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Amplitude Spectral Area: Predicting the Success of Electric Shock Delivered by Defibrillators with Different Waveforms

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Objectives: Prolonged ventricular fibrillation (VF) is associated with a low rate of return of spontaneous circulation (ROSC) following electric shock. Moreover, electric shock that does not reestablish spontaneous circulation causes myocardial dysfunction even if ROSC is subsequently achieved. Amplitude spectral area (AMSA), calculated by analysis of VF waveforms immediately before electric shock, is considered to predict the outcome of electric shock. This study aimed to evaluate the prognostic value of AMSA in relation to waveforms of defibrillators in prehospital settings.
Methods: The AMSA values of 81 patients with VF confirmed by ambulance crews were compared according to the type of defibrillators with different waveforms and between those with and without ROSC.
Results: With a biphasic defibrillator, the mean AMSA was significantly different between the 14 patients who achieved ROSC (25.3 ± 9.5 mV-Hz) and the 43 subjects who did not achieve ROSC (15.4 ± 8.1 mV-Hz; p = 0.0006). No significant difference was seen in the corresponding values when a monophasic defibrillator was used, at 19.1 ± 2.4 mV-Hz for 3 ROSC patients and 16.1 ± 7.5mV-Hz for 21 non-ROSC patients.
Conclusion: AMSA may serve as a predictive measure for ROSC following electric shock delivered by a biphasic defibrillator.

Key words: AMSA, prediction, Out-of –hospital cardiac arrest, ventricular fibrillation, defibrillation

INTRODUCTION

Although the significance of early defibrillation for ventricular fibrillation (VF) is well known, the efficacy of early defibrillation for prolonged VF remains to be elucidated.

Since myocardial oxygen demand during VF is increased compared to that during normal heart rate [1, 2] prolonged VF results in depleted energy in the myocardium and causes a state of acidosis [3]. Return of spontaneous circulation (ROSC) is unlikely to be achieved by applying electric shock in this state. Indeed, the more time that elapses after the onset of VF, the more unlikely ROSC will be achieved by electric shock [4].

The use of electric shock for VF may cause cardiac dysfunction after resuscitation. Xie *et al.* induced untreated VF lasting for 4 min in 3 groups of rats, performed 6-min cardiopulmonary resuscitation (CPR), applied electric shock at 2, 10, and 20 J, and evaluated cardiac function and survival rate after resuscitation [5]. The results demonstrated that an increased energy of electric shock was associated with decreased cardiac function markers, including dp/dt, -dp/dt, and cardiac index, increased lactate level, decreased $EtCO_2$ level, and reduced final survival rate. In addition, Gazmuri *et al.* demonstrated that repeated application of low-energy electric shocks impaired postischemic diastolic dysfunction in particular, by reducing the unstressed left ventricular end-diastolic volume [6].

Thus, when ROSC is unlikely to be achieved, priority should be given to improving myocardial condition by performing CPR, while at the same time maintaining coronary perfusion pressure (CPP) at a reasonable level. In rats, when CPR was started after VF lasting for 10 min, a higher success rate for ROSC was achieved by performing defibrillation after 6 min of chest compression than by starting to apply electric shock 2 or 4 min after initiating CPR [7]. When an automated external defibrillator (AED) is used, the application of electric shock not leading to ROSC may result in chest compression being discontinued for electrocardiogram analysis, and will therefore adversely affect the success of ROSC. In other words, the discontinuation of chest compression results in decreased CPP and this decrease in CPP below the cut-off level reduces the success rate for electric shock, especially after prolonged cardiac arrest [8].

To achieve ROSC after prolonged VF, the aim is to improve complicating conditions such as acidosis by performing chest compression in an appropriate fashion and applying electric shock at an appropriate timing, rather than by applying electric shock immediately. When applying electric shock for VF, the amplitude spectral area (AMSA), as determined by analyzing the VF waveforms, can be used as a predictive variable for determining the effectiveness of electric shock applied for VF [9-13]. AMSA is the Fourier transform

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of the VF waveform multiplied by the amplitude and frequency:

$$AMSA = \Sigma \, Ai \times Fi \quad (1)$$

Here, A denotes amplitude, F denotes frequency, and i denotes a range of 4–48 Hz.

