá spojený s více následky a vysokou náchylností k infekčním komplikacím. Tito pacienti jsou přijímáni do specializovaných popáleninových center a vyžadují rozsáhlou multidisciplinární spolupráci. V této studii se snažíme odhalit prevalenci, typy a charakteristiky mikrobiálních infekcí, které se vyvíjejí po vysokonapěťovém elektrotraumatu, a identifikovat rizikové faktory, které mohou přispívat k náchylnosti pacientů k infekcím.

Materiál a metodika: Pro účely této publikace byla zpracována data všech 37 pacientů hospitalizovaných na jednotce intenzivní péče Kliniky popálenin a plastické chirurgie FN Brno s diagnózou úraz elektrickým proudem vysokým napětím v letech 2006–2016. Otisky a stěry z exfoliovaných oblastí byly opakovaně odebírány k mikrobiální analýze spolu s tracheobronchiálním aspirátem, sputem nebo bronchoalveolární laváží, močí a periferní krví. Získaná data byla zpětně analyzována.

Výsledky: Mezi 37 pacienty byl medián věku 31,9 s průměrnou dobou hospitalizace 44,3 dne a úmrtností 8,1 %. Na umělé plicní ventilaci bylo závislých celkem 28 osob. Výskyt infekčních komplikací se v průběhu hospitalizace liší podle místa kultivace odběru a doby strávené v nemocnici. U 97,3 % pacientů se vyvinula infekce alespoň v jednom tělesném kompartmentu. V 88,8 % případů byla multipatogenní a ve 41,6 % se rozvinul septický stav. V naší studijní kohortě dominovaly G+ nad G-kmeny. Nejčastějšími zástupci z G+ spektra byli koaguláza negativní stafylokoky (97 %), *Staphylococcus aureus* (57 %), *Enterococcus fecalis et faecium* (51 %). V G-spektru bylo pořadí následující: *Klebsiella pneumoniae* (46 %), *Pseudomonas aeruginosa* (41 %), *Escherichia coli* (35 %) a *Acinetobacter baumannii* (18,9 %). Nejčastější pozorovanou infekcí byla infekce popálenin (BWI), následovaná infekcemi krevního řečiště (BSI), infekcemi dolních cest dýchacích (LRTI) a infekcemi močových cest (UTI), primárně způsobené G+ patogeny. Je pozoruhodné, že delší doba hospitalizace byla spojena s rostoucí prevalencí G-patogenů, zejména *K. pneumoniae, P. aeruginosa* a *A. baumannii*, které vykazovaly vysoký stupeň antimikrobiální rezistence.

Závěr: Tato studie poskytuje podrobný pohled na výskyt a následky úrazů elektrickým proudem s vysokým napětím na Moravě v průběhu desetiletí. Faktory významně ovlivňující přežití a závažnost výsledků zahrnovaly celkovou plochu popálenin, popáleniny v celé tloušťce, inhalační poranění a potřebu tracheostomie. Studie je však limitována relativně malou velikostí vzorku, dlouhou dobou sběru dat s potenciálními změnami v klinické praxi a jednocentrovým designem, což může ovlivnit zobecnění nálezů. K ověření těchto výsledků a zpřesnění strategií prevence infekcí u této populace pacientů jsou zapotřebí další multicentrické studie.

KLÍČOVÁ SLOVA
úraz elektrickým proudem – mikrobiologický dohled – péče na JIP – popáleninová rána – nozokomiální infekce – *Pseudomonas aeruginosa*

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INTRODUCTION

By its nature and consequences, high voltage electrotrauma (ET) is one of the most serious injuries we can encounter in modern medicine. Not only is it unique pathophysiology associated with the effect of the passage of electrical voltage through human tissue, but also a few number of associated disabilities in connection with the mechanism of injury [1]. Worldwide, electric shocks represent more than 3.000 patients admitted to specialized burn centers each year. Of this total, about 1.000 are fatal [2]. Electrical injuries are commonly categorized into different types, including high voltage (above 1000V), low voltage (below 1000V), "flash burn" (resulting from electrical discharge but without current passing through the patient), and injuries caused by lightning strikes [3, 4].

The treatment of such patients is a major challenge and often requires extensive multidisciplinary collaboration [5]. It is the presence of a number of associated injuries, together with the systemic effect of electric current and high susceptibility to infectious complications, that contributes to the often-devastating consequences and overall lethality of those affected.

Advancements in effective resuscitation, stabilizing patients' hemodynamics, ensuring proper nutrition, and successfully treating inhalation injuries have enhanced the chances of survival for individuals with burns [6–8]. While the initial phase of burn care can be effectively handled, a significant and persistent challenge is the risk of infection-related deaths and potential for secondary complications, particularly those arising from microbial infections among burn patients during their hospitalization [9, 10]. The Centers for Disease Control and Prevention (CDC) have documented the highest rates of bloodstream infections in burn patients with central venous lines, likely to originate from burn wounds. As in patients with burns, infectious complications represent a significant proportion of mortality and morbidity in patients with high-voltage electro trauma. In patients with this type of injury, we can expect different representatives of individual potentially pathogenic microorganisms than in patients with burns. Given the structure of the wounds, presence of the deep tissue damage creates ideal conditions for microbial colonization and subsequent infections due to compromised tissue integrity and impaired immune responses [11]. The combination of burn wounds, tissue necrosis, and altered microenvironments provides an excellent growth medium for various potentially pathogen microorganisms, including bacteria, fungi, and viruses. Having such an environment, it is not surprising that anaerobic microorganisms are also more prevalent in the etiology of infectious complications [12]. As such, a thorough understanding of the microbial dynamics following high-voltage electro trauma is crucial for informed clinical decision-making, appropriate antibiotic management, and improved patient outcomes.

