Anaesth Intensive Care 2008; **36:** 46-50

Prediction of successful defibrillation in human victims of out-of-hospital cardiac arrest: a retrospective electrocardiographic analysis

G. RISTAGNO*, A. GULLO†, G. BERLOT‡, U. LUCANGELO§, F. GEHEB**, J. BISERA††

Weil Institute of Critical Care Medicine, Rancho Mirage, California, United States of America

SUMMARY

In the present study we sought to examine the efficacy of an electrocardiographic parameter, 'amplitude spectrum area' (AMSA), to predict the likelihood that any one electrical shock would restore a perfusing rhythm during cardiopulmonary resuscitation in human victims of out-of-hospital cardiac arrest. AMSA analysis is not invalidated by artefacts produced by chest compression and thus it can be performed during CPR, avoiding detrimental interruptions of chest compression and ventilation. We hypothesised that a threshold value of AMSA could be identified as an indicator of successful defibrillation in human victims of cardiac arrest.

Analysis was performed on a database of electrocardiographic records, representing lead 2 equivalent recordings from automated external defibrillators including 210 defibrillation attempts from 90 victims of out-of-hospital cardiac arrest. A 4.1 second interval of ventricular fibrillation or ventricular tachycardia, recorded immediately preceding the delivery of the shock, was analysed using the AMSA algorithm. AMSA represents a numerical value based on the sum of the magnitude of the weighted frequency spectrum between two and 48 Hz.

AMSA values were significantly greater in successful defibrillation (restoration of a perfusing rhythm), compared to unsuccessful defibrillation ($P < 0.0001$). An AMSA value of 12 mV-Hz was able to predict the success of each defibrillation attempt with a sensitivity of 0.91 and a specificity of 0.97.

In conclusion, AMSA analysis represents a clinically applicable method, which provides a real-time prediction of the success of defibrillation attempts. AMSA may minimise the delivery of futile and detrimental electrical shocks, reducing thereby post-resuscitation myocardial injury.

Key Words: ventricular fibrillation, ECG, amplitude spectrum area, defibrillation

More than 50% of all patients initially resuscitated from cardiac arrest subsequently die before leaving hospital[1-3] and the majority of these deaths are due to impaired myocardial function[4].

Electrical defibrillation is the unique treatment for ventricular fibrillation (VF) cardiac arrest. However, we have recognised that the severity of post-resuscitation myocardial dysfunction is also related to the magnitude of the electrical energy delivered with defibrillation[5,6]. Increases in the energy of defibrillation are associated with decreased post-resuscitation myocardial function[5,7].

Current guidelines suggest consideration of a "one- to three-minute period of CPR before attempting defibrillation in adults with out-of-hospital VF or pulseless VT and EMS response (call to arrival) intervals greater than four to five minutes"[8]. The guidelines cite evidence that this period of CPR may increase the likelihood of successful defibrillation, though this appears to be time-dependent[8-11]. Early CPR, such as to restore coronary perfusion pressure and myocardial blood flow, delays onset of ischaemic myocardial injury and facilitates defibrillation[12].

Chest compressions, however, create artefacts on the electrocardiographic (ECG) signal such that pauses in CPR are mandatory for rhythm analysis prior to attempting defibrillation[13,14]. Substantial

*M.D., Resident, Department of Perioperative Medicine, Intensive Care and Emergency, University Hospital, Trieste, Italy and Fellow, Weil Institute of Critical Care Medicine.
†M.D., Professor, Anaesthesiologist, Director, Postgraduate Specialisation School in Anaesthesiology and Intensive Care, University of Catania and Head, Department of Anaesthesia and Intensive Care, Catania University Hospital, Italy.
‡M.D., Professor, Anaesthesiologist, Director, Postgraduate Specialisation School in Anaesthesiology and Intensive Care, University of Trieste and Director, Department of Perioperative Medicine, Intensive Care and Emergency, University Hospital, Trieste, Italy.
§M.D., Assistant Professor, Anaesthesiologist, Department of Perioperative Medicine, Intensive Care and Emergency, University Hospital, Trieste, Italy.
**Ph.D., Consultant, ZOLL Medical Corporation, Massachusetts.
††M.S.E.E, Biomedical Engineer.

Address for reprints: Professor A. Gullo, Department of Anaesthesia and Intensive Care, Policlinico University Hospital, School of Medicine, via Santa Sofia 78—Building 29, 95123 Catania, Italy.

Accepted for publication on August 22, 2007.

interruptions of chest compressions have detrimental effects on the success of cardio-pulmonary resuscitation[14-16], reducing the likelihood of success of defibrillation due to immediate declines of coronary perfusion[15,17,18].