The success rate for electric shock is also affected by the type of defibrillator used. Biphasic defibrillators are known to provide a higher success rate for defibrillation than monophasic ones [14]. However, monophasic defibrillators are still occasionally in use.

The objective of this study was to determine whether AMSA can be used to predict the outcome of electric shock delivered by defibrillators with different waveforms (monophasic or biphasic) in patients who develop out-of-hospital cardiac arrest resulting from VF.

PATIENTS AND METHODS

Subjects were 83 individuals who had experienced out-of-hospital cardiac arrest and received CPR by paramedics or fire station officers in four cities located in western Kanagawa prefecture, Japan between 2006 and 2008. All were transported to emergency hospitals for further treatment. CPR was performed according to the 2005 American Heart Association guidelines, and VF was treated with a TEC-2313 or TEC-2513 defibrillator (Nihon Kohden, Tokyo, Japan) or a Heart Start 4000 defibrillator (Laerdal Medical Japan, Tokyo, Japan). Patient electrocardiograms recorded during prehospital treatment were collected for research purposes only, after obtaining approval from 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.

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 × 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. The following three types of filters were used to process the waveforms: (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 a Hanning window. The quantity of data transformed was 1,024 points, FFT resolution was 0.244 Hz, and FFT analysis range was 0–31 Hz. AMSA values were calculated using Equation 1, where AMSA and i were in the range 4.0–48 Hz.

Analysis

Of the 81 subjects, 57 were treated with a biphasic defibrillator (biphasic group) and 24 were treated with a monophasic defibrillator (monophasic group). For each subject group, AMSA was calculated for the last 4 s before electric shock, and differences between those who achieved ROSC following electric shock and those who did not were examined using the Mann-Whitney test.

RESULTS

In the biphasic group, 14 subjects who achieved ROSC (ROSC group) had a mean AMSA of 25.3 ± 9.5 mV-Hz, while 43 subjects who did not achieve ROSC (non-ROSC group) had a mean AMSA of 15.4 ± 8.1 mV-Hz, showing a significant difference between the two groups ($p = 0.0006$) (Fig. 1). In the monophasic group, 3 subjects in the ROSC group had a mean AMSA of 19.1 ± 2.4 mV-Hz, while 21 patients in the non-ROSC group had a mean AMSA of 16.1 ± 7.5mV-Hz. No significant difference was found between the two groups, although this may be due to a narrow range of data for the small ROSC group (Fig. 2).

Using data from the biphasic group, where a significant difference in AMSA was observed between the ROSC and non-ROSC groups, we attempted to determine the cut-off level of AMSA in order to determine the indication for using electric shock. Assuming that all the patients who achieved ROSC are candidates for electric shock, the cut-off level of AMSA is determined to be ≥ 15 mV-Hz (Fig. 3).

If the cut-off value of AMSA for achieving ROSC by electric shock is set at 15 mV-Hz, it provides a sensitivity of 1.0, specificity of 0.64, positive predictive value of 0.42, and negative predictive value of 1.0. If this cut-off level is applied to the monophasic group, all 3 patients who achieved ROSC would be considered candidates for electric shock.

DISCUSSION

The success rate for defibrillation of VF by electric shock decreases over time [3]. For witnessed cardiac arrest, time from onset of VF can be easily estimated; if only a short time has elapsed from VF onset, electric shock should be applied immediately for maximal efficacy; if a long time has elapsed from VF onset, chest compression should be performed instead of electric shock. If the onset time is known, the success rate for electric shock can be estimated from the duration of VF. In many clinical cases, however, no witness is available and the duration of VF is unknown.