In this study, we embark on a comprehensive exploration of the multifaceted landscape surrounding high-voltage electro trauma, with a specific focus on its associated injuries and the imperative role of microbiological surveillance. Through a meticulous analysis of clinical cases, wound cultures, and patient data, we aim to uncover the prevalence, types, and characteristics of microbial infections that develop in the aftermath of high-voltage electro trauma. Additionally, we seek to identify risk factors that may contribute to the susceptibility of patients to infections, as well as potential strategies for preventing and managing these complications effectively.

MATERIAL AND METHODOLOGY

For the purposes of this publication, data of all 37 patients hospitalized in the intensive care unit of the Department of Burns and Plastic Surgery of the University Hospital in Brno with a diagnosis of high-voltage electrical injury between 2006–2016 were processed. The basic epidemiological indicators were evaluated, the spectrum of associated injuries was described together with their consequences, and the rate and causes of infectious complications in such affected patients were identified.

Samples collection

Imprints and swaps from exfoliated areas were repeatedly taken for microbial analysis, as well as the tracheobronchial aspirate fluid (TBAS), sputum, or bronchoalveolar lavage (BAL), urine and peripheral blood. The presence of bacteria, yeasts and filamentous fungi was detected in the primary examination. Blood agar, chocolate agar, MacConkey agar (selective agar for Gram-negative microbes), blood agar with NaCl (selective medium for *Staphylococcus* sp.), Wilkins Chalgren agar (for the culture of anaerobic microorganisms), URIselect (chromogenic medium for detection of both G+ and G- microorganisms enabling detection according to the color change), and Sabouraud agar (selective medium for yeasts and filamentous fungi) were used as cultivation media. Incubation period and condition were set for 18–24 hours at 35–37 °C, blood agar and chocolate agar in the atmosphere with increased pCO_2, anaerobic (Wilkins Chalgren) agar in the anaerobic atmosphere, remaining media in the normal atmosphere. Negative cultivation after 24 hours was subsequentlly extended up to 48–72 h. Blood culture tubes were cultured in the automatic system (Bactec, Becton Dickinson, UK) for 6 days. Sabouraud agar was incubated for 6 days at a temperature of 28–30 °C for yeast culture and for 7 days at a room temperature for filamentous fungi culture. MALDI-TOF (Matrix Assisted Laser Desorption/Ionization) was used for microorganisms' identification base ond the mass scpetrum od the microorganisms.

Imprints from the burn wounds

Frequent microbiological surveys are necessary for detailed and accurate monitoring of wound colonization. Only in this way is it possible to capture adequate process dynamics, thanks to which it is possible to prevent the progression of colonization in local and thus systemic infection. Furthermore, thanks to this, it is possible to strictly manage local and systemic therapy. Surface wound imprints were taken by placing strips of sterile filtration paper (5x5 cm) on the exfoliated surface and immediately transferred on the blood agar [13, 14]. The medium was transported into the microbiological laboratory in the shortest time possible.

Swabs from the burn wounds

Sterile cotton swabs were used for swabs from wound surfaces (anaerobic culture). Swabs were immediately after sampling immersed into the transport Amies medium (Amies, COPAN, Italy). After transportation into the microbiological laboratory, the material was transferred on the culture medium.

Samples from upper and lower respiratory tract

Samples from airways were collected during bronchoscopy. Biological material from the area of the upper and lower respiratory tract, cultured on the aforementioned media; a microscopic mount was always prepared as well.

Urine samples

9 mL of urine were collected into a sterile test tube and 1 µL samples were transferred on the culture media with a calibrated inoculation loop.

Blood samples

5–10 mL of peripheral blood was taken for culture and immediately they were inoculated into special blood culture tubes (BACTEC Plus Aerobic, BACTEC Lytic Anaerobic, Becton Dickinson, UK). The tubes were transported to the microbiological lab and samples were analyzed using an automated culture device (Bactec, Becton Dickonson, UK).

ABSI (Abbreviated Burn Severity Index)

We also employed an essential parameter known as the Abbreviated Burn Severity Index (ABSI) scoring system [15] in our study. The ABSI scoring system considers five primary risk factors, assigning points to each: gender (1 point), age (5 points), total body surface area (TBSA) affected (10 points), inhalation injury (1 point), and full-thickness burns (1 point). This index allows us to estimate survival probabilities that range from less than 10% to greater than 90%. Accurate mortality prediction plays a critical role in assessing the prognosis of each patient. The ABSI scoring system offers a comprehensive tool for evaluating the quality of care provided to patients in burn centers.

