# Electrical Defibrillation Outcome Prediction by Waveform Analysis of Ventricular Fibrillation in Cardiac Arrest Out of Hospital Patients

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**Objective: Indexes such as amplitude spectrum area (AMSA) and power spectrum area (PSA) obtained from electrocardiogram waveform analysis are possible predictors of outcome after electrical defibrillation for ventricular fibrillation (VF). In this study, we examined AMSA and PSA to determine whether these parameters can predict defibrillation outcome.**
**Materials and Methods: A total of 83 out-of-hospital VF victims were classified into four groups according to type of cardiac rhythm after shock: return of spontaneous circulation (ROSC), VF, pulseless electrical activity (PEA), and asystole. AMSA and PSA were calculated from electrocardiograms prior to shock and compared between groups.**
**Results: The mean AMSA (4.0–48 Hz) in the ROSC group was 24.2 ± 8.5 mV-Hz, which was significantly higher than that in the VF and asystole groups.**
**Conclusion: It is possible by analyzing the AMSA of VF to predict cases where electrical defibrillation is more likely to return cardiac rhythm. Furthermore, unnecessary electrical shocks with a low possibility of ROSC can be avoided, and chest compression should be continued to prevent myocardial damage and consequently improve prognosis.**

**Key words: ventricular fibrillation, waveform analysis, amplitude spectrum area (AMSA), prediction, resuscitation**

## INTRODUCTION

Excessive electrical defibrillation may cause severe myocardial dysfunction during and after resuscitation. An increase in the energy delivered for defibrillation was associated with a corresponding decrease in cardiac index and an increase in left ventricular end-diastolic pressure after resuscitation. Eventually, duration of survival was found to be inversely related to the delivered electrical energy [1]. When a shock is delivered repeatedly, it causes myocardial dysfunction [2]. In an isolated heart model, electrical energy for defibrillation causes myocardial injury when myocardial perfusion is reduced during untreated ventricular fibrillation (VF) [3]. However, as myocardial dysfunction can also reduce the possibility of spontaneous circulation (ROSC) return, electrical defibrillation is a double-edged sword.

On the other hand, VF and pulseless ventricular tachycardia (VT), as the initial cardiac rhythms, are associated with better neurological outcome than asystole and pulseless electrical activity (PEA), with or without a bystander. Identifying victims with a shockable rhythm (VT or pulseless VT) and treating them by electrical defibrillation at the earliest possible stage are considered important points for improving prognosis [4, 5]. There is no doubt that effective pre-hospital electrical defibrillation at an early stage directly after the onset of cardiac arrest in the case of VF or pulseless VT is crucial for reducing sudden death. However, electrical defibrillation is not always successful, and the success rate is known to decrease in a time-dependent manner after onset of VF; the success rate declines by approximately 10% per min of delay in intervention with electrical defibrillation when bystander-CPR is not provided [6].

Successful administration of an electric shock to the heart can both defibrillate and permit re-establishment of a cardiac rhythm, whereas an unsuccessful attempt is associated with a risk of myocardial dysfunction. Thus, it is advisable to avoid applying an electric shock when the chance of restoration of a perfusing rhythm is low and to continue chest compression. On the basis of our experience, electrical defibrillation is more likely to restore cardiac rhythm when the amplitude of the VF signals is large, which will cause cardiac asystole when the cardiogram shows ripple-like waveforms. However, visual judgment of waveforms is subjective and not necessarily accurate.

Recent studies have demonstrated that indexes obtained from cardiac waveform analysis are possible predictors of outcome after electrical defibrillation for VF [7–15]. These include the following two indexes obtained from the Fourier transform of VF waveforms:

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Amplitude spectrum area (AMSA) = $\sum$ Ai • Fi
(Ai: amplitude at frequency Fi)
Power spectrum area (PSA) = $\sum$ (Pi • Fi)
(Pi: power at frequency Fi)

In particular, Young *et al.* demonstrated a positive correlation between AMSA and the probability of successful recovery from VF, suggesting that AMSA-based prediction can prevent myocardial dysfunction caused by repetitive attempts of unsuccessful electrical defibrillation [9, 10]. In this report, we examine whether outcome after electrical defibrillation can be predicted by the use of AMSA and PSA values in out-of-hospital VF patients in Japan who received shock treatment by paramedics at the site of onset.