In the present study, we therefore sought to examine the efficacy of an electrocardiographic parameter, 'amplitude spectrum area' (AMSA), to predict the likelihood that any one electrical shock would restore a perfusing rhythm, during cardiopulmonary resuscitation, in human victims of out-of-hospital cardiac arrest. The AMSA analysis was conducted on electrocardiographic recordings of frontal plane lead 2 equivalent recorded during cardiac resuscitation. We hypothesised that a threshold value of AMSA could be identified that would be applicable as an indicator of successful defibrillation in human victims of cardiac arrest.

MATERIALS AND METHODS

A database of 369 episodes of ventricular fibrillation or ventricular tachycardia with defibrillation attempts, obtained from 139 human victims of out-of-hospital cardiac arrest, was available through the courtesy of ZOLL Medical Corporation, Massachusetts, U.S.A. Electro-cardiograms were recorded from ZOLL AED PLUS and ZOLL AED PRO automated external defibrillators at a sample rate of 250 Hz. These defibrillators provided escalating biphasic shocks in the sequence, 120-150-200 joules; subsequent shocks were delivered with energy of 200 joules. Events prior to and after delivery of each electrical shock were recorded.

AMSA analysis algorithm has been previously described[19-21]. In brief review, the ECG signal is filtered between two and 48 Hz to minimise low frequency artefacts produced by chest compression and to exclude the electrical interference of ambient noise at frequencies greater than 48 Hz. Analog ECG signals are digitalised and converted from a time to a frequency domain by fast Fourier transformation. The resulting amplitude spectrum relationship is the so-called AMSA. The sum of individual amplitudes and frequencies, i.e. AMSA = $\sum$ Ai · Fi, where Ai represents the amplitude at i^{th} frequency Fi.

Our analysis was performed on a 4.1 second interval of electrocardiographic recordings immediately preceding the delivery of the defibrillatory shock. For purpose of this study, the outcome of the shock was defined according to the following criteria: return of a perfusing rhythm (PR), if defibrillation restored an organised rhythm with heart rate ≥40 /min commencing within the one-minute post-shock period and persisting for a minimum of 30 seconds; or failure of return of a perfusing rhythm (NR), if ventricular fibrillation, ventricular tachycardia (heart rate >150 /min), asystole or pulseless electrical activity, with pauses >five seconds, occurred. Only ECG recordings with adequate pre- and post-shock durations, for the purpose of analysis, and in which the defibrillation outcomes could be confirmed, were included in the study.

AMSA was computed with the aid of Matlab 7.2 computing software (Natick, MA). Two independent readers reviewed the electrocardiographic recordings to confirm defibrillation outcomes. Normal distribution of the data was confirmed using Kolmogorov-Smirnov Z test. Differences in AMSA values between successful and unsuccessful defibrillation attempts were analysed by the Student's t-test for independent samples. Data are presented as mean ± SD.

RESULTS

A total of 210 defibrillation attempts on ECG recordings from 90 human victims of out-of-hospital cardiac arrest were included for analysis. There was a significant difference in the AMSA values between successful defibrillation (restoration of a perfusing rhythm) and unsuccessful defibrillation (failure to restore a perfusing rhythm), as shown in Table 1 (P <0.0001).

TABLE 1

Amplitude spectrum area and success of defibrillation attempts (mean ± SD)

	PR	NR	*P* value
AMSA mV-Hz (all DF attempts)	16±3.4	7.1±2.6	<0.0001
AMSA mV-Hz (first DF attempt)	16±3.7	7.8±2.6	<0.0001

PR=return of a perfusing rhythm, NR=failure of return of a perfusing rhythm, DF=defibrillation.

Using the intersection of sensitivity and specificity curve for different AMSA values, we selected a threshold that provided a balance of sensitivity and specificity (Figure 1). An AMSA value of 12 mV-Hz predicted successful defibrillation with return of perfusing rhythm, with a sensitivity of 0.91 and a specificity of 0.97. The positive predictive value, which refers to the proportion of the shocks that were correctly predicted to restore a perfusing rhythm, was 0.95. The negative

predictive value, which instead refers to the proportion of the shocks that were predicted to fail and actually failed to restore a perfusing rhythm, was 0.97 (Table 2). We further confirmed the predictive ability for successful defibrillation by use of the area under the ROC curve, relative to the AMSA value of 12 mV-Hz. The area under the ROC curve was 0.991 (Figure 2).