Statistical analysis

The data obtained were statistically processed with the help of the Institute of Biostatistics and Analysis of the Faculty of Medicine of Masaryk University. Due to the abnormality of the data distribution, continuous variables are described with the median and quartile range. For comparison purposes with other publications in which the median values do not appear, we have added the mean value with a standard deviation to the tables. Category variables are described with the number (n) and percentage (%) of patients in the defined groups. The Mann-Whitney (MW) test was used to compare the probability of distribution of continuous or ordinal variables between two groups of patients. A non-parametric test was chosen due to violation of the assumption of data normality. Given the low expected frequencies in the contingency tables, the independence of the two categorical variables was evaluated using Fisher's exact test. The results of statistical tests are given with p values. The significance level was set at 0.050.

RESULTS

Basic epidemiological parameters

From the obtained data of 37 patients after high-voltage electro trauma, we described the basic modalities, when the average age of patients in the group slightly exceeded 30 years (median 31.9), these patients spent an average of 44.3 days in hospital and a total of 3 patients died (8.1%). Of the total number, 28 individuals (75.7%) were at least part of the hospitalization dependent on artificial lung ventilation, and 17 of them (60.7%) underwent early tracheostomy. In a total of 19 patients (51.4%), the passage of electric current was identified. The above is summarized in Table 1 together with the effect on the lethality of the cohort. The extent of full thickness burn area (FTBA) had a statistically significant effect on the lethality of patients.

Abbreviated Burn Severity Index

In our study group, we observed the following distribution of ABSI scores (Table 2): 1 patient (2.7%) in the

Table 1. Basic epidemiological parameters of the study group

		Death			
		Total N = 37	**Yes n = 3**	**no n = 34**	**p-value[2]**
Age		33 (21; 39)/32 ± 12	43 (21; 56)/40 ± 18	33 (21; 37)/31 ± 11	0.319
Sex	**male**	37 (100%)	3 (8.1%)	34 (91.9%)	–
Electricity passing	**yes**	19 (100%)	2 (10.5%)	17 (89.5%)	1.000
	no	18 (100%)	1 (5.6%)	17 (94.4%)	
TBSA in %		22 (10; 52)/31 ± 23	61 (35; 75)/57 ± 20	20 (10; 50)/29 ± 22	0.071
FTBA		6 (2; 21)/16 ± 19	50 (35; 61)/49 ± 13	6 (2; 16)/13 ± 17	**0.011**
Mechanical ventilation	**yes**	28 (100%)	3 (10.7%)	25 (89.3%)	0.562
	no	9 (100%)	0	9 (100%)	
Duration of MV		7 (2; 12)/8 ± 8	8 (2; 18)/9 ± 8	7 (0; 12)/8 ± 8	0.733

[1]Sex, electricity passing and mechanical ventilation are described by the number and percentage representation of the patients, who died and survived. The median with quartile range and mean with SD describe the remaining continuous variables.

[2]For the continuous variables, Mann-Whitney test was used; for the categorical variables, Fisher's exact test was used.

TBSA (total body surface area), FTBA (full-thickness burned area), MV (mechanical ventilation)

Table 2. Summary of the survival in the study group according to the ABSI score

ABSI score group	Survived patients	Predicted survival	Actual survival	Difference
2–3	1/1	>99%	100%	within range
4–5	16/16	98%	100%	>2%
6–7	6/6	80–90%	100%	>10%
8–9	10/11	50–70%	90%	>20%
10–11	1/3	20–40%	33%	within range
12–13	0/0	>10%	N/A	N/A

2–3 score range, 16 patients (43.2%) in the 4–5 score range, 6 patients (16.2%) with scores between 6 and 7, 11 patients (29.7%) scoring 8–9, and 3 patients (8.1%) with severe burns in the 10–11 score range. Notably, there were no patients (0.0%) in our study group falling within the 12–13 score range.

Table 2 provides a clear overview of the ABSI scores observed in our patient population, helping us assess the severity and prognosis of burn cases in our study.

The overall mortality in our group was 8.1% (n = 3). The patients were categorized into six distinct score groups, and we computed the variance between the observed survival rates and the predicted survival rates. In our group of patients, we recorded relatively big difference between predicted and actual survival in moderately severe (6–7) and serious (8–9) ABSI score group and we stayed within range in severe (10–11) and very low (2–3) ABSI score group. Additionally, we did not have any patients with the maximum number of points (12–13).

Microbiology and infectious complications

The incidence of infectious complications caused by pathogens over time. The obtained data were divided not only according to the location of sampling for cultivation (urinary system, lower respiratory tract, bloodstream and exfoliated areas), but also depending on time period (1st–5th day, 6th–10th day, 11th–15th day, day 16 and more). Almost all patients 97.3% (n = 36) developed infection in at least one body compartment. In 32 cases (88.9%) it was a multipathogenic agent and in 15 (41.7%) cases a septic condition developed. The spectrum is dominated by representatives from the G + strains of bacteria (n = 35), compared to G- (n = 24), and the smallest group consisted of representatives of micromycetes (n = 4). In the spectrum of gram-positive bacteria, the most common representatives were Coagulase negative Staphylococci (97.3% patients), *Staphylococcus aureus* (56.7% patients), *Enterococcus fecalis et faecium* (51.3% patients) and *Streptococcus sp.* (40.5% patients). In gram negative spectrum, which was much less frequent, the most common were *Klebsiella pneumoniae* (45.9% patients), *Pseudomonas aeruginosa* (40.5% patients) and *Escherichia coli* (35.1% patients). *Acinetobacter baumannii* was cultivated in only 7 patients (18.9%).