## MATERIALS AND METHODS

Subjects comprised 83 out-of-hospital cardiac arrest victims who had previously received CPR by paramedics of fire stations in four cities located in western Kanagawa prefecture in Japan between 2006 and 2008. All victims were transported to emergency hospitals. CPR was performed according to the 2005 American Heart Association guidelines, and VF was treated with a TEC-2313 or TEC-2513 (Nihon Kohden, Tokyo, Japan) or a Heart Start 4000 (Laerdal Medical Japan, Tokyo, Japan) defibrillator. Patient electrocardiograms recorded during prehospital treatment were collected for research purposes only, after obtaining approval by the institutional review board of Tokai University and the divisions responsible for information disclosure in each of the four cities. Data collected were handled carefully as confidential personal data. Anonymity was preserved, and thus, none of the subjects are traceable.

### Analysis

The 83 VF patients were classified into four groups according to the following types of recorded cardiac rhythms: ROSC (n = 17), VF (n = 25), PEA (n = 8), and asystole (n = 33).

### Electrocardiogram analysis and calculation of AMSA values

When electrocardiograms were available in printed form only, they were scanned at a resolution of at least 600 dpi with a TASkalfa 400ci scanner (Kyocera Mita Co, Osaka, Japan) and converted to portable document files (PDF). The resulting PDF files were then digitized using Simple Digitizer version 3.1 (http://www.agbi.tsukuba.ac.jp/~fujimaki/download/index.html). Digital data were processed to the following cardiac waveforms using a waveform extraction tool, Extract Wave Data (Nihon Kohden; sampling frequency, 250 Hz; data length, 10 bit; data resolution, 8 μV/bit; data analysis time, 4.096 s (1,024 sampling points x 4 ms)).

An AMSA calibration tool, Analyze VF (AMSA) ver. 090707 (Nihon Kohden), was employed to process waveforms further using three filters, perform fast Fourier transform (FFT) analysis and calculate AMSA values. For processing the waveforms, the following three types of filters were used: (1) a notch filter to remove alternating current interference at 50–60 Hz; (2) a high-pass filter (cutoff frequency, 1 Hz) to remove elements causing baseline drifting; and (3) a low-pass filter (cutoff frequency, 40 Hz) to remove myographic noise.

FFT was performed using the Hanning window. The quantity of data transformed was 1,024 points, FFT resolution was 0.244 Hz and FFT analysis range was between 0 to 31 Hz.

AMSA values were calculated using the following formulae:
AMSA (1.3–48 Hz) = $\sum$ (Ai × Fi) (i = 1.3–48)
AMSA (4.0–48 Hz) = $\sum$ (Ai × Fi) (i = 4.0–48)

PSA values were calculated using the following formulae:
PSA (1.3–48 Hz) = $\sum$ (Pi × Fi) (i = 1.3–48)
PSA (4.0–48 Hz) = $\sum$ (Pi × Fi) (i = 4.0–48)

The obtained AMSA and PSA values were compared among the four patient groups. The mean AMSA and PSA values (mean ± standard deviation) were analyzed for statistical significance ($P < 0.05$) between two groups using a Turkey-type multiple comparison test.

## RESULTS

The mean AMSA value (4.0–48 Hz) in the ROSC group was 24.2 ± 8.5, while that in the VF, PEA, and asystole groups was 16.4 ± 8.0, 15.7 ± 7.5, and 15.8 ± 8.9, respectively. Multiple comparisons showed that the mean AMSA (4.0–48 Hz) value was significantly higher in the ROSC group than in the VF (p = 0.0071) and asystole (p = 0.0213) groups, but not significant higher than in the PEA group (p = 0.0969) (Fig. 1).

The mean AMSA value (1.3–48 Hz) in the ROSC group was 40.2 ± 20.0, while that in the VF, PEA, and asystole groups was 28.4 ± 14.0, 26.9 ± 12.8, and 26.1 ± 10.8, respectively. Similarly, the mean AMSA value (1.3–48 Hz) was significantly higher in the ROSC group than in the VF (p = 0.0067) and asystole (p = 0.0476) groups, but not significant higher than in the PEA group (p = 0.1327) (Fig. 2).

The mean PSA value (4.0–48 Hz) in the ROSC group was 21.9 ± 21.7, while that in the VF, PEA, and asystole groups was 8.4 ± 7.3, 8.3 ± 9.2, and 10.2 ± 13.1, respectively. Multiple comparison results confirmed no statistically significant difference in mean PSA (4.0–48 Hz) values among the four patient groups (Fig. 3).