Subsequently we analysed the AMSA values that preceded the delivery of the first electrical shock. A total of 83 defibrillation attempts were included. We again confirmed a significant difference in AMSA values between successful and unsuccessful defibrillation ($P < 0.0001$, Table 1). An AMSA value of 12 mV-Hz was able to predict the success of the first defibrillation attempt with a sensitivity of 0.95 and a specificity of 1. High positive and negative predictive values were also confirmed (Table 2).

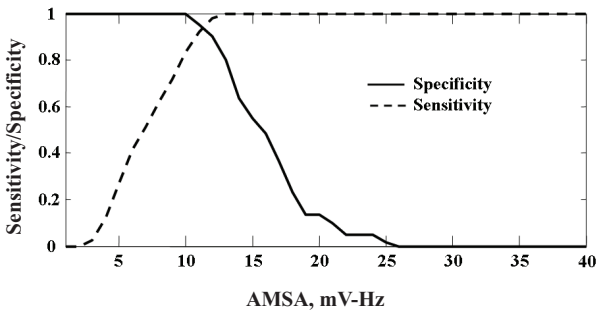

FIGURE 1: Intersection of sensitivity and specificity curves for different AMSA values. From the intersection we could select the threshold with the highest sensitivity and specificity, 12 mV-Hz.

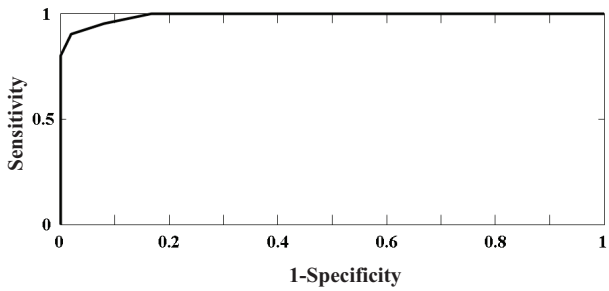

FIGURE 2: Return of a perfusing rhythm: predictive ability. ROC curve for AMSA value of 12 mV-Hz. The area under the ROC curve is 0.991.

DISCUSSION

The ability to predict defibrillation success may minimise the damaging effects of repetitive and unnecessary electrical shocks. In the present study, AMSA analysis was applied to the ECG signals of human victims of out-of-hospital cardiac arrest, and was able to discriminate with high sensitivity and specificity those shocks that effectively terminated ventricular fibrillation and those that failed.

Existing predictors of successful resuscitation include coronary perfusion pressure[22,23] and end-tidal CO_2[24,25]. Coronary perfusion pressure is highly correlated to the myocardial blood flow, but is generally inapplicable in preclinical settings. End-tidal CO_2 may serve as a surrogate measurement for cardiac output, but has not been evaluated in the setting of prediction of shock success in humans. Other investigators focused their attention on the morphology of the ventricular fibrillation waveform in order to predict the success of resuscitation. Greater VF amplitude together with dominant and median frequency were associated with improved outcomes[26-31]. However, the challenge is to ensure high sensitivity and specificity, especially during precordial compression, in order to identify the ideal moment to deliver the defibrillatory shock.

The ASMA approach represents an accurate predictor for successful defibrillation. Under experimental conditions, in porcine models of cardiac arrest and resuscitation, AMSA[19,21] has already been shown to uniformly predict the success of electrical shocks, yielding sensitivity and specificity of about 90%. AMSA predicted (with a negative predictive value of more then 95%) when an electrical shock failed to restore spontaneous circulation.

AMSA analysis is a simple parameter that can be easily obtained by a conventional surface electrocardiogram that is part of the routine current practice of advanced cardiac life support. Moreover, this method has the potential advantage that it is not invalidated by artefacts produced by chest compression and thereby it can be utilised during CPR, without detrimental interruptions of chest compression and ventilation[19,21]. However,

TABLE 2
Prediction of successful defibrillation attempts

	Sensitivity	Specificity	Positive predictive value	Negative predictive value
AMSA: 12 mV-HZ (all DF attempts)	54/59=0.91	148/151=0.97	54/57=0.95	148/153=0.97
AMSA: 12 mV-HZ (first DF attempt)	22/23=0.95	60/60=1	22/22=1	60/61=0.98

DF=defibrillation.

this study did not assess AMSA during chest compressions.

The results of the present study are consistent with a previous retrospective analysis of electrocardiograms of human victims of cardiac arrest. In that study, different defibrillators with different energies and waveform of electrical shocks were employed. An AMSA value of 13 mV-Hz predicted successful defibrillation, with a sensitivity of 91% and a specificity of 94%[20]. These results confirm that AMSA represents an excellent predictor of success of an electrical shock attempt, independently from the defibrillatory energies and waveforms utilised.