In the following figure 1, we present complete infection data showing close relationship between duration of hospitalization and development of infection complication. Statistically significant data appear more during long-term hospitalization (detailed results are specified in the section "The incidence of pathogens in particular compartment"). In other words, with increasing patient hospitalization, there is an exponential increase in the incidence of infection.

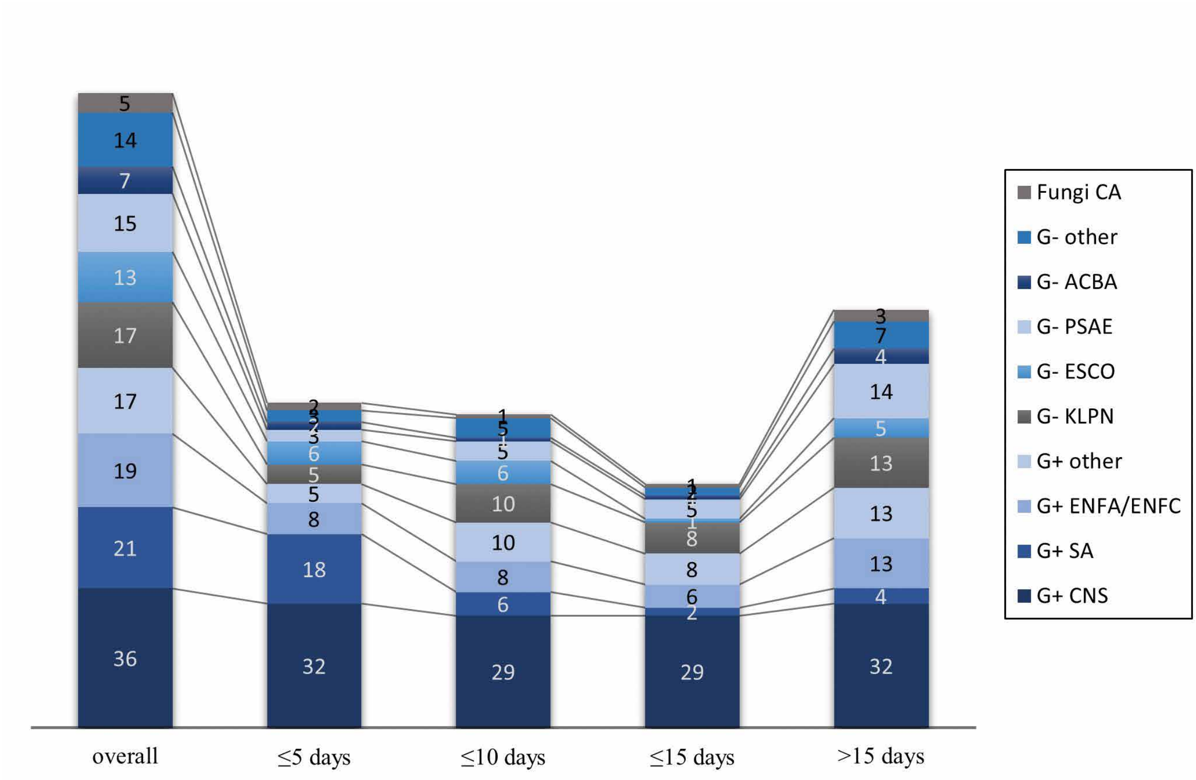

Figure 1. The incidence of pathogens according to the time period

CA – *Candida albicans*, G- other – *Serratia marcescens*, *Enterococcus cloacae*, *Proteus* sp., ACBA – *Acinetobacter baumannii*, PSAE – *Pseudomonas aeruginosa*, ESCO – *Escherichia coli*, KLPN – *Klebsiella pneumoniae*, G+ other – *Streptococcus* sp., ENFA/ENFC – *Enterococcus faecalis/faecium*, SA – *Staphylococcus aureus*, CNS – Coagulase negative Staphylococci

The incidence of pathogens in particular compartment

The following data reveal the development of infections in individual compartments during the hospitalization of patients. Within the first 5 days, infections were observed in nearly all 37 patients, n = 35 (94.6%), with a prevalence of G+ pathogens over G- (34:14). Fungal infections were detected in 3 out of 35 infected patients (8.6%). The most common pathogens were Coagulase negative *Staphylococci* (91.4%), followed by *S. aureus* (51.4%), and *Streptococcus sp.* (31.4%). The most infected cohorts were burned wound infection (BWI) and lower respiratory tract infection (LRTI), 97.1% and 45.7% respectively. Infections of the urinary tract occurred in only 2 patients (5.7%), while bloodstream infections occurred in 9 patients (25.7%) from the infected cohort. When comparing the different compartments regarding confirmed pathogens, G+ infections were prevalent almost everywhere except the urinary tract, where the balance between G+ and G- was equal. Fungal infections were confirmed in the lower respiratory tract in 3 patients (8.6%) and in the bloodstream in 1 patient (2.9%) within the first 5 days. No presence of fungi was detected in the burned area or the urinary tract.