The mean PSA value (1.3–48 Hz) in the ROSC group was 92.6 ± 128.3, while that in the VF, PEA, and asystole groups was 54.2 ± 103.0, 27.7 ± 23.2, and 28.3 ± 25.0, respectively. No statistically significant difference was confirmed for mean PSA values (1.3–48 Hz) among the four patient groups (Fig. 4).

Fig. 5 showed a typical case of successful defibrillation. VF wave looked rough. AMSA value of this case was 37.9 mV-Hz. Fig. 6 showed failed resuscitation attempt. VF wave looked very fine. AMSA value of this case was 8.54mV-Hz.

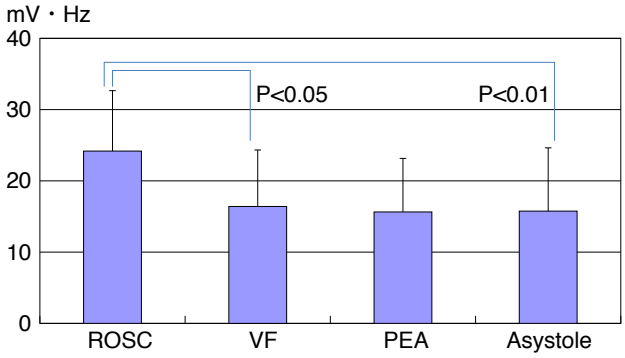


**Fig. 1** Comparison of mean AMSA (4.0–48.0 Hz) between groups.

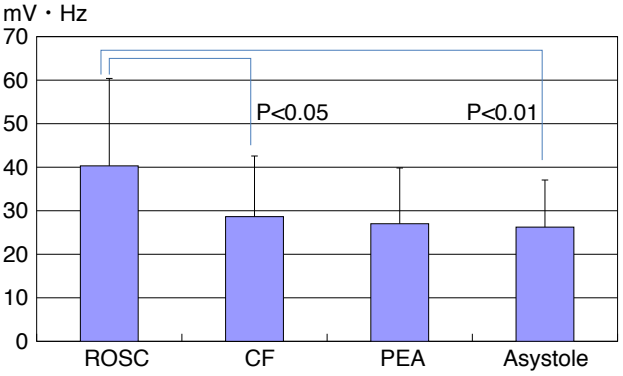


**Fig. 2** Comparison of mean AMSA (1.3–48.0 Hz) between groups.

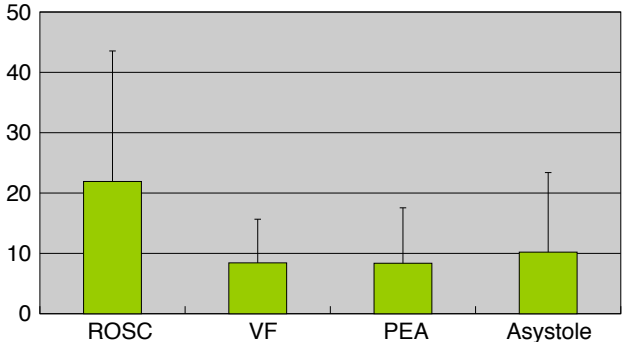


**Fig. 3** Comparison of mean PSA (4.0–48.0 Hz) between groups.

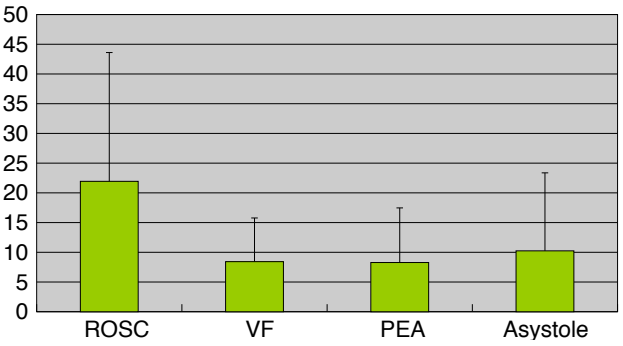


**Fig. 4** Comparison of mean PSA (1.3–48.0 Hz) between groups.

## DISCUSSION

Pernat *et al.* used a pig VF model and demonstrated that the AMSA values were significantly higher in victims who presented with successful restoration of cardiac rhythm after administration of a single electrical shock than in those with unsuccessful restoration [8]. When the minimal filtered frequency was reduced from 4–1.3 Hz, there was no measurable effect on AMSA to discern ROSC and absence of ROSC. As Pernat showed, AMSA 4–48 Hz and AMSA 1.3–48 Hz have a similar effect on discerning ROSC and no ROSC. Furthermore, Young *et al.* found a positive correlation between AMSA values and the prevalence of recovery from VF, in other words, restoration of a cardiac rhythm in out-of-hospital cardiac arrest patients, suggesting the use of AMSA as a predictor of outcome (successful or unsuccessful restoration of cardiac rhythm) of electrical defibrillation [9].

