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Defibrillation data analysis of prehospital resuscitation scenarios having different impulse durations

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Abstract: The objective of this study was to assess and present technical data related to resuscitation procedures that involved the application of a defibrillator for at least one shock. Specifically, we sought to distinguish two rectangular defibrillation impulses in terms of varying phase durations. The evaluation encompassed a range of defibrillation metrics and metadata, including transthoracic impedance, mean and peak currents. The results of this analysis provide valuable insights into the technical aspects of defibrillation.

Keywords: defibrillation, impulse duration, prehospital data

1 Introduction

As the only effective treatment option in cardiac arrest, early defibrillation is indispensable neither in clinical nor pre-hospital settings [1]. Defibrillators, from automated external defibrillators (AED) to complex monitoring systems, have nowadays become part of the basic equipment for medical professionals. To continually enhance success rates, scientific research delves into specific contexts, and devices are consistently refined. This project will evaluate a technical dataset of resuscitation operations from prehospital emergency medical services, where at least one defibrillation was administered per mission. Since the collected interventions were conducted with two different shock impulses, having varying phase durations, the data to be evaluated can be differentiated accordingly to gather an insight from the technical perspective.

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2 Methods

The analysis is based on retrospectively collected operational data of the corpuls3 system (GS Elektromedizinische Geräte G. Stemple GmbH, Kaufering, Germany) with defibrillations performed at least once per mission. Since mid-2020, the rectangular-shaped biphasic impulse of the device has been updated. While the previous one lasted 4 ms in the positive and 3 ms in the negative phase (4/3), the recent shock impulse was extended to 6 ms and 4 ms, respectively (6/4).

Data generated during operations are stored on the device. Assessable parameters include selected defibrillation energies, transthoracic impedance (TTI), and current measurements. Hereby, the peak and the mean currents can be determined, with the former defined as the maximum current during impulse delivery. To calculate the mean current, only the first phase of the impulse was averaged, either the 4 ms part of the 4/3, or the 6 ms phase of the 6/4. A potential relationship between mean current and TTI is evaluated by cross-checking of both values. The defibrillation mode, either manual or AED, can also be accessed. In the former, operators set the therapy parameters individually and are required to take self-reliant shock decisions. Contrary, these determinations are made automatically by the device in AED mode.

The results are described below, whereby the information in parentheses includes *n* for the number of shock deliveries and *N* denotes the number of missions.

3 Results

3.1 General defibrillation statistics

For this study, the data of 2388 resuscitation procedures were provided. Within these missions, a total of 8008 shocks, either using 4/3 (n = 5708) or 6/4 (n = 2300), were delivered by the defibrillator. Only adhesive electrodes for adult (n = 8002) or pediatric (n = 6) usage were attached. The defibrillation mode applied in most cases was manual mode (n = 7955) and rarely AED mode (n = 53). Usually, only a single shock occurred during the entire intervention (N = 887). Less than half as often there were two energy releases within one operation (N = 420). The six procedures with the highest number of shock deliveries contained 18 defibrillations.

3.2 Mission metadata

The operations occurred between January 2016 and March 2022. 1842 male and 560 female patients were included. The age distribution, arranged in 10-year groups and categorized by gender, is shown in the figure below. Mostly, for both men and women, patients between 70 and 80 years of age were treated. The youngest was a 6-year-old boy. In contrast, the oldest patient's age can only be specified over 90 years, as 91 years is the maximum that can be set on the device.

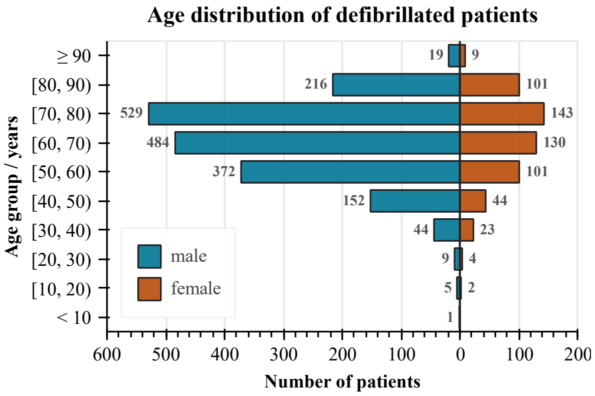

Figure 1: Age distribution according to the gender of defibrillated patients in 10-year groups.