In the time frame from the 6th to the 10th day of hospitalization, infections were confirmed in 31 out of 36 patients (86.1%) as one patient out of our 37 patient's cohort had passed away during the first 2 days of hospitalization. G+ pathogens still prevailing (29 : 17) over G-. In terms of individual pathogens, Coagulase negative Staphylococci continued to dominate (93.5%), but *K. pneumoniae* (32.2%) moved into the second position, followed by *E. faecalis et feacium* (25.8%), and a notable contribution from *P. aeruginosa* (16.1%). Fungal infections were confirmed in 2 patients (6.5%) in the burned areas. In the lower respiratory tract compartment, G- pathogens started to outnumber G+ (9 : 8).

From the 11th to the 15th day of hospitalization, we confirmed infectious complications in 30 (88.2%) out of 34 patients, as another 2 patients had passed away before this time frame commenced. The dominance of G+ pathogens remained significant (30 :12), and fungal infections were only confirmed in 1 patient (3.3%). The distribution of individual pathogens did not change significantly, with Coagulase negative Staphylococci (96.6%) continuing to dominate, followed by *K. pneumoniae* (26.6%), *E. faecalis* (20%), and *P. aeruginosa* (16.6%). The most frequently affected compartment was the burned area, n = 28 (93.3%), followed by bloodstream infections, n = 11 (36.6%). G+ pathogens dominated in all compartments again. Fungal infections were only confirmed in the compartment of burned areas.

We observed a significant increase in the prevalence of *P. aeruginosa* (43.8%), *K. pneumoniae* (40.6%), and *E. faecalis* (40.6%) in patients hospitalized for more than 15 days where infections were confirmed. This

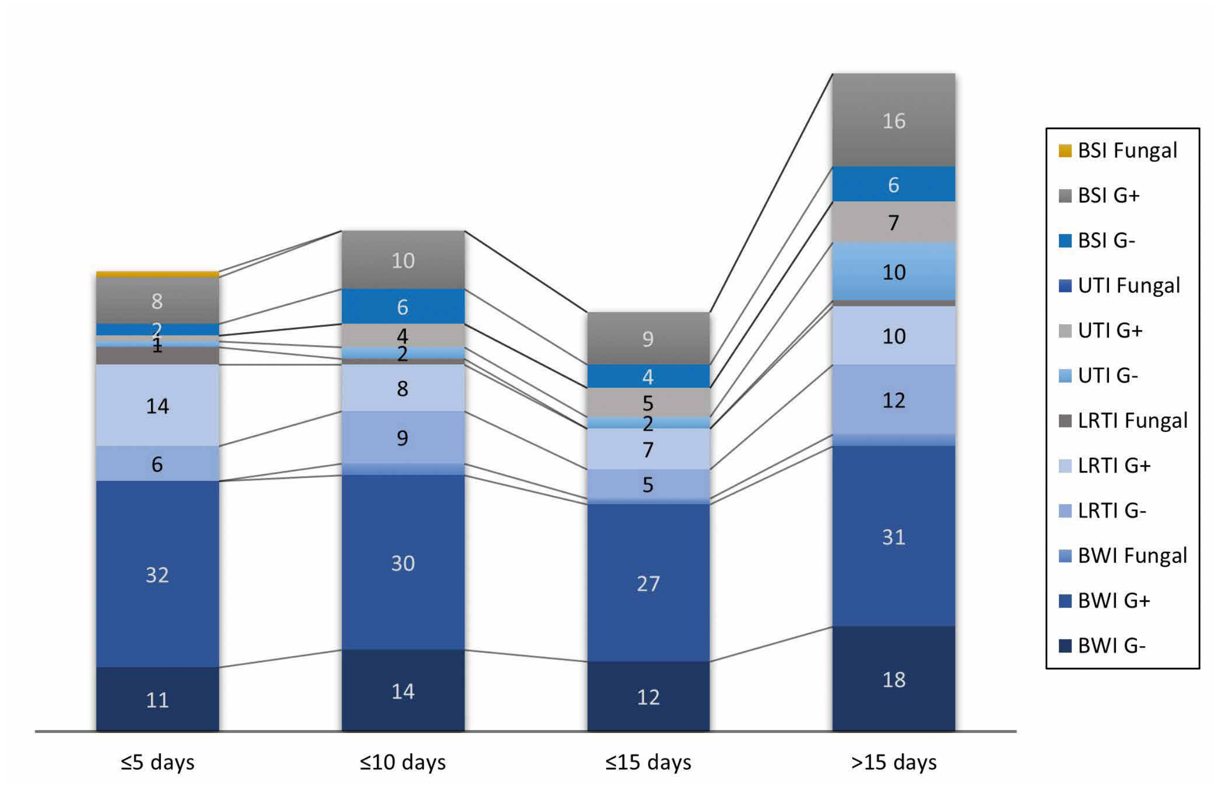

Figure 2. The incidence of pathogens in particular compartment

BSI – blood stream infection, UTI – urinary tract infection, LRTI – lower respiratory tract infection, BWI – burned wound infection was observed in 32 (97.0%) out of 33 cases. The prevalence of *A. baumannii* increases fourfold with an extended hospital stay, reaching a 12% occurrence rate. Pathogens that were not previously detected have also appeared, including *Streptococcus pneumoniae* n = 3 (9.4%), and fungal infections were confirmed in 3 patients (9.4%) in the compartment of burned areas (2) and the lower respiratory tract (1). Dominance of G+ pathogens is only present in the burned areas and bloodstream. G- pathogens dominate in the compartments of the lower respiratory tract (12 10) and urinary tract (10 : 7). The above-mentioned information is depicted in the Figure 2.