In this study, we examined AMSA and PSA values in out-of-hospital VF patients in Japan. Our results suggest the use of AMSA values for distinguishing cases of restorable cardiac rhythms from unrestorable ones (electrocardiographic findings of asystole, PEA and VF).

We used electrocardiographic waveforms representing rhythms in a 4.096-s period immediately before applying an electrical shock. This means that the AMSA value in VF patients, calculated from the waveforms in the 4.096-s period, can be used as an indicator for electrical defibrillation, thereby contributing to further advancement of AED. For example, electrical shocks are used in patients with a high AMSA value, indicative of a high likelihood of restoration of a cardiac rhythm, while chest compressions are performed in those with a low AMSA value since administration of electrical shocks has only an adverse effect on the myocardium. Because calculating an AMSA value does not require interruption of chest compressions [8], it does not interfere with CPR quality.

The question then arises as to what threshold of AMSA distinguishes waveforms associated with high probabilities of restoration of cardiac rhythm from others? Young *et al.* examined 108 electrical defibrillation attempts in out-of-hospital VF patients and found a positive correlation between AMSA and the probability of successful restoration of cardiac rhythm by electrical shock. In particular, an AMSA value of > 13.0 mV-Hz could be used to predict successful defibrillation with a sensitivity of 0.91 and a specificity of 0.94 [9].

Moreover, Ristagno et al. examined 210 defibrillation attempts performed on 90 victims of out-of-hospital cardiac arrest and calculated AMSA values from VF or VT waveforms in a 4.1-s period prior to the delivery of a shock [12]. Results revealed that a sensitivity of 0.91 and a specificity of 0.97 were achieved in predicting successful defibrillation by using an AMSA threshold of 12 mV-Hz.

When the results of this study were assessed by receiver operating curve analysis, a threshold of 15.8 mV-Hz was obtained, yielding a sensitivity of 0.94 and a specificity of 0.59. Threshold values of AMSA pro-