It has been reported that a better outcome is obtained by performing CPR first if the ambulance response time is ≥ 5 min [15]; however, it has also been reported that 3-min CPR performed before electric shock did not alter the outcome of electric shock compared to when no CPR was performed [16]. One

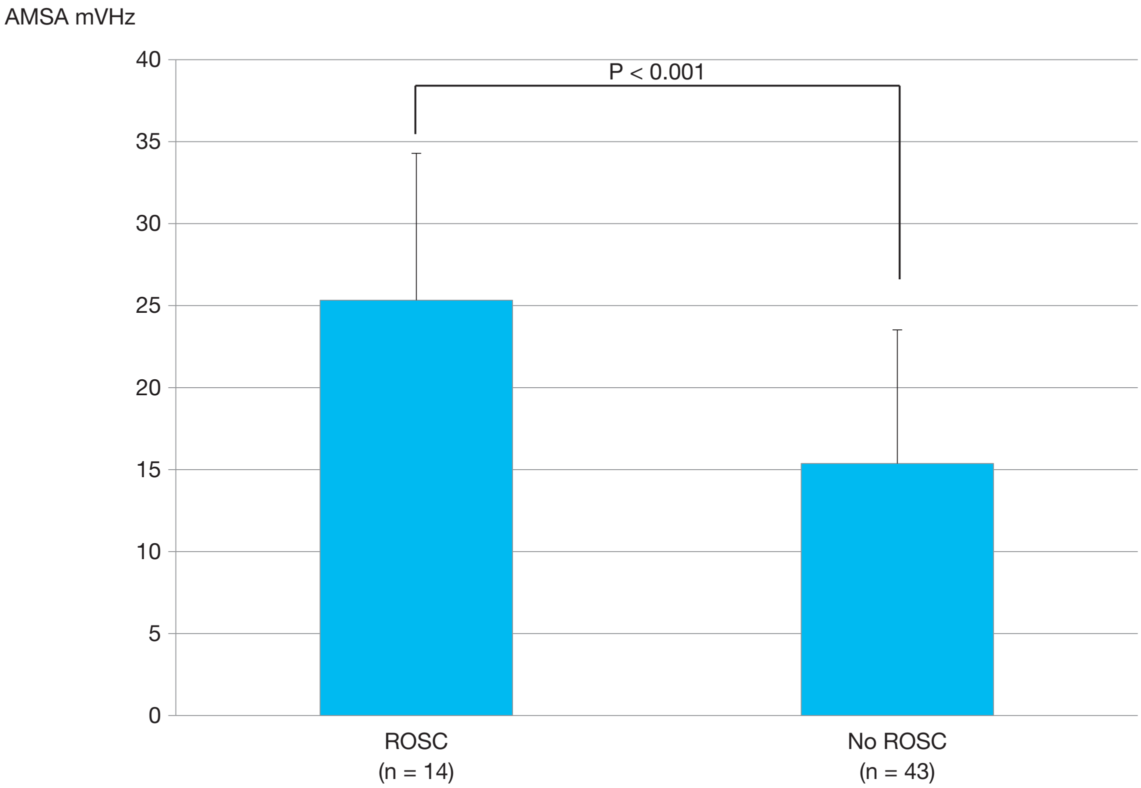

Fig. 1 Comparison of amplitude spectral area (AMSA) between the return of spontaneous circulation (ROSC) and non-ROSC groups when using a biphasic defibrillator