The incidence of LRTI in patients dependent on artificial pulmonary ventilation

Another parameters under observation was the incidence of Lower Respiratory Tract Infections (LRTI) in patients dependent on artificial pulmonary ventilation. In our study group, LRTI emerged as the second most frequent complication during the first 10 days of hospitalization and as the third most frequent complication as the stay at the hospital progressed.

Among the 28 patients dependent on artificial pulmonary ventilation, 15 (53.6%) developed LRTI within the first 5 days (Table 3). Notably, one non-ventilated patient also developed LRTI. The prevalence of G+ pathogens significantly exceeded G- ones (13 : 6). Fungal infections were detected in 10.7% (3) of ventilated patients.

Between the 6th and 10th day of hospitalization, LRTI was confirmed in 13 out of 27 intubated patients (48.1%). During this period, G- pathogens began to dominate over G+ (8 : 9), while fungal LRTI was confirmed in only one patient (7.7%). Moving forward to the 11th to 15th day of hospitalization, only 9 out of 26 ventilated patients developed LRTI (34.6%), with G+ again prevailing (7 : 5) over G-. Notably, no LRTI caused by fungal pathogens was confirmed in this time frame.

After 15 days of admission, LRTI began to dominate again, with a 66.7% increase (9 to 15) compared to the previous time frame. G- pathogens prevailed over G+ (10 : 12), and fungal LRTI was confirmed in one patient.

The incidence of LRTI in patients dependent on artificial pulmonary ventilation with tracheostomy

The provided data unveils the development of infectious complications in the lower respiratory tract in ventilated patients with tracheostomy. Out of a total of 28 patients dependent on artificial pulmonary ventilation, tracheostomy had to be performed in 17 (60.7%) of them (Table 4). In the first 5 days post-trauma, LRTI (Lower Respiratory Tract Infection) was observed in 11 out of 17 patients with tracheostomy (64.7%). In patients without tracheostomy, the ratio was significantly lower. Only 4 out of 11 patients (36.4%) developed LRTI in the first 5 days. G+ bacteria dominated among pathogens in patients both with and without tracheostomy. G- pathogens were absent in the group

Table 3. Development of infectious complications in patients dependent on artificial ventilation (N = 28 patients)

Mechanical ventilation yes [N (row %)]/no [N (row %)]	**Development of infectious complications**			
	total	yes	no	**p-value [Fisher's exact test]**
LRTI ≤ 5 days	28 (76%)/9 (24%)	15 (94%)/1 (6%)	13 (62%)/8 (38%)	0.050
G+ LRTI ≤ 5 days	28 (76%)/9 (24%)	13 (93%)/1 (7%)	15 (65%)/8 (35%)	0.112
G- LRTI ≤ 5 days	28 (76%)/9 (24%)	6 (100%)/0	22 (71%)/9 (29%)	0.302
Fungal LRTI ≤ 5 days	28 (76%)/9 (24%)	3 (100%)/0	25 (74%)/9 (26%)	0.562
LRTI 6–10 days	27 (75%)/9 (25%)	13 (100%)/0	14 (61%)/9 (39%)	**0.014**
G+ LRTI 6–10 days	27 (75%)/9 (25%)	8 (100%)/0	19 (68%)/9 (32%)	0.160
G- LRTI 6–10 days	27 (75%)/9 (25%)	9 (100%)/0	18 (67%)/9 (33%)	0.076
Fungal LRTI 6–10 days	27 (75%)/9 (25%)	1 (100%)/0	26 (74%)/9 (26%)	1.000
LRTI 11–15 days	26 (76%)/8 (24%)	9 (100%)/0	17 (68%)/8 (32%)	0.077
G+ LRTI 11–15 days	26 (76%)/8 (24%)	7 (100%)/0	19 (70%)/8 (30%)	0.160
G- LRTI 11–15 days	26 (76%)/8 (24%)	5 (100%)/0	21 (72%)/8 (28%)	0.309
Fungal LRTI 11–15 days	26 (76%)/8 (24%)	0	26 (76%)/8 (24%)	–
LRTI > 15 days	26 (79%)/7 (21%)	15 (100%)/0	11 (61%)/7 (39%)	**0.009**
G+ LRTI > 15 days	26 (79%)/7 (21%)	10 (100%)/0	16 (70%)/7 (30%)	0.073
G- LRTI > 15 days	26 (79%)/7 (21%)	12 (100%)/0	14 (67%)/7 (33%)	**0.032**
Fungal LRTI > 15 days	26 (79%)/7 (21%)	1 (100%)/0	25 (78%)/7 (22%)	1.000

LRTI – lower respiratory tract infection of patients without tracheostomy during this early post-trauma period. Fungal pathogens were detected in one patient (5.9%) with tracheostomy and in 2 patients (18.2%) without tracheostomy.