We recognise important limitations in the present findings. Our analysis was conduced in a variable number of 210 episodes on 90 victims of cardiac arrest and the outcome data reflect only initial restoration of a perfusing rhythm rather than hospital survival. In addition, the potential confounding variable of 'hands off time before defibrillation' was not controlled for in this study. Finally, the 2005 guidelines[8] introduced the single shock protocol in order to minimise interruptions in chest compressions and previous investigations have already reported better outcomes with adoption of this algorithm[32]. The database employed for our study presented the sequence of 'up to three' escalating electrical shocks. We did not focus our attention on the comparison of the effects on outcome of the first and subsequent electrical shocks. However, when we analysed the AMSA values that preceded the delivery of the first shock, we confirmed the possibility to discriminate between successful and unsuccessful defibrillation. Moreover, sensitivity and specificity of this approach increased. These results suggest that AMSA approach may be useful to predict the defibrillation outcome independently from the number of electrical shocks and energy delivered. However, such hypotheses require additional studies to be proven. Nevertheless, the present study provided consistent evidence that amplitude spectrum area analysis represents a clinically applicable method, derived from the electrocardiographic tracing, which may provide a real-time indicator for prediction of the success of defibrillation. We therefore anticipate that the AMSA algorithm, incorporated into conventional AEDs, will allow for a more optimal timing of defibrillation, minimising interruption in CPR and minimising the delivery of futile and detrimental electrical shocks, with possible reduction in post resuscitation myocardial injury.

CONCLUSIONS

AMSA analysis represents a clinically applicable method which may provide a real-time prediction of the success of defibrillation attempts. The use of AMSA may minimise interruptions in CPR and reduce the delivery of futile and detrimental electrical shocks.

DECLARATION OF INTEREST

The Weil Institute of Critical Care Medicine, Rancho Mirage, California, is the recipient of the U.S. patent for AMSA algorithm. U.S. patent no.: 5,957,856.

ACKNOWLEDGEMENTS

The database utilised for this study was available through the courtesy of ZOLL Medical Corporation, Massachusetts, U.S.A.

REFERENCES

1. Peatfield RC, Sillett RW, Taylor D, McNicol MW. Survival after cardiac arrest in the hospital. Lancet 1977; 1:1223-1225.
2. DeBard ML. Cardiopulmonary resuscitation: analysis of six years' experience and review of the literature. Ann Emerg Med 1981; 10:408-416.
3. Schenenberger RA, von Planta M, von Planta I. Survival after failed out of hospital resuscitation. Are further therapeutic efforts in the emergency department futile? Arch Intern Med 1994; 154:2433-2437.
4. Tang W, Weil MH, Sun S, Noc M, Yang L, Gazmuri RJ. Epinephrine increases the severity of postresuscitation myocardial dysfunction. Circulation 1995; 92:3089-3093.
5. Xie J, Weil MH, Sun S, Tang W, Sato Y, Jin X et al. High-energy defibrillation increases the severity of postresuscitation myocardial dysfunction. Circulation 1997; 96:683-688.
6. Osswald S, Trouton TG, O'Nunain SS, Holden HB, Ruskin JN, Garan H. Relation between shock-related myocardial injury and defibrillation efficacy of monophasic and biphasic shocks in a canine model. Circulation 1994; 90:2501-2509.
7. Tang W, Weil MH, Sun S, Jorgenson D, Morgan C, Klouche K et al. The effects of biphasic waveform design on post-resuscitation myocardial function. J Am Coll Cardiol 2004; 43:1228-1235.
8. International Liaison Committee on Resuscitation. Part 3: Defibrillation. Resuscitation 2005; 67:203-211.
9. Cobb LA, Fahrenbruch CE, Walsh TR, Copass MK, Olsufka M, Breskin M et al. Influence of cardiopulmonary resuscitation prior to defibrillation in patients with out-of-hospital ventricular fibrillation. JAMA 1999; 281:1182-1188.
10. Wik L, Hansen TB, Fylling F, Steen T, Vaagenes P, Auestad BH et al. Delaying defibrillation to give basic cardiopulmonary resuscitation to patients with out-of-hospital ventricular fibrillation: a randomized trial. JAMA 2003; 289:1389-1395.
11. Jacobs IG, Finn JC, Oxer HF, Jelinek GA. CPR before defibrillation in out-of-hospital cardiac arrest: a randomized trial. Emerg Med Australas 2005; 17:39-45.