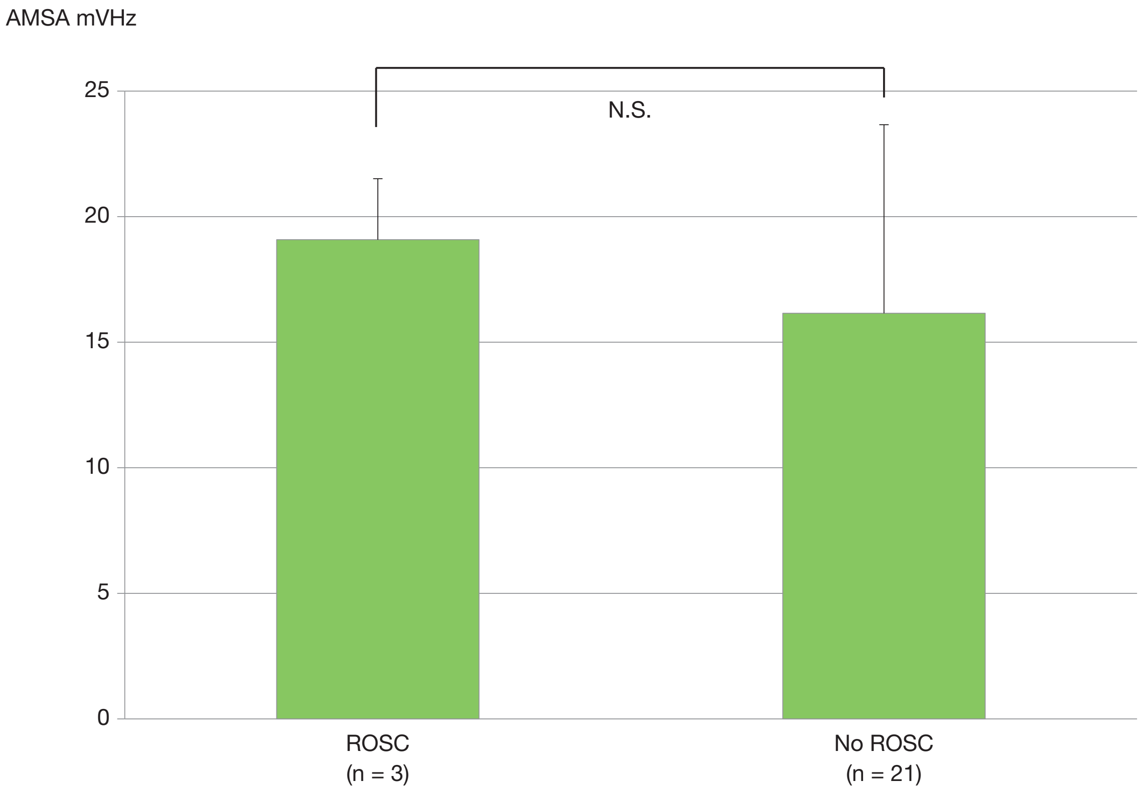

Fig. 2 Comparison of AMSA between the ROSC and non-ROSC groups when using a monophasic defibrillator

of the reasons why no definitive conclusion has been reached regarding whether CPR or electric shock should be performed first is because the ambulance response time does not accurately reflect the duration of VF in many clinical cases.