In the 6–10 day hospitalization period, the number of LRTI cases did not change in patients with tracheostomy. In patients without tracheostomy, the number of LRTI cases decreased from the original 4 to 2. The incidence of G+ and G- pathogens equalized (7 : 7) in patients with tracheostomy, and G- pathogens appeared in two ventilated patients without tracheostomy. Fungal pathogens were not detected in patients without tracheostomy during this time period.

As hospital stay prolonged, LRTI decreased in ventilated patients in both groups. No pathogens were detected in the group of patients without tracheostomy. G+ pathogens began to dominate again with a ratio of 7 : 5. Fungal pathogens were not detected in any patient during this period.

In the last observed period, after 15 days of hospitalization, a significant progression of LRTI development occurred in ventilated patients. LRTI was demonstrated in 14 out of 16 patients (87.5%) with tracheostomy, with G- pathogens prevailing over G+ (11 : 10). Also, one ventilated patient (10.0%) without tracheostomy showed evidence of a G- pathogen causing LRTI.

From the above data, it is evident that tracheostomy is a significant factor in the development of infectious complications in ventilated patients. The information mentioned above is illustrated in the Table 4.

DISCUSSION

The consequences of high voltage injury are similar to burn trauma. However, the overall effect on organism is what makes this issue unique. Electric shock injuries account for roughly 5% of patients admitted to burn centers. These numbers vary according to the demographic distribution depending on the social status in the region. The overall mortality rate from electrical burns is known to be somewhere in between 0% and 21.7%. In this study, 100% of the subjects were male and the morbidity of the cohort was 8.1%. Most patients were active young male (mean age 32 years). The etiology of injury was closely joined with occupational performance or with risky behaviors and adrenaline experiences. In some cases, the injury were closely linked to a difficult socio-economic situation associated with criminal activity. High voltage injuries show a higher incidence of associated injuries compared to burns, this is due to one mechanism and etiology of the injury which is directly related to the conditions in which the injury occurred. The most fundamental consequences include amputation of limbs, neurological deficits and cardiovascular abnormalities. This is due to the typical effect of electric current on the body and the accompanying mechanism of injury such as falling from a height.

While progress in treatment has significantly increased the chances of survival for burn victims, combatting infections remains an ongoing obstacle [16].

Table 4. Development of infectious complications in ventilated patients with and without tracheostomy

Only patients with MV	**Development of infectious complications**			
Tracheostomy yes [N (row %)]/ no [N (row %)]	Total	yes	no	**p-value [Fisher's exact test]**
LRTI ≤ 5 days	17 (61%)/11 (39%)	11 (73%)/4 (27%)	6 (46%)/7 (54%)	0.246
G+ LRTI ≤ 5 days	17 (61%)/11 (39%)	10 (77%)/3 (23%)	7 (47%)/8 (53%)	0.137
G- LRTI ≤ 5 days	17 (61%)/11 (39%)	6 (100%)/0	11 (50%)/11 (50%)	0.055
Fungal LRTI ≤ 5 days	17 (61%)/11 (39%)	1 (33%)/2 (67%)	16 (64%)/9 (36%)	0.543
LRTI 6–10 days	17 (63%)/10 (37%)	11 (85%)/2 (15%)	6 (43%)/8 (57%)	**0.046**
G+ LRTI 6–10 days	17 (63%)/10 (37%)	7 (88%)/1 (13%)	10 (53%)/9 (47%)	0.190
G- LRTI 6–10 days	17 (63%)/10 (37%)	7 (78%)/2 (22%)	10 (56%)/8 (44%)	0.406
Fungal LRTI 6–10 days	17 (63%)/10 (37%)	1 (100%)/0	16 (62%)/10 (38%)	1.000
LRTI 11–15 days	16 (62%)/10 (38%)	9 (100%)/0	7 (41%)/10 (59%)	**0.004**
G+ LRTI 11–15 days	16 (62%)/10 (38%)	7 (100%)/0	9 (47%)/10 (53%)	**0.023**
G- LRTI 11–15 days	16 (62%)/10 (38%)	5 (100%)/0	11 (52%)/10 (48%)	0.121
Fungal LRTI 11–15 days	16 (62%)/10 (38%)	0	16 (62%)/10 (38%)	–
LRTI > 15 days	16 (62%)/10 (38%)	14 (93%)/1 (7%)	2 (18%)/9 (82%)	**0.0002**
G+ LRTI > 15 days	16 (62%)/10 (38%)	10 (100%)/0	6 (38%)/10 (63%)	**0.003**
G- LRTI > 15 days	16 (62%)/10 (38%)	11 (92%)/1 (8%)	5 (36%)/9 (64%)	**0.005**
Fungal LRTI > 15 days	16 (62%)/10 (38%)	1 (100%)/0	15 (60%)/10 (40%)	1.000

