Submitted: 05 January, 2024 Accepted: 06 May, 2024 Published: 08 October, 2024 DOI:10.22514/sv.2024.125

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Signa Vitae

ORIGINAL RESEARCH

Amplitude spectrum area as an indicator of effective return of spontaneous circulation in prehospital resuscitation—experience from a single regional center in Romania

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Abstract

Analysis of electrocardiography (ECG) signals recorded during cardiopulmonary resuscitation showed that it could be effectively used to predict successful defibrillation. The amplitude spectrum area (AMSA) was not affected by chest compression and showed potential as a monitoring parameter for defibrillators. This retrospective observational study aimed to evaluate AMSA values during out-of-hospital cardiac arrest (OHCA) due to ventricular fibrillation (VF) and to identify the optimal AMSA value indicating a higher chance of return of spontaneous circulation (ROSC) maintained until Emergency Department (ED) admission. Additionally, we examined factors influencing AMSA and ROSC in our emergency medical services (EMS) system. To achieve these, we analyzed the AMSA values of each patient with OHCA and VF using ECGs recorded before each manual defibrillation. Patient data were collected from the EMS database, prospectively gathered from 01 July 2014, to 30 April 2015. The cohort of 46 patients was divided into two groups: Group 1, admitted to the ED with ROSC (n = 25), and Group 2, who died at the scene (n = 21). Successful defibrillation resulted in ROSC for 21 patients (45.65%). Statistically significant higher AMSA values ($p < 0.0029$) were observed in Group 1 (30.77 ± 13.20 mV-Hz) compared to Group 2 (23.21 ± 10.73 mV-Hz). AMSA values of 27.6 mV-Hz were associated with a specificity of 73.33% for ROSC after manual defibrillation. In Group 1, 64% of patients had a shorter time to start advanced life support (ALS) of less than 5 minutes ($p = 0.0798$). Additionally, a significantly lower dose of adrenaline was observed in Group 1 ($p < 0.0001$). Fewer defibrillation attempts were required in Group 1 compared to Group 2 ($p = 0.0872$). In conclusion, a delay in the initiation of ALS (>5 minutes) and delayed manual defibrillation attempts are associated with lower AMSA values and reduced defibrillation efficiency.

Keywords

Amplitude spectrum area (AMSA); Ventricular fibrillation (VF); Defibrillation; Out-of-hospital cardiac arrest (OHCA); Return of spontaneous circulation (ROSC)

1. Introduction

Annually, over 55 out of 100,000 people suffer cardiac arrest in Europe [1]. The European Resuscitation Council introduced the Registry of Cardiac Arrest (EuReCa), which is composed of 29 countries that cooperate to provide data on out-of-hospital cardiac arrest (OHCA). The recorded data show an incidence of OHCA between 67 and 170 per 100,000 inhabitants, with a low rate of bystander cardiopulmonary resuscitation (CPR) (average 58%, range 13%–83%) and insufficient use of automated external defibrillators (AEDs) (average 28%, range 3.8%–59%) [2]. In 20–30% of cardiac arrest cases, ventricular fibrillation (VF) is the initial registered arrhythmia [3]. Current resuscitation guidelines recommend defibrillation as the initial therapy for VF [4]. However, repetitive unsuccessful defibrillation attempts may cause myocardial injury, ranging from a reversible decrease in myocardial contraction to irreversible myocardial necrosis [5–7]. When a shock is not immediately available, CPR prior to defibrillation increases coronary artery perfusion, thus improving the chances of successful defibrillation and return of spontaneous circulation (ROSC) [8]. Most of the time, CPR is unable to generate adequate coronary blood flow, necessitating the use of a vasopressor agent, such as adrenaline [8]. A predictive indicator for successful defibrillation, such as the amplitude spectrum area (AMSA), reflecting the myocardial energy state, could be very useful in deciding when to stop CPR for defibrillation [9].

The interpretation of the electrocardiogram (ECG) can be challenging due to the effects of chest compression, making it necessary to interpret the ECG without this interference. According to the literature, AMSA has been reported as an ECG parameter unaffected by chest compression [10, 11]. The analysis of AMSA during resuscitation has proven valuable in predicting the success of defibrillation [12–14]. However, AMSA analysis is not yet sufficiently reliable to be adopted as an indicator and, therefore, is not integrated into defibrillator software.

Several studies have analyzed short strips of VF, ranging from 2.05 to 5 seconds, with threshold values ranging from 10 to 27.6 mV-Hz reported in the scientific literature [8, 9, 13–15]. However, AMSA analysis is not yet sufficiently reliable to be adopted as an indicator because the reported performances are heterogeneous and, therefore, are not integrated into defibrillator software (Table 1) [13, 15–18].

Moreover, Ruggeri *et al.* [18] highlighted that AMSA values below 6.5 mV-Hz are ineffective in 86% of cases. Comorbidities, drug therapy, bystander CPR, time to start advanced life support (ALS), and adrenaline dosages during CPR have all been demonstrated to influence AMSA [12, 18, 19]. However, no single factor affecting AMSA has yet been identified.