An additional consideration is that the success rate

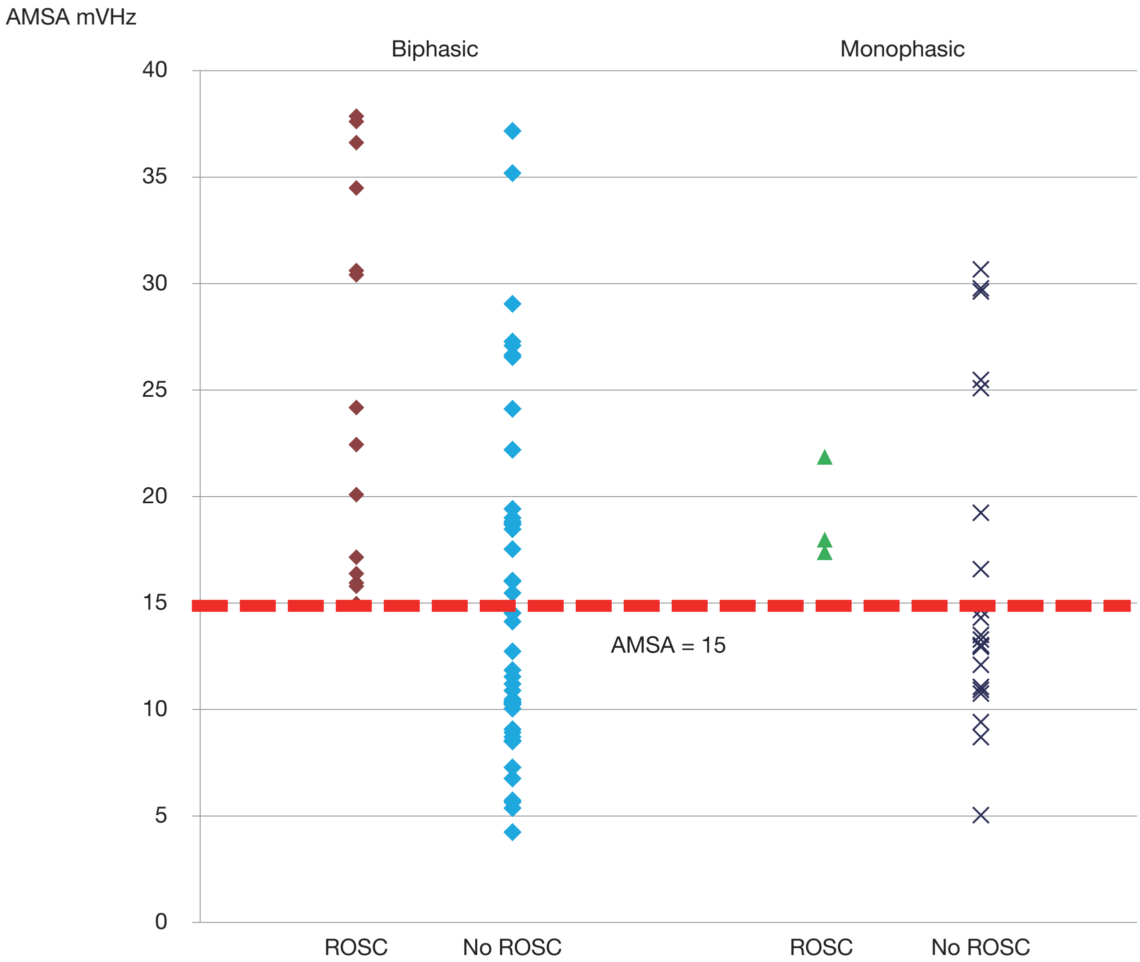

Fig. 3 AMSA values preceding each electric shock. Dotted line represents the threshold value of 15 mV-Hz.

of electric shock defibrillation in actual prehospital settings does not decrease as a linear function of time. The success rate is also affected by the presence or absence and the quality of bystander CPR. Other factors influencing the success rate include interruption of CPR during transportation of the patient and administration of medication by the ambulance crew. Thus, the success rate is affected by various factors and changes from moment to moment during CPR.

AMSA, as determined by analyzing the VF waveforms, can be used as a predictive variable for determining the effectiveness of electric shock applied for VF. Animal experiments have been conducted to determine the cut-off level of AMSA for successful ROSC. These have been conducted based on the observation that when VF is artificially induced, CPR is performed, and an electric shock is applied, AMSA before the electric shock is significantly higher in animals that achieve ROSC than in those that do not [9, 10]. AMSA has also been shown to be significantly correlated with CPP, an important predictive variable for ROSC [9]. Thus, AMSA is considered a dynamic variable that can be used to predict whether ROSC can be achieved by VF.

The prognostic value of AMSA for the outcome of electric shock for VF has also been evaluated in humans. In a study involving 46 patients who developed out-of-hospital cardiac arrest as a result of VF, Yong *et al.* demonstrated that AMSA ≥ 13.0 mV-Hz can be used to predict ROSC at a sensitivity of 0.91 and specificity of 0.94 [11]. Ristagno *et al.* demonstrated in a study involving 90 patients with out-of-hospital cardiac arrest resulting from VF or VT that AMSA can predict whether or not ROSC can be achieved by electric shock with ≥ 90% sensitivity and specificity [12].