MV – mechanical ventilation, LRTI – lower respiratory tract infection

Numerous research studies have aimed to pinpoint the most prevalent multi-drug-resistant microorganisms [17–20], yet the influence of these resistant pathogens on survival and other outcome measures remains uncertain. The extent of burned skin area is among the recognized risk factors for infection complications, along with the duration of hospital stay. This aligns with the findings of our study, as most patients in our research were classified as severely burned and experienced an extended hospitalization period which escalates the risk of infections caused by multidrug-resistant bacterial pathogens. During the initial days of post-burn hospitalization, we mostly observe G+ microorganisms, which correlate with another centers [231, 22]. However, as time at the hospital progressed, more resilient G- microorganisms became prevalent [23, 24]. A prolonged hospital stay among burn patients has been reported as a risk factor for acquiring multidrug-resistant nosocomial infections, such as *P. aeruginosa* and *A. baumannii* [22, 25], which aligns with our study findings. In our research, we identified G+ microorganisms as the most frequently isolated pathogens among patients with extended hospitalization. The average hospital stay duration, which was 44 days, was associated with a higher likelihood of acquiring infections caused by G- microorganisms, such as *Pseudomonas* and *Acinetobacter*. These observations have implications for the selection of initial antibiotic treatments for critically burn patients [26]. According to I. A. Bahemia et al. [11] who delivered a retrospective review of 341 patients with 44.6% mortality, had the most frequent cultured pathogens *A. baumannii*, *P. aeruginosa* and methicillin-resistant *S. aureus* (MRSA). As an illustration, two separate studies conducted in different burn units in Turkey identified *A. baumannii* and *P. aeruginosa* as the most frequently isolated microorganisms. However, they differed regarding the third most commonly cultured pathogen, with one study noting *E. coli* [27] and the other detecting MRSA [28]. In the study already mentioned above, Öncül O. et al. [28] introduced a paper involving 658 patients, of whom 469 acquired 602 nosocomial infections. The mortality rate 16.5% was close to ours (8.1%) with. Another study from Brazil conducted by Santucci SG et al. [20] involved 320 patients, with 175 (55%) of them developing 388 nosocomial infections. The most commonly identified pathogens were *S. aureus* (24%), *P. aeruginosa* (18%), and *Acinetobacter* sp. (14%). *Candida* spp. was cultured in 8% of cases. Numerous publications indicate that the most frequently identified causative agents are *P. aeruginosa*, followed by *A. baumannii* and *S. aureus*. Conversely, publications emphasizing the predominance of G+ bacteria also contribute to this body of research [29, 30]. The literature recognizes these three bacterial species, albeit with variations in their prevalence order, as the primary microorganisms responsible for causing hospital-acquired infections in burn patients. These variations could be attributed to local factors, such as a hot and humid climate [31]. A similar climate-related circumstance was observed in a French study, which documented an increase in *A. baumannii* prevalence during the summer months [32].

Our findings indicate that the most frequently affected area was the burn wound infection (BWI), which differs from other studies where bloodstream infections (BSI) [20], lower respiratory tract infections (LRTI) [10] or urinary tract infections (UTI) [33] were more prevalent.

There are few works dealing with infectious complications in the case of high-voltage electric injuries, unlike typical burn injuries. Last year López-Jácome [34] published their paper regarding Microbiology and Infection profile of electric burned patients. In their work, the overall infection rate was 72.9 cases per 100 patients. Mortality was observed in 4 (3.6%) patients. About 59.1% (443/749) had growth for G- bacteria. Multidrug-resistant *P. aeruginosa* was the most frequent microorganism isolated. Fungi were present in 4.9% of cases. These results are in considerable contradiction to our work where the dominant representatives were *Staphylococcus* and representatives of G+ pathogens. This fact can be explained by regional and epidemiological differences that are typical of infectious complications. Although *S. aureus* remains a common cause of early burn wound infection, *P. aeruginosa* from the patient's endogenous gastrointestinal flora and/or an environmental source is the most common cause of burn wound infections in many centers. These findigs are very similar to ours. *Staphyloccocus* is one of the dominant pathogens, although in the case of *P. aeruginosa* it is not among the dominant representatives, but it is one of the frequently occurring gram negative pathogens.

Limitations of the Study

This study has several limitations that should be acknowledged. First, the sample size is relatively small (37 patients), which may limit the generalizability of our findings. Additionally, the study spans a long period (2006–2016), during which treatment protocols, infection control measures, and antimicrobial resistance patterns may have evolved, potentially influencing the results. The variability in the severity of injuries and associated complications among patients introduces heterogeneity, which could affect the interpretation of the findings. Furthermore, as a single-center study, institutional practices and specific patient demographics may not fully reflect the broader population of patients with high-voltage electrical injuries. Lastly, the retrospective nature of the study carries inherent limitations, including potential inconsistencies in data collection and missing information, which may impact the robustness of our conclusions.

CONCLUSION

In this work we managed to map in detail the occurrence, extent and consequences of high voltage electro traumas in Moravia region of the Czech Republic during the last decade of the existence of the burn center in Brno. We have successfully identified at risk groups of affected individuals along with factors that significantly contribute to survival and the extent of the consequences of electric shock. The infection rate among the cohort of patients can be considered high. The most common infection observed was burn wound infection (BWI), followed by bloodstream infections (BSI), lower respiratory tract infections (LRTI), and urinary tract infections (UTI), primarily caused by Gram-positive pathogens. Notably, an increased hospital stay duration was associated with a rising prevalence of Gram-negative pathogens, particularly *K. pneumoniae* and *P. aeruginosa*, which exhibited a high degree of antimicrobial resistance.

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