This study aims to evaluate the AMSA values of VF in OHCA and determine the optimal value to predict the return and maintenance of spontaneous circulation until admission to the Emergency Department (ED). Furthermore, we also aimed to identify factors that affect AMSA and ROSC, considering the specific characteristics of the emergency medical service (EMS) system in Romania.

2. Materials and methods

The prehospital emergency medical system in the studied region is operated by three types of prehospital ambulance teams with different resuscitation competencies: (1) SMURD (Mobile Emergency Service for Resuscitation and Extrication) team with higher competencies, capable of performing basic life support (BLS), manual defibrillation, and ALS; (2) Nurses' team with medium competences, capable of performing BLS and defibrillation using AEDs, and sometimes ALS under regional hospital guidance in remote areas until SMURD teams arrive; and (3) Fire department paramedics team with low competences, capable of performing BLS and using AED.

In Romania, CPR training (BLS and defibrillation with AED) for laypersons is limited compared to other European countries, despite sustained efforts by EMS workers to emphasize the importance of early resuscitation. Dispatchers are able to guide laypeople to deliver CPR over the phone in only a small number of cases, and even then, they often face reluctance from the public to start CPR. Given these conditions, for this study, we analyzed data from the SMURD teams, which handle more than 85% of OHCA cases in the region. These teams are standardized and use the same manual defibrillator device, the Corpuls 3 (GS Elektromedizinesche Geräte G. Stemple GmbH, Kaufering, Bavaria, Germany).

2.1 Study design

We conducted a retrospective, observational cohort analysis using a database of OHCA patients from 01 July 2014, to 30 April 2015. Data from the register were prospectively collected during this interval primarily to gather post-ROSC biomarker information. The study included all consecutive patients with OHCA, older than 18 years, who experienced VF either as the initial ECG rhythm (iVF) or developed VF during prehospital resuscitation (noted as no-iVF). The eligible population with OHCA comprised patients diagnosed with cardiac arrest by emergency physicians working on the prehospital EMS of Cluj County, specifically the SMURD teams. The SMURD team comprised an emergency physician, a nurse, and two paramedics. The teams had standardized equipment, including a manual Corpuls 3 defibrillator with patches, and they followed the European Resuscitation Council Guidelines protocol for cardiac arrest.

We excluded patients younger than 18 years, those with known end-stage oncological diseases (information obtained from the patient's family or medical records on site), patients with polytrauma (defined as having at least two injuries, one of which is life-threatening), those with medium or severe head trauma according to the Miller scale, with severe thoracic trauma (defined as rib fractures associated with pneumothorax or hemothorax), and patients with proximal limb amputation. Additionally, we excluded patients with incomplete ECG recordings and ECG strips under 10 seconds from the analysis.

Patients were declared in cardiac arrest if they were found unconscious and without spontaneous breathing, following

TABLE 1. Amplitude spectrum area cutoff and associated performances (data from the literature).

Authors	No. of ECG VF traces	ECG trace duration analyzed (seconds)	AMSA value (mV-Hz)	Se (%)	Sp (%)	NPV (%)	PPV (%)
Nakagawa *et al.* [17] (2012)	n/a	n/a	24.2	n/a	n/a	n/a	n/a
Ristagno *et al.* [15] (2013)	1260	2.0	17.0	n/a	97	n/a	n/a
Indik *et al.* [16] (2014)	n/a	4.1	24.5	n/a	n/a	n/a	n/a
Ristagno *et al.* [13] (2015)	1381	2.0	15.5	36	97	76	84
Ruggeri *et al.* [18] (2023)	2447	2.0–5.0	15.5	n/a	n/a	84	77

No.: number; ECG: electrocardiography; VF: ventricular fibrillation; AMSA: amplitude spectrum area; Se: sensitivity; Sp: specificity; NPV: negative predictive value; PPV: positive predictive value; n/a: not available.

resuscitation guidelines. The initiation of chest compressions, attachment of defibrillation patches for rapid rhythm assessment, and support of ventilation were immediately and synchronously performed by the members of the SMURD resuscitation team, according to their assigned roles and professional training. Resuscitation medication was provided in accordance with the identified cardiac arrest rhythm, following the recommendations of the resuscitation guidelines.

ROSC was defined as the return of a sustained cardiac rhythm that could allow blood circulation throughout the body after cardiac arrest, according to resuscitation guidelines. Death at the scene was declared when a life-sustaining heart rhythm was not achieved despite following the entire ALS protocol, including asystole lasting more than 20 minutes, and after all potential reversible causes of cardiac arrest had been identified and corrected, in accordance with resuscitation guidelines.

2.2 Source of raw data

The patient's ECG strip was continuously recorded during CPR and collected on the Corpuls 3 defibrillator card. The defibrillators recorded patient data, which was later extracted, transferred, and analyzed. The ECG strips did not contain any information that could identify individual patients. The prehospital teams collected the following data for each patient: age, sex, urban or rural residence, initial cardiac arrest ECG rhythm (iVF/no-iVF), time to ALS (time from the call being received by the dispatch center to the ambulance arriving at the scene and starting resuscitation), bystander CPR, acute myocardial infarction (AMI), history of cardiovascular disease (CVD), number of defibrillations and dosages of adrenaline during resuscitation.