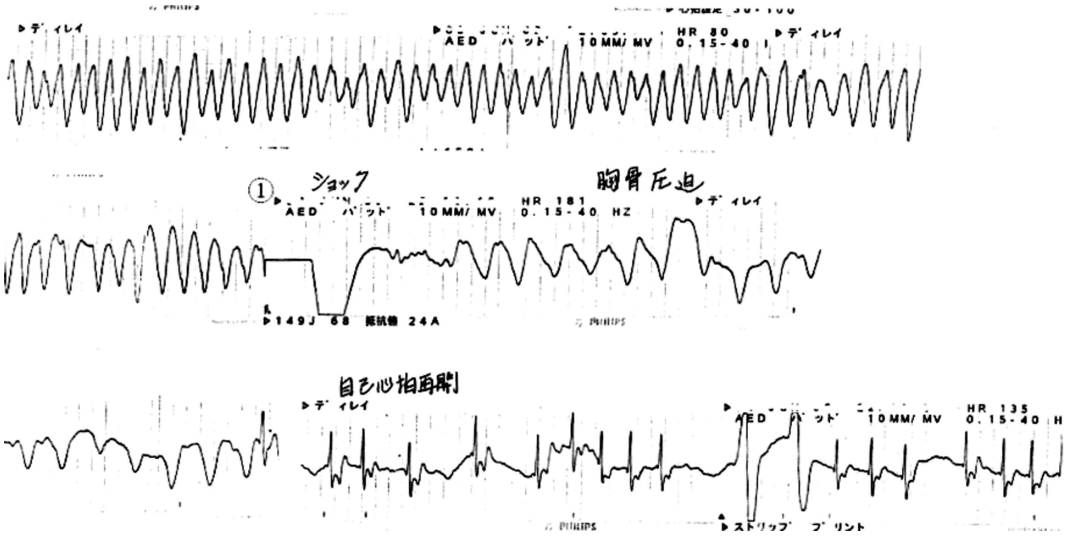


**Fig. 5** ECG of successful defibrillation.

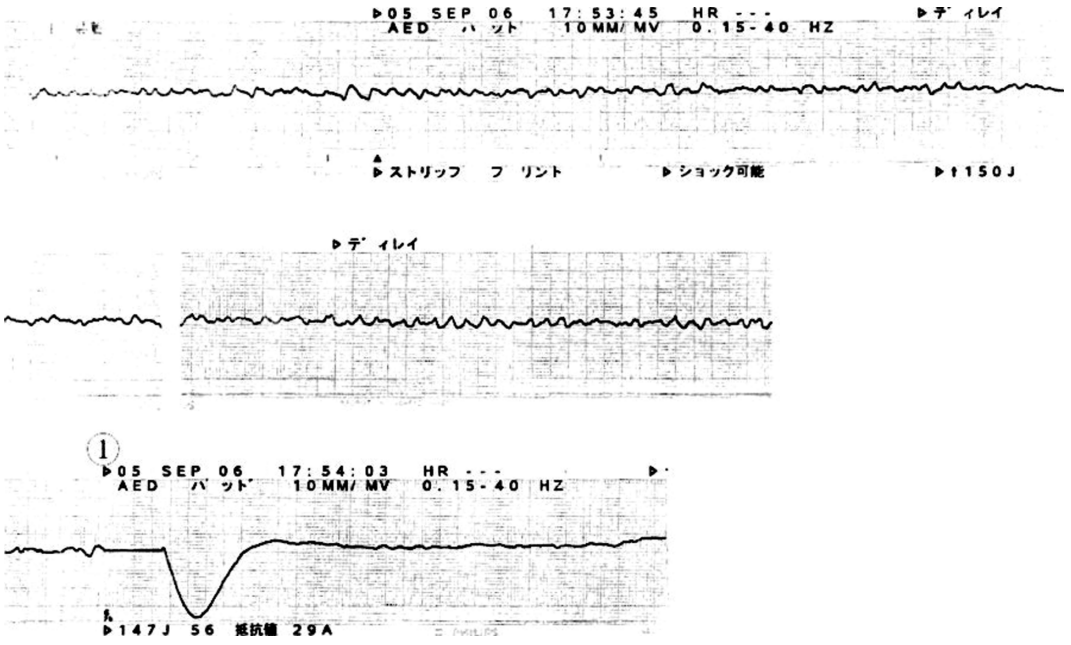


**Fig. 6** ECG of failed defibrillation.

posed in the above studies are not uniform, suggesting the necessity for further investigation using a large number of cases. Moreover, the concept of obtaining the AMSA threshold that differentiates shockable cases from non-shockable cases to prevent or minimize myocardial damage caused by unnecessary electrical shocks is regarded as important.

Continuing chest compressions when AMSA values are below the threshold is also considered important. Effective CPR for VF appeared to have a significant impact on the AMSA value, and gradual increases in the AMSA value during the course of CPR have been shown in previous studies [8, 14]. If the AMSA value reaches the threshold during CRP, electrical defibrillation may be performed.

There are three limitations to this study. Firstly, the number of PEA cases is smaller than that of other studies. This is most likely a reason why differences in the AMSA values between the ROSC and PEA groups were not statistically significant, despite the fact that the mean AMSA (4.0−48 Hz) value in the PEA group (15.7 ± 7.5, n = 8) was comparable to that in the VF group (16.4 ± 8.0, n = 25) and asystole group (15.8 ± 8.9, n = 33), both of which were significantly lower than that in the ROSC group. Thus, the differences in AMSA values between the ROSC and PEA groups may become significant when more PEA cases are examined. Secondly, the AMSA value changes depending on the frequency range used for sampling, and is also affected by the use of lead [16]. Therefore, it is important to stipulate waveform analysis conditions in advance. Lastly, because of the confidentiality agreement made with each of local authorities, anonymous electrocardiographic data were collected through fire

stations, and therefore, it was impossible to examine one-month and long-term prognosis of individual cases. In future, it is important to investigate the association of AMSA with prognosis after resuscitation, as well as to accumulate evidence by studying more cases.

In conclusion, this study demonstrated that by analyzing AMSA values of VF waveforms it is possible to predict cases wherein electrical defibrillation is more likely to restore a cardiac rhythm. However, unnecessary electrical shocks on those with a low possibility of restoration of cardiac rhythm should be avoided, thereby preventing myocardial damage after resuscitation, and consequently improving prognosis.

**Competing interest:** This research was not funded by a third party, and there are no potential competing interests.

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