3.3 Shock energy and strategy

The operator can choose the shock energy to be delivered in steps of 5 J up to a maximum of 200 J. Mostly, those were selected at 200 J (n = 7753). Other settings included 195 J (n = 127), 190 J (n = 13), 180 J (n = 8), 150 J (n = 86), and 100 J (n = 20). Least frequently, 50 J (n = 1) were used. The first defibrillation among the 2388 operations was mostly (97.36 %) delivered with 200 J (N = 2325).

Different approaches regarding the energy settings during operations with multiple shocks (N = 1501) were observed. Although in most cases the dose remained unchanged at either 200 J (N = 1406), 150 J (N = 6), 195 J (N = 4), or 100 J (N = 3), escalation strategies were also applied. Thereby, the energies were most often increased from initial 150 J settings up to 200 J (N = 11). Escalations also happened from 195 J to 200 J (N = 3) and from 100 J to 150 J (N = 1).

3.4 Transthoracic impedance

The TTI ranged from 34 Ω to 274 Ω with a mean of 99.47 Ω, and from 39 Ω to 277 Ω with a mean of 98.83 Ω for 4/3 and 6/4, respectively. Welch's t-test was used to conclude that there is no statistically significant difference concerning mean TTI values for both impulse durations ($p = 0.28$).

3.5 Emitted current

Concerning peak currents, the 4/3 generally achieved higher values with a median of 26.69 A and an average of 26.74 A in a range between 13.14 A and 40.78 A. The 6/4 averaged lower at 20.86 A and a median of 20.61 A, ranging from 11.82 A to 33.41 A. In contrast, the results were higher for the 6/4 regarding the mean current distribution with a median of 17.05 A and an average of 17.33 A in a range between 9.48 A and 28.77 A. The median for 4/3 was lower at 14.69 A with an average of 14.84 A, ranging from 7.53 A to 23.90 A. Both comparisons show statistically highly significant differences ($p < 0.001$ each).

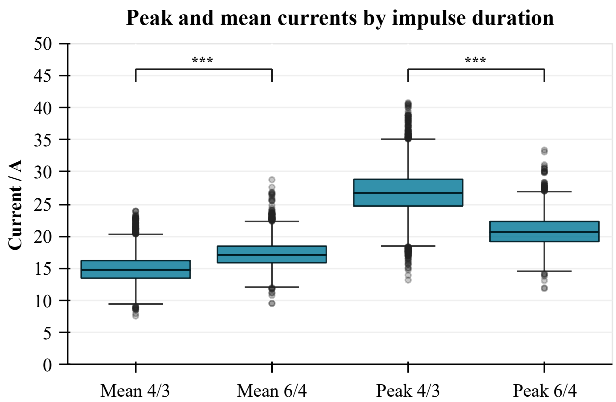

Figure 2: Mean and peak currents for different impulse durations. (***: statistically highly significant with $p < 0.001$)

The 6/4 provides higher mean currents over the entire range of corresponding TTI measurements, despite occasional outliers. The calculated ratio of both mean current and TTI showed a high significance when differentiating between 4/3 and 6/4 ($p < 0.001$). Spearman's rank correlation coefficient showed a clearly negative correlation ($r = -0.96$, $p < 0.001$ for 4/3; $r = -0.95$, $p < 0.001$ for 6/4).

4 Interpretation

The ages of the studied population are distributed over a wide range. If one compares these preclinical data, for example, with statistics provided by the German Resuscitation Registry for in-hospital resuscitations, the latter states that the average patient is just over 72 years old [2]. In the present data, the average patient is around 65 years old, which may be biased as 91 years can be set on the device as a maximum. However, very young and very old patients were resuscitated only to a comparatively small extent in both evaluations, as well as more men than women regarding their gender. [2]

Defibrillations should primarily be performed with self-adhesive electrodes instead of hard paddles according to recent resuscitation guidelines, due to several advantages, including minimization of the pre-shock pause [3–5]. Only such patches were used in the present dataset.

According to current opinion, manual mode defibrillation is preferable to AED mode [5], as experienced operators can quickly and accurately analyze the patient's heart rhythm, minimizing hands-off times and increasing the chances of a successful outcome [6, 7]. In our data analysis, compliance with this recommendation was observed, with shocks being emitted in manual mode as method of choice for 99.34 %.