2.3 Electrocardiogram analysis

The ECG strips recorded by the manual Corpuls 3 defibrillator were set at a speed of 25 cm/s on the second standard bipolar limb lead (DII) and exported to MATLAB (MathWorks, Natick, MA, USA). We analyzed periods of VF during the 10 seconds before each shock delivery, which is the time interval from the detection of a shockable rhythm to the actual delivery of the shock.

Each period was visualized using the memory card of the Corpuls 3 defibrillator, extracted as *.jpg files (Fig. 1), and converted from the time domain to the frequency domain using Fourier Transformation. The AMSA was calculated using the MATLAB platform. AMSA represents the sum of the products of individual amplitudes and their frequencies, according to the formula: $\text{AMSA} = \Sigma\, A_i \times F_i$, where A_i represents the amplitude and F_i is the frequency. The AMSA values were analyzed individually and divided into two groups: "success", defined as being admitted to the ED with ROSC after defibrillation (Group 1), and "failure", defined as prehospital death (Group 2). No filter for artifacts was applied, based on the findings of Young *et al*. [10], which indicated no significant changes in sensitivity or specificity when using a lower cutoff frequency to filter chest compression artifacts.

2.4 Statistical analysis

An independent sample *t*-test was used to compare normally distributed raw data and summarized as means and standard deviations. The Mann-Whitney test was used to compare groups that did not follow a normal distribution and reported as medians and IQR (Interquartile Range defined as [Q1 to Q3], where Q1 represents the first quartile and Q3 the third quartile). Categorical data are shown as absolute and relative frequencies, and comparisons between groups were performed using the Chi-Squared test or Fisher's exact test, depending on the theoretical frequencies.

Regression analysis was conducted to identify factors associated with ROSC. Independent variables with a *p*-value of up to 0.10 were included in the univariable regression analysis using the Wald stepwise methodology. All variables identified in the univariable model with at least a tendency toward statistical significance were included in the multivariable regression analysis.

Sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive value (NPV), and accuracy (Acc) were calculated for different AMSA thresholds. The criteria used to establish the cutoff AMSA values included the minimum AMSA value in Group 1, the arithmetic mean of AMSA in Group 2, the AMSA third quartile in Group 2, and the 90th percentile of AMSA in Group 1.

Statistical analysis was performed using the Statistica program (v8, StatSoft, Tulsa, OK, USA) and JASP (Jeffreys's Amazing Statistics Program, v.v0.18.30., Amsterdam, Netherlands). A significance level of 5% was applied, with *p*-values < 0.05 considered statistically significant.

3. Results

3.1 Characteristics of the patients with OHCA

Of the 73 cases retrieved, 46 met the inclusion criteria and were included for study analysis. The results showed that only 25 (14.20%) defibrillation attempts of 176 "10-second ECG strips" recorded during this study were successful. In 21 cases, defibrillation attempts resulted in ROSC (11.93%), and in 4 cases, a rhythm compatible with life, pulseless electrical activity (PEA), was followed by ROSC (Fig. 2).

The patients' age ranged from 26 to 87 years, with a mean of 58.59 ± 14.19 years. No statistically significant differences were observed between the study groups, except for the incidence of acute myocardial infarction and doses of adrenaline administered during resuscitation (Table 2). Most of the patients were men from urban settings, and half of the patients admitted to the ED had a diagnosis of myocardial infarction. Only 34.78% of patients received bystander assistance for OHCA before the arrival of the ambulance team.

3.2 AMSA and defibrillation efficiency

The number of VF sequences (AMSA values calculated) for each patient recorded during 10 seconds varied from one to eight (median = 3, IQR = [1 to 4]) in Group 1, and from two to thirteen (median = 4, IQR = [2 to 7]) in Group 2 (Mann-

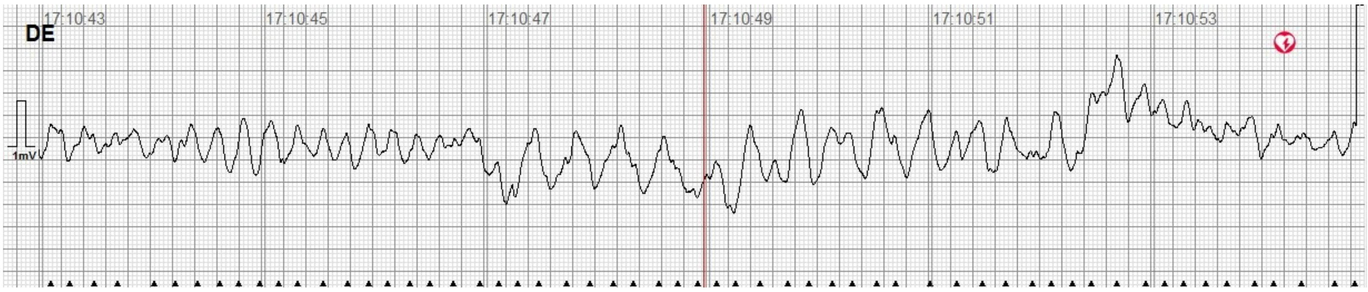

FIGURE 1. Illustration of 10-second ventricular fibrillation strips used for amplitude spectrum area analysis. DE: Deutschland (screen device inscription).