If AMSA is above a certain level and thus indicates a high possibility of ROSC, electric shock should be given immediately. In contrast, chest compression should be continued if AMSA is low. Performing chest compression while maintaining CPP at a reasonable level improves myocardial condition and increases AMSA [9, 10, 13]. By waiting to apply electric shock until after CPR increases AMSA, unnecessary electric shock given at a low level of AMSA can be avoided and cardiac dysfunction after resuscitation can be prevented, ultimately leading to a better prognosis.

The use of AMSA enables the success rate for electric shock, which changes on a real time basis, to be predicted from the VF waveforms obtained immediately before applying electric shock. Its use makes the CPR strategy for VF more pronounced and effective. Electric shock should be applied immediately if AMSA is sufficiently high, as it indicates that ROSC is likely to be achieved by electric shock.

Representative cases in the present study are shown in Figs. 4 (case 1) and 5 (case 2). In case 1, the VF waveforms are large, with an AMSA of 37.9 (Fig. 4). Electric shock successfully achieved ROSC in this case.

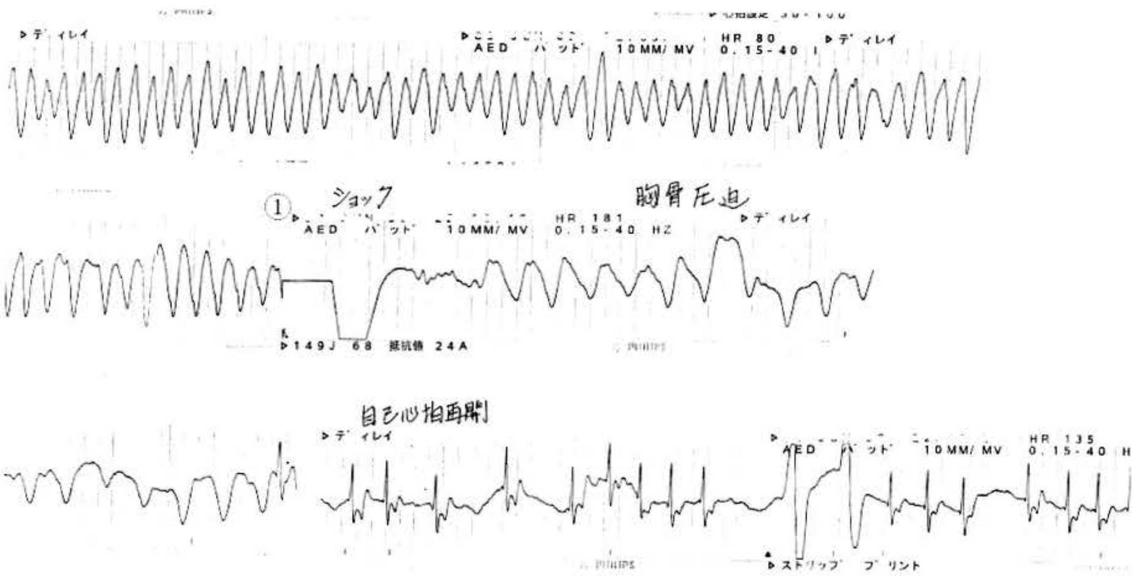

Fig. 4 A case 1 in the ROSC group. AMSA was as large as 37.9, restarting heartbeats by electric shock.