In some operations, there were multiple defibrillations observed within a single mission. Nevertheless, it was often a sole shock that led to the end of the intervention. Presumably, these single countershocks were sufficient to defibrillate the patient's heart. Anyways, this cannot be said with certainty, as the treatment could have been terminated prematurely and ended without shock success.

Generally, the first shock was most frequently chosen with an energy of 200 J. This can probably be explained by the fact that it corresponds to the default setting of the device and the adjustable maximum. Resuscitation guidelines recommend selecting that highest possible dose if the user does not know any details about the energy to use [4]. There were several shocks being delivered at 195 J, which may, due to the proximity, probably be attributed to an unintentional deviation from the aim of setting 200 J. The third most frequent setting was 150 J, which energy level can also be found in relation to guidelines, as they intend a minimum energy of 150 J for the first defibrillation before escalating, if further shocks may be required [4, 5]. While the energy dose was used consistently in most of the missions, only 14 cases showed an increase of the energies that were set initially.

Biphasic impulses are considered state-of-the-art in terms of higher effectiveness and lower energy levels required for shock success compared to monophasic ones [8, 9]. According to Lapique's fundamental research, most efficient stimulation at minimum energy is possible at the chronaxie [10]. The length of the first part of the impulse should consequently be close to a human heart muscle cell's chronaxie. Following different studies, this is in the range of 2 ms to 6 ms, whereby the longer duration would be preferred. [11–13] Nevertheless, the devices available on the market differ in terms of impulse shape and duration. In the present analysis, more data of the 4/3 impulse was available because of the aggregation period between 2016 and 2022 and the change to 6/4 in 2020 [14].

In transthoracic defibrillation, only about one-fifth of the current reaches the heart, whereby the remainder is absorbed by the thorax area. This is probably due to differences in body mass index, body fat and thoracic geometry. [15–17] Actual TTI values measured during human defibrillation are usually reported between 60 Ω and 100 Ω, although they can reach up to over 150 Ω [18–20]. Our data largely reflects the above-mentioned range, although it contains some outliers, a few in the lower but also upper span. Reasons for these may be patient-specific or due to inadequate electrode positioning. There was no significant difference regarding TTI between 4/3 and 6/4, ensuring subsequent analyses of other parameters are not influenced or biased by TTI. However, the relevance of TTI for survival is not entirely clarified, with literature tending to no lasting effect on survival [21].

Although energy levels are typically set for defibrillation, the transmyocardial current is physiologically relevant. In consequence, that intensity correlates with shock success. [19] A study relying on peak currents for patients who achieved a return of spontaneous circulation (ROSC) reported these values to be in the range of 8.96 A to 37.39 A. The authors concluded that currents between 15 A to 20 A had the best chance for ROSC at average or higher TTI. [22] Although the present analysis showed significantly higher peak currents for 4/3, ranges of both impulses are basically within the reported values of the study mentioned above, except for a few outliers for 4/3. Another investigation concluded the mean current represents a more dependable parameter than peak intensities for characterizing the therapeutic dosage [23]. Thus, mean currents for the first phase of each defibrillation were calculated. As the 6/4 holds significantly higher results than the 4/3, the lower values of the latter are due to rapid decreases after higher initial peaks. Therefore, the means are lower than those of the 6/4, which drop relatively flat after the peaks.

5 Conclusion

The present study provides valuable insights into the topic of defibrillation, including differentiation between two impulses and presentation of technical parameters that may not be apparent during routine device usage. Despite occasional outliers in the recorded and analyzed data, the literature comparison suggests that the results generally align with those of previous studies. The evaluation's reliance on operational data from real-world resuscitations, as opposed to simulations or meticulously controlled settings, may account for some of the variability. As expected, the prolonged 6/4 shock impulse exhibits distinct characteristics compared to the 4/3 in certain factors, although it remains unclear which impulse is more effective in achieving actual defibrillation success. Further investigations are warranted to establish clear trends and draw more definite conclusions.

Author Statement

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Conflicts of interest: Jonas Fischer was student at Furtwangen University and is employed at GS Elektromedizinische Geräte G. Stemple GmbH, Kaufering, Germany. Folker Wenzel has nothing to disclose.
Ethical approval: The study has been approved by the local ethics commission of Furtwangen University (request 22-068).

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