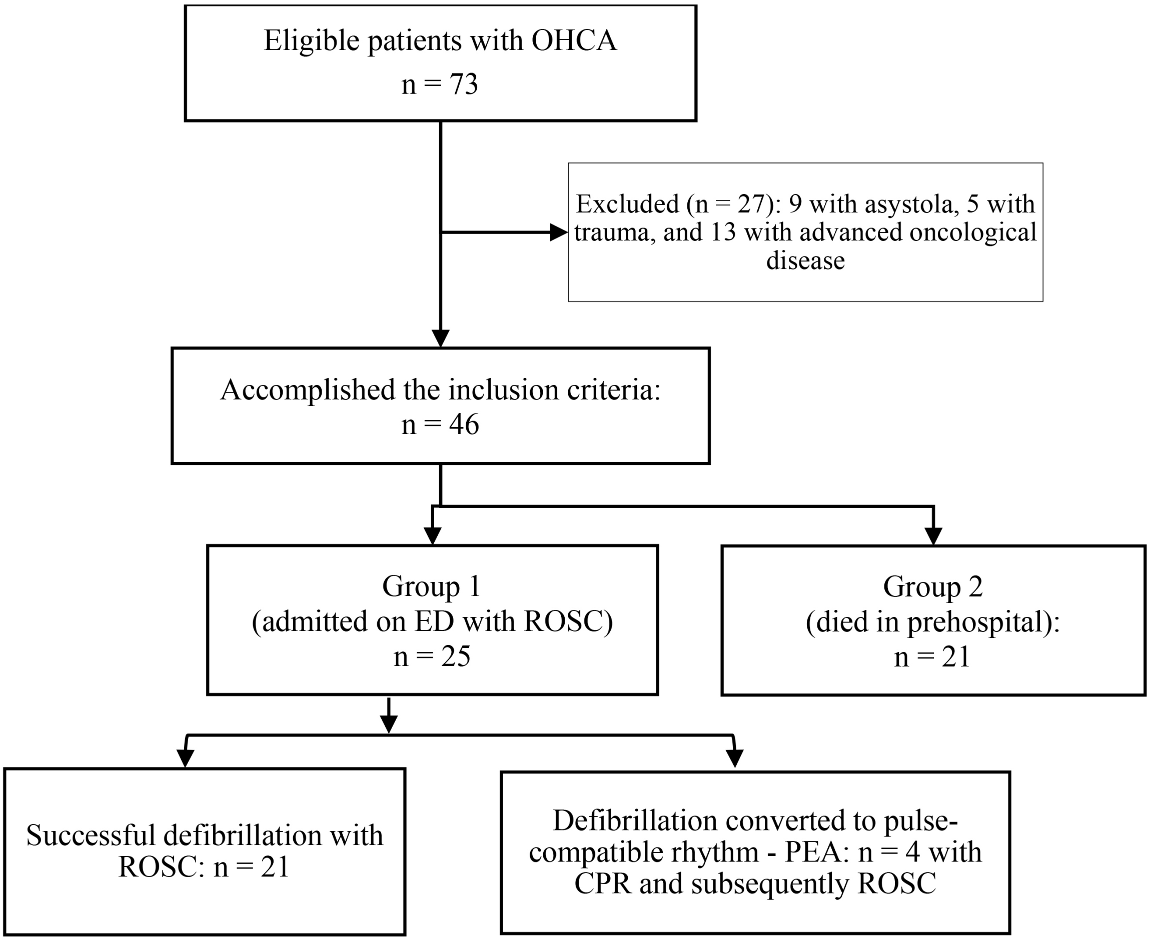

FIGURE 2. Flow diagram summarizing the out-of-hospital outcome: from subjects with out-of-hospital cardiac arrest (OHCA) identification to the selection of patients included in the study. n: sample size; ED: emergency department; ROSC: return of spontaneous circulation; PEA: pulseless electrical activity; CPR: cardiopulmonary resuscitation.

Whitney test: $p = 0.160$). The AMSA values were significantly higher ($p = 0.003$, Fig. 3) in Group 1, with a mean of 30.77 ± 13.20 mV-Hz (ranging from 13.60 mV-Hz to 72.49 mV-Hz), compared with Group 2, which had a mean of 23.21 ± 10.73 mV-Hz (ranging from 7.43 mV-Hz to 68.85 mV-Hz).

Further analysis showed that the values of the last AMSA (mV-Hz) were statistically significantly higher in Group 1 (median = 29.99, IQR= [18.99 to 33.85]) than in Group 2 (median = 15.59, IQR= [10.77 to 25.01]) (Mann-Whitney test: $p = 0.007$). As expected, although different performances for various AMSA cutoff values were observed, all demonstrated limited abilities in identifying ROSC (Table 3).