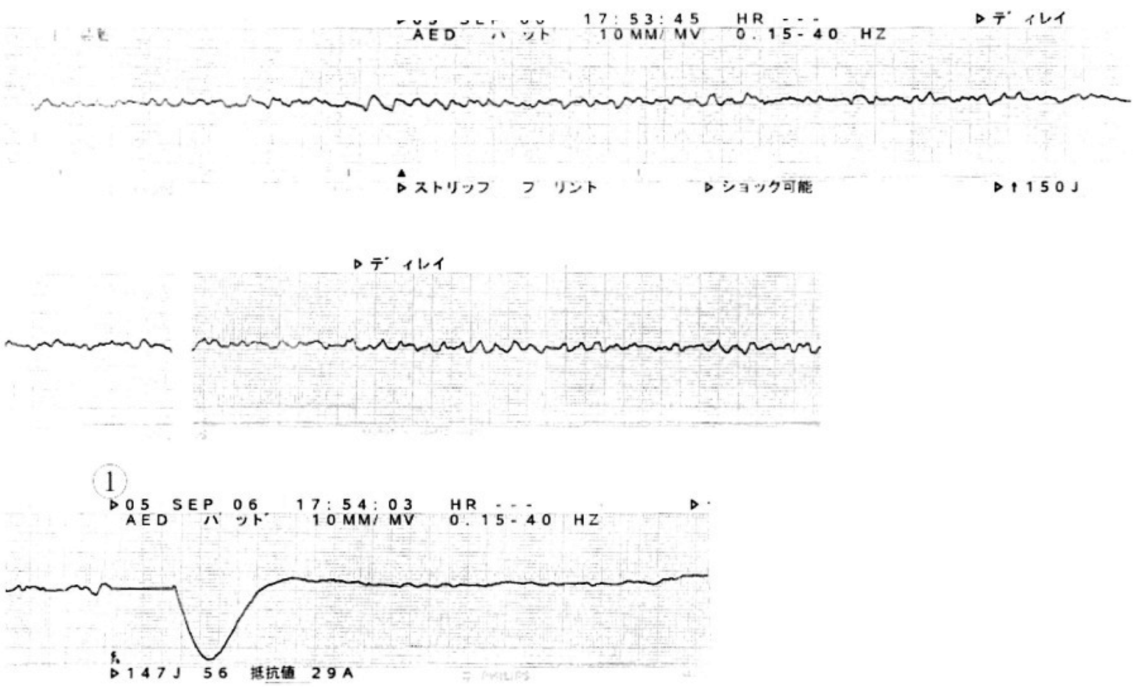

Fig. 5 A case 2 in the non-ROSC group. With a small AMSA value of 8.5, electric shock failed to restart heartbeats.

On the other hand, case 2 had small ripple-like VF waveforms, and the AMSA was 8.5 (Fig. 5), failing to achieve ROSC.

The type of defibrillator used affects the success rate for electrical shock. In the biphasic group in the present study, AMSA was significantly higher in the ROSC group than in the non-ROSC group, suggesting that electric shock given by a biphasic defibrillator is more likely to produce an outcome close to that estimated from AMSA values.

The present study has some limitations, which include a small population size. Also, the cut-off level for AMSA used to determine the indication for applying electric shock was determined to be 15 mV-Hz in this study, but this is still inadequate in terms of specificity (0.64) and positive predictive value (0.42).

The rate of successful ROSC in the biphasic group was 24.6% and thus higher than the 12.5% in the monophasic group, but the difference was not statistically significant. The AMSA value of the non-ROSC group in the monophasic group was 16.1, which was almost as low as the AMSA of 15.4 in the non-ROSC group in the biphasic group.

Further studies should be conducted with a larger population size to improve the accuracy of the cut-off level. For the monophasic group, significance of the difference in success rate between the ROSC and non-ROSC groups could not be determined due to a small population size. Future investigations are warranted to address whether the effectiveness of monophasic electric shock can be predicted by AMSA and to compare its predictive value between monophasic and biphasic groups. Another limitation was that neither the subjects' background data nor long-term outcome data were available due to confidentiality of personal information. Outcome data should also be analyzed in future studies.

How AMSA changes during the course of resuscitation should also be addressed in future studies. We believe that further investigations are necessary to determine how AMSA changes under continued CPR or after administration of medication, in relation to the success or failure of electric shock.

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