12. Deshmukh HG, Weil MH, Gudipati CV, Trevino RP, Bisera J, Rackow EC. Mechanism of blood flow generated by precordial compression during CPR. I. studies on closed chest precordial compression. Chest 1989; 95:1092-1099.
13. Eftestol T, Sunde K, Steen PA. Effects of interrupting compressions on the calculated probability of defibrillation success during out-of-hospital cardiac arrest. Circulation 2002; 105:2270-2273.
14. Snyder D, Morgan C. Wide variation in cardiopulmonary resuscitation interruption intervals among commercially available automated external defibrillators may affect survival despite high defibrillation efficacy. Crit Care Med 2004; 32:421-424.
15. Sato Y, Weil MH, Sun S, Tang W, Xie J, Noc M et al. Adverse effects of interrupting precordial compression during cardiopulmonary resuscitation. Crit Care Med 1997; 25:733-736.
16. Sanders AB, Kern KB, Atlas M, Bragg S, Ewy GA. Importance of the duration of inadequate coronary perfusion pressure on resuscitation from cardiac arrest. J Am Coll Cardiol 1985; 6:113-118.
17. Steen S, Liao Q, Pierre L, Paskevicius A, Sjoberg T. The critical importance of minimal delay between chest compressions and subsequent defibrillation: a haemodynamic explanation. Resuscitation 2003; 58:249-258.
18. Yu T, Weil MH, Tang W, Sun S, Klouche K, Povoas H et al . Adverse outcome of interrupted precordial compression during automated defibrillation. Circulation 2002; 106:368-372.
19. Povoas H, Weil MH, Tang W, Bisera J, Klouche K, Barbatis A. Predicting the success of defibrillation by electrocardiographic analysis. Resuscitation 2002; 53:77-82.
20. Young C, Bisera J, Gehman S, Snyder D, Tang W, Weil MH. Amplitude spectrum area: measuring the probability of successful defibrillation as applied to human data. Crit Care Med 2004; 32 Suppl 9:S356-358.
21. Pernat AM, Weil MH, Tang W, Pernat A, Bisera J. Optimizing timing of ventricular defibrillation. Crit Care Med 2001; 29:2360-2365.
22. Paradis NA, Martin GB, Rivers EP, Goetting MG, Appleton TJ, Feingold M et al. Coronary perfusion pressure and the return of spontaneous circulation in human cardiopulmonary resuscitation. JAMA 1990; 263:1106-1113.
23. Sanders AB, Ogle M, Ewy GA. Coronary perfusion pressure during cardiopulmonary resuscitation. Am J Emerg Med 1985; 3:11-14.
24. Weil MH, Bisera J, Trevino RP, Rackow EC. Cardiac output and end-tidal carbon dioxide. Crit Care Med 1985; 13:907-909.
25. Falk JL, Rackow EC, Weil MH. End-tidal carbon dioxide concentration during cardiopulmonary resuscitation. N Engl J Med 1988; 318:607-611.
26. Noc M, Weil MH, Gazmuri RJ, Sun S, Bisera J, Tang W. Ventricular fibrillation voltage as a monitor of the effectiveness of cardiopulmonary resuscitation. J Lab Clin Med 1994; 124:421-426.
27. Noc M, Weil MH, Tang W, Sun S, Pernat A, Bisera J. Electrocardiographic prediction of the success of cardiac resuscitation. Crit Care Med 1999; 27:708-714.
28. Weaver WD, Cobb LA, Dennis D, Ray R, Hallstrom AP, Copass MK. Amplitude of ventricular fibrillation waveform and outcome after cardiac arrest. Ann Intern Med 1985; 102:53-55.
29. Strohmenger HU, Lindner KH, Keller A, Lindner IM, Pfenninger EG. Spectral analysis of ventricular fibrillation and closed-chest cardiopulmonary resuscitation. Resuscitation 1996; 33:155-161.
30. Strohmenger HU, Lindner KH, Brown CG. Analysis of the ventricular fibrillation ECG signal amplitude and frequency parameters as predictors of countershock success in humans. Chest 1997; 111:584-589.
31. Eftestol T, Wik L, Sunde K, Steen PA. Effects of cardiopulmonary resuscitation on predictors of ventricular fibrillation defibrillation success during out-of-hospital cardiac arrest. Circulation 2004; 110:10-15.
32. Tang W, Snyder D, Wang J, Huang L, Chang YT, Sun S et al. One-shock versus three-shock defibrillation protocol significantly improves outcome in a porcine model of prolonged ventricular fibrillation cardiac arrest. Circulation 2006; 113:2683-2689.