3.3 Possible confounders and clinical outcome

Data analysis showed that the time to ALS and the presence of bystanders influenced the evolution of VF and its parameters, including the AMSA value, thereby reducing the chances of survival. A shorter ALS time (≤5 minutes) was more common in Group 1, but the comparison showed only a tendency towards statistical significance when compared to Group 2 (Table 4).

Although the number of initial bystander CPR instances was low (approximately one-third in each group), the absence of bystanders had a statistically significant negative impact on

TABLE 2. Baseline characteristics of the patients included in the study.

Variable	Group 1 (n = 25)	Group 2 (n = 21)	*p*-value
Age, yr[1]	57.28 ± 15.18	60.14 ± 13.11	0.5016
Male[2]	19 (76.0)	18 (85.7)	0.4777[3]
Urban[2]	21 (84.0)	16 (76.2)	0.7114[3]
iVF[2]	15 (60.0)	7 (33.3)	0.0713
Time to ALS, min[4]	5 [4 to 6]	7 [4 to 12]	0.0723
Bystander CPR[2]	9 (36.0)	7 (33.3)	0.8500
AMI[2]	13 (52.0)	1 (4.8)	<0.0001
History of CVD[2]	16 (64.0)	17 (81.0)	0.1878
Hypertension[2]	14 (56.0)	16 (76.1)	0.1521
Ischemic cardiomyopathy[2]	11 (44.0)	12 (57.1)	0.3745
Congestive heart failure[2,3]	3 (12.0)	6 (28.6)	0.1133
Other cardiovascular comorbidities[2]	0	5 (23.8)	n/a
Defibrillation attempts[4]	3 [1 to 4]	4 [2 to 7]	0.0872
Adrenaline during resuscitation, mg[4]	4 [3 to 7]	13 [10 to 15]	<0.0001

[1]*m ± SD, where m: mean and SD: standard deviation, comparison between groups with student t-test;* [2]*no. (%), where no.: count and %: percentage, comparison between groups with Chi-squared test or* [3]*Fisher's exact test;* [4]*median [Q1 to Q3], where Q1: 25th percentile; Q3: 75th percentile, comparison between groups with Mann-Whitney test. n: sample size; yr: year; iVF: initial ventricular fibrillation rhythm of cardiac arrest; ALS: advanced life support; min: minute; CPR: cardiopulmonary resuscitation; AMI: acute myocardial infarction; CVD: cardiovascular disease; n/a: not applicable; mg: milligram.*

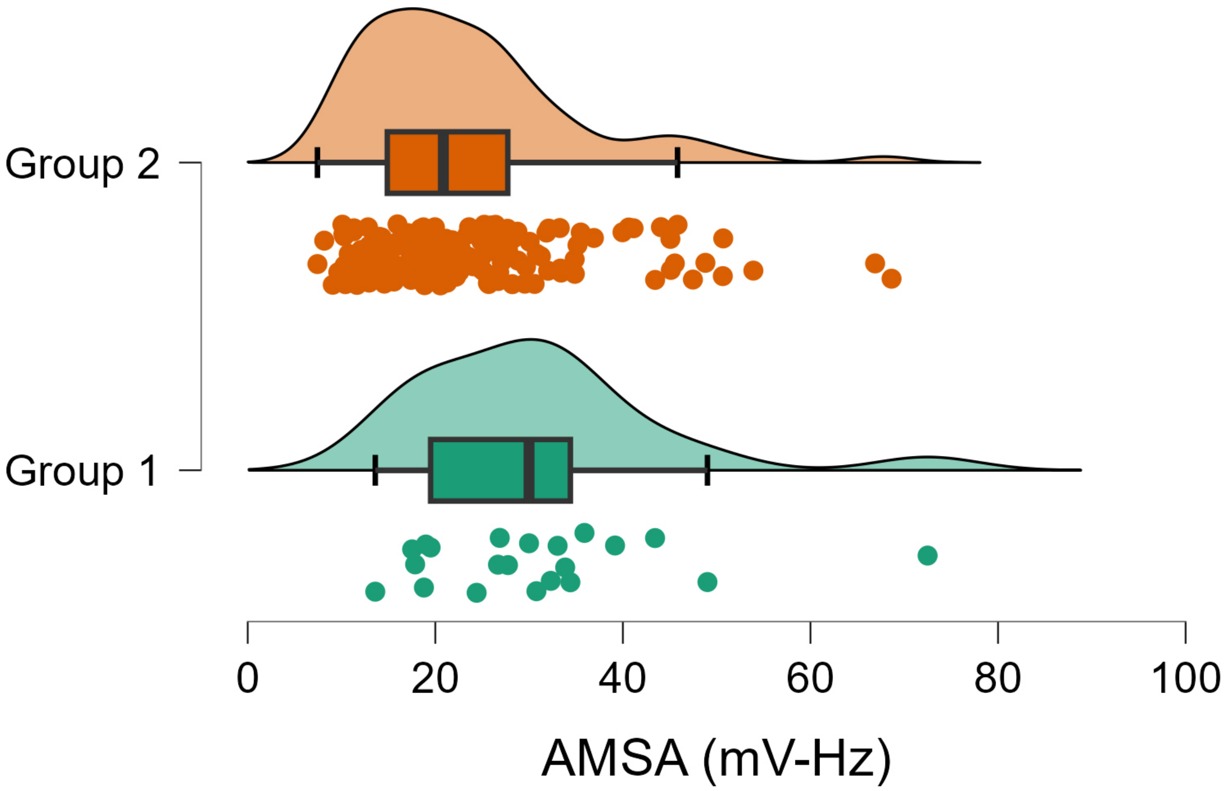

FIGURE 3. AMSA values in Group 1 compared with Group 2: success *vs.* failure in ROSC. The value of median gives the line in the box, the lower and upper box are the values of first and respectively third quartile, while the whiskers are the minimum and maximum values. The ° show raw data. AMSA: amplitude spectrum area; ROSC: return of spontaneous circulation.

TABLE 3. Analysis of AMSA values performances for successful ROSC.

AMSA (mV-Hz) cutoff	Se (%)	Sp (%)	PPV (%)	NPV (%)	Acc (%)
13.6	95.2	25.8	14.8	2.4	34.0
23.2	84.6	57.8	15.0	2.3	60.0
27.6	57.1	73.3	23.0	7.5	71.3
39.0	20.0	89.2	6.2	3.1	86.3

AMSA: amplitude spectrum area; ROSC: return of spontaneous circulation; Se: sensitivity; Sp: specificity; PPV: positive predictive value; NPV: negative predictive value; Acc: accuracy.

TABLE 4. Distribution of potential confounders in the context of clinical outcome in each group.

Characteristic	All (n = 46)	Group 1 (n = 25)	Group 2 (n = 21)	*p*-value
ALS ≤5 minutes	24 (52.2)	16 (64.0)	8 (38.1)	0.0798[1]
Bystander CPR	16 (34.8)	9 (36.0)	7 (33.3)	0.8500[1]
ALS ≤5 minutes and bystander CPR				
ALS ≤5 & CPR	10 (21.7)	5 (20.0)	5 (23.8)	0.0599[2]
ALS ≤5 & no bystander CPR	14 (30.4)	11 (44.0)	3 (14.3)	
ALS >5 & CPR	6 (13.0)	4 (16.0)	2 (9.5)	
ALS >5 & no bystander CPR	16 (34.8)	5 (20.0)	11 (52.4)	
History of CVD and iVF				
No history of CVD & iVF	6 (13.0)	3 (12.0)	3 (14.3)	0.0055[2]
History of CVD & iVF	16 (34.8)	12 (48.0)	4 (19.0)	
History of CVD & no-iVF	17 (37.0)	4 (16.0)	13 (61.9)	
No history of CVD & no-iVF	7 (15.2)	6 (24.0)	1 (4.8)	

Data are expresses as number (%); n: sample size; ALS: advanced life support; CPR: cardiopulmonary resuscitation; CVD: cardiovascular disease; iVF: initial ventricular fibrillation rhythm of cardiac arrest; no-iVF: ventricular fibrillation is not the first rhythm of cardiac arrest; [1]Chi-squared test; [2]Fisher's exact test.

the time to ALS, with longer times observed in Group 2. The probability of success increased when ALS was administered early and bystanders were present (Table 4).

Most patients in our study had a history of cardiovascular disease (CVD) (Table 2). A statistically significant association was observed between CVD and initial VF (iVF), with most patients in Group 1 having both CVD and VF as the initial rhythm, while Group 2 had CVD but no initial VF (Table 4).

The significance obtained by different factors in univariable logistic regression models was not necessarily retained in the multivariable model, except for adrenaline (Table 5). The combination of variables in the multivariable model showed an overall accuracy of 89.1%, with a sensitivity of 88% and a specificity of 90.5%.

4. Discussion

In this study, we identified several barriers that hindered achieving successful ROSC in prehospital settings and ED admission after OHCA with initial VF, such as a low incidence of bystander CPR (Tables 2 and 4), prolonged time to ALS team arrival (greater than 5 minutes), and low AMSA values (the lowest successful defibrillation AMSA value being 13.6 mV-Hz). The specificity and accuracy of AMSA values for successful defibrillation using the first manual defibrillation by the ALS team were acceptable, reaching up to 70% at an AMSA value of 27.6 mV-Hz.

4.1 Study findings

Previous studies have reported that myocardial defibrillation produces electrical injury and alters the energy state of the myocardium, potentially creating ectopic sites that could trigger life-threatening arrhythmias [5–7, 9]. The use of a manual defibrillator and the continuous registration of cardiac rhythm using patches is a particularity of our study, distinguishing it from previous studies using AED defibrillators [12–15]. We measured AMSA over 10 seconds, in contrast to earlier studies that used shorter periods (2–5 seconds) [13, 15], aligning with more recent studies reporting periods between 8 and 11 seconds [12, 14, 18]. A 10-second period offers a practical "on the field" approach for establishing AMSA values in a prehospital population. However, the specific conditions of our study may impact AMSA values and their effectiveness in predicting ROSC. Severe myocardial ischemia and delayed resuscitation are known to modify AMSA values by decreasing the amplitude of VF waves, thereby reducing the AMSA value. The discrepancies observed in sensitivity and specificity between our present study and current literature could be explained by the difference in the length of analysis

TABLE 5. Univariate and multivariate regression analysis for ROSC as the outcome.

	Univariable models			Multivariable models		
	Estimate (SE)	OR [95% CI]	*p*	Estimate (SE)	OR [95%CI]	*p*
Intercept				2.728 (1.729)		0.115
Age, yr	−0.015 (0.021)	0.985 [0.945 to 1.028]	0.493			
Sex (M)	−0.639 (0.780)	0.528 [0.114 to 2.432]	0.413			
iVF (yes)	1.099 (0.617)	3.000 [0.895 to 10.058]	0.075	0.595 (1.080)	1.813 [0.218 to 15.052]	0.582
Time to ALS, min	−0.101 (0.066)	0.904 [0.795 to 1.028]	0.124			
Adrenaline, mg	−0.480 (0.138)	0.619 [0.472 to 0.811]	<0.001	−0.451 (0.148)	0.637 [0.477 to 0.851]	0.002
AMI (yes)	3.076 (1.100)	21.667 [2.508 to 187.159]	0.005	2.468 (1.378)	11.803 [0.792 to 175.854]	0.073
Last AMSA (mV-Hz)	0.066 (0.030)	1.068 [1.007 to 1.132]	0.028	0.016 (0.044)	1.016 [0.932 to 1.108]	0.716

ROSC: return of spontaneous circulation; yr: year; M: masculine; iVF: initial ventricular fibrillation rhythm of cardiac arrest; ALS: advanced life support; min: minute; mg: milligram; AMI: acute myocardial infarction; AMSA: amplitude spectrum area; OR: Odds Ratio; CI: Confidence Interval; SE: Standard Error.

(10 seconds *vs*. 2–5 seconds) and the differences in digitization and calculation methods used to evaluate AMSA values.

When using a longer analysis period of 10 seconds, chest compressions may artifact the rhythm just before defibrillation, potentially leading to an overestimation of AMSA [13, 14, 20]. The literature reports various techniques to reduce or remove chest compression artifacts from ECG analysis [13, 14, 21, 22], and some studies have identified deep-learning strategies for sliding ECG analysis during resuscitation with AEDs [23]. Corpuls 3 can be used to effectively reduce the influence of chest compressions on the VF signal, allowing for analysis without the need for chest compression corrections.

The AMSA value analysis using manual defibrillation revealed higher specificity and accuracy at 27.6 mV-Hz compared to the 15.5 mV-Hz using AEDs in different health system organizations reported in literature [13, 15, 16]. A consistent finding was the decreased number of defibrillations (Table 2) in patients with higher AMSA values and positive short-term outcomes. AMSA values are influenced by factors such as early and high-quality chest compressions, bystander CPR response, and medication [10, 24]. In this context, the regional EMS system and health policies play an essential role in improving short-term outcomes (ROSC and ED admission) by organizing public access defibrillation programs, dispatcher-assisted CPR training, and promoting comprehensive bystander response [25, 26]. Due to the low incidence of bystander CPR (approximately one-third in both groups), the study could not demonstrate the well-documented benefit of bystander CPR on ROSC (Table 2). However, we observed a significantly lower incidence of bystander CPR and an increased time to start ALS (>5 minutes) in the prehospital death group (Group 2), which thereby highlights the role of EMS teams in providing early defibrillation and achieving ROSC, even when bystander CPR is not provided [4, 26]. Insufficient education and awareness of the Romanian population regarding CPR initiation and AED use reduces short-term outcomes, which depend directly on early defibrillation provided by EMS teams (Table 2). Implementing bystander CPR training in Romanian schools, in accordance with the 2021 European Resuscitation Council Guidelines, could improve outcomes for OHCA and VF patients as the training would increase the likelihood of early defibrillation, resulting in higher AMSA values and thereby enhancing the chances for effective defibrillation, ROSC and ED admission.

AMSA reflects the energy state of the myocardium and is dependent on coronary perfusion. Adrenaline administration combined with chest compression could improve AMSA values [8]. In this study, the observed lower dosage of adrenaline in Group 1 compared to Group 2 (Table 2) suggests an association between high AMSA values and a reduced need for vasopressors, which may decrease negative effects after ROSC [4]. Univariable regression analysis for ROSC as an outcome of successful defibrillation identified several significant predictors, including adrenaline ($p < 0.001$), AMI ($p < 0.005$), and AMSA value ($p < 0.028$) (Table 5).

Ristagno *et al*. [13] reported a higher incidence of successful defibrillation in patients with a history of CVD and an initial VF rhythm. This study confirms that patients with an initial VF rhythm had a higher number of sustained ROSC and were more likely to be admitted to the ED compared to those with a different initial cardiac arrest rhythm (Table 4). Additionally, in cases of CVD, we observed a 32% decrease in success rates when the time to start ALS exceeded 5 minutes. The data confirm that initiating ALS (which includes the first defibrillation attempts in our health system) within the first 5 minutes for patients with VF increases the success of defibrillation, thereby improving the ROSC rate and ED admission (Table 4).

As observed in previous studies, acute myocardial infarction is a significant cause of cardiac arrest [2, 4, 27]. In this study, the results demonstrate a significantly higher ROSC rate and ED admission among VF patients with acute myocardial infarction (52% in Group 1, Table 2), suggesting that effective defibrillation of VF in patients with acute myocardial infarction could be more likely to result in ROSC [27–29].

4.2 Study limitations

This study had several limitations that should be clarified. First, it was conducted at a single center, using prospectively recorded data over a short period of 10 months; therefore, the number of patients and analyzed ECG tracks was limited. In addition, the reported results reflect only the evaluated cohort and should be validated in larger cohorts. Moreover, the small cohort size might have affected the cutoff AMSA value's performance, limiting its clinical relevance. However, the results suggest potential utility in establishing a clinically useful cutoff, supporting the need to extend the study to a larger cohort. Second, we did not use any methods to filter ECG artifacts, relying on the defibrillator technology to minimize the influence of chest compressions on the ECG rhythm. Third, due to the limited number of patients, we could not stratify the performances according to factors that could have influenced AMSA changes. Thus, analyzing indicators related to myocardial dysfunction (*i.e.*, the number of defibrillation attempts and adrenaline dosages), individual factors (*i.e.*, presence of CVD), and out-of-hospital conditions (*i.e.*, bystander CPR response, public access defibrillator availability, and time to ALS) could provide key information for defining computer-assisted models to evaluate AMSA efficiency for defibrillation. Further research could develop defibrillator algorithm software to report AMSA values predictive of successful defibrillation.

5. Conclusions

This study demonstrated high specificity (90.5%) for predicting ROSC and ED admission and that an AMSA value up to 27.6 mV-Hz could be significantly associated with sustained ROSC and ED admission in OHCA cases when using a manual defibrillator (specificity, 73.3%). In addition, the results show the negative impact of current deficiencies, such as limited access to public defibrillators and a low incidence of bystander CPR, on short-term outcomes, which ultimately adversely affect VF waves and decrease AMSA values. A prolonged time from the initiation of ALS (>5 minutes) combined with delayed manual defibrillation attempts reduces AMSA values and shock efficiency.

Moreover, the study results could be extrapolated to in-hospital resuscitation. Larger cohort studies and evaluation of potential confounding factors could help develop a prognostic score for hospital admission by analyzing the reported out-of-hospital factors, such as bystander CPR, public access to AEDs, time to start ALS, AMSA value, adrenaline dosages, and the presence of CVD.

ABBREVIATIONS

Acc, accuracy; AED, automated external defibrillator; ALS, advanced life support; AMI, acute myocardial infarction; AMSA, amplitude spectral area; BLS, basic life support; CI, Confidence Interval; CPR, cardiopulmonary resuscitation; CVD, cardiovascular diseases; DII, the second standard bipolar limb lead; ECG, electrocardiography; ED, Emergency Department; EMS, emergency medical services; n, sample size; n/a, not applicable; No., number; NPV, negative predictive value; OHCA, out-of-hospital cardiac arrest; OR, Odds Ratio; PEA, pulseless electrical activity; PPV, positive predictive value; ROSC, return of spontaneous circulation; SD, standard deviation; Se, sensitivity; SMURD, Mobile Emergency Service for Resuscitation and Extrication; Sp, specificity; VF, ventricular fibrillation; iVF, initial ventricular fibrillation rhythm of cardiac arrest; no-iVF, ventricular fibrillation is not the first rhythm of cardiac arrest.

AVAILABILITY OF DATA AND MATERIALS

The raw data are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

AG, CD—designed the research study. SDB, RT—verify the study protocol and give advice. CD, AS, RT—performed the research. AG—provided help and advice of the research. CD, SDB—analyzed the initial data. AG, RT—discuss the results of the initial data. AG, CD, SDB—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was approved by the Ethics Committee of the Iuliu Haţieganu University of Medicine and Pharmacy Cluj-Napoca, Romania (No. 107/28.02.2014) and was conducted following the principles of the Declaration of Helsinki. In accordance with Directive 2001/20/EC, an adapted informed consent was applied. The study was observational and did not involve any changes to the resuscitation protocol. The absence of consent did not affect patients' healthcare rights. The data were used in accordance with national regulations on patient confidentiality (Order of the Romanian Health Ministry 46/2003).

ACKNOWLEDGMENT

The authors thank Filip Cristian for the specialized consulting in MATLAB and all paramedics and the nurses for the help in data collection.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Adela Golea, Christiana Dumulesc, Andrei Stărică, Sorana D. Bolboacă, Raluca Tat. Amplitude spectrum area as an indicator of effective return of spontaneous circulation in prehospital resuscitation—experience from a single regional center in Romania. Signa Vitae. 2024; 20(10): 47-55. doi: 10.22514/sv.2024.125.