Influence of Analysis Duration on the Accuracy of a Shock Advisory System

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Abstract

This study evaluates the influence of analysis duration on the accuracy of AED shock advisory system (SAS), which is adapted to provide 'Shock'/'No Shock' decision in real time at every second from 2s to 10s. MIT-BIH Malignant Ventricular Arrhythmia database is used for validation of the SAS accuracy on a computer.

Four basic ECG criteria used in the presented SAS are evaluated: heart rate, slope uniformity of positive vs. negative peaks, deflections from signal extrema and signal mean in a narrow frequency band for enhancement of the QRS complexes. They show significant differences for shockable and non-shockable rhythms, considering all analysis durations.

The presented SAS with analysis duration from 2s to 10s is fully compliant with the AHA performance goal for AEDs. Short ECG episodes, however, require verification for consistency of the rhythm over time.

1. Introduction

Minimizing the duration of the pre-shock pauses without chest compressions (CC) is beneficial for the survival rate after defibrillation [1-4]. In this respect, the 2010 American Heart Association (AHA) Guidelines for resuscitation recommend limiting CC interruptions to less than 10s [5] which constrains the time for analysis of artifact-free electrocardiogram (ECG) in automatic external defibrillators (AEDs).

Anticipating the new requirements, some researchers have recently published a number of methods for ECG analysis during CC, applying mostly adaptive filtering techniques for suppression of the CC-induced artifacts [6-9] or sophisticated algorithms which are running the rhythm analysis during CC [10,11]. Despite all efforts, accuracy of such methods is 80-90% - still below the AED performance goals recommended by AHA [12].

Another solution for minimizing the pre-shock pause is reduction of the ECG analysis duration. Rosado et al [13] describe a fast ventricular fibrillation detection method, based on Pseudo-Wigner-Ville distribution, using ECG segments of 1.024s. However, it provides limited 86% sensitivity and 94.3% specificity. Other studies report that algorithms, analyzing ECG signal crossings with preset thresholds, improve their performance by increasing the analysis duration, and that a reliable accuracy can be achieved after 7s [14,15]. Throne and Gupta [16] estimate the effect of short duration signal analysis for detection of ventricular fibrillation based on autocorrelation (ACF) and scatter diagram analysis. They have found that, in general, increase of the analysis duration from 1s to 4s improves the accuracy. This relation is also observed by the authors of the ACF method who report adequate performance for 4.5s [17].

The objective of this study is to evaluate the influence of analysis duration (2s to 10s) on the accuracy of AED shock advisory system (SAS).

2. Materials and methods

2.1. ECG signals

The test set of ECG signals is extracted from the first channel of MIT-BIH Malignant Ventricular Arrhythmia Database (MIT-vfdb) [18]. The recordings are subsets of the general databases recognized as standard in ECG testing. These subsets were chosen because they contain a wide variety of shockable and non-shockable rhythms.

ECG strips of 10s are independently annotated by three cardiologists. The annotations follow the AHA classification scheme for shockable and non-shockable rhythms [12] where performance goals are defined only in absence of artifacts. Excluding all cases with inconsistent rhythm over the strip, the following noise-free strips are identified:

510 strips with shockable rhythms:

- 308 VF – coarse ventricular fibrillation > 200μV;
- 202 VThi – rapid ventricular tachycardia with rate > 150 beats-per-minute (bpm);

2448 strips with Non-shockable rhythms:

- 1023 NSR – normal sinus rhythm;
- 1425 ONS – other non-shockable rhythms, including supra-ventricular tachycardia, sinus bradycardia, SA/AV and bundle branch blocks, atrial fibrillation, atrial/ventricular ectopic beats.

2.2. Shock advisory system

This study evaluates SAS of a commercial AED (Fred Easy, Schiller Médical, France) previously validated for analysis duration of 10s [19].

Four basic ECG criteria are considered:

- Heart rate (HR) and slope uniformity of positive vs. negative peaks (SU) based on detection of significant peaks in ECG.
- Deflections from signal extrema (SE) and signal mean (SM) in a narrow pass-band adjusted for QRS complexes enhancement.

The SAS is modified on a computer to feedback 'Shock'/'No Shock' decision at every second from 2s to 10s. The adaptation process has been performed with a training set of ECG signals from AHA fibrillation database (A8000 series) [20] and Creighton university ventricular tachyarrhythmia database (MIT-cudb) [18]. Details from the training phase are not a subject of this study.

3. Results

Several examples are illustrating the SAS performance for 10-second strips with different arrhythmias from MIT-vfdb (Figure 1-5). The decision 'Shock' (Sh) or 'No Shock' (NSh) is depicted at each second in order to follow the sequence of feedback decisions over time. The reasons for errors are discussed below each example.

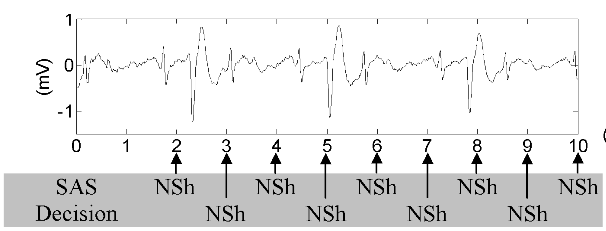

Figure 1. ONS from file 425 for which SAS takes correct stable 'No Shock' decisions over time.

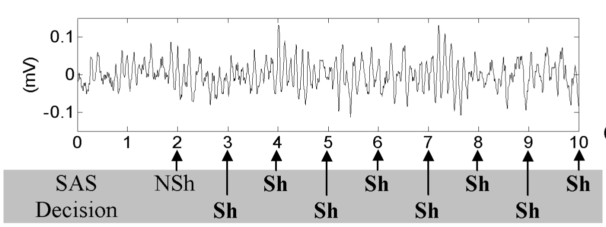

Figure 2. VF from file 426 with low amplitude – SAS requires time for validation of high-amplitude VF waves which needs at least 3s in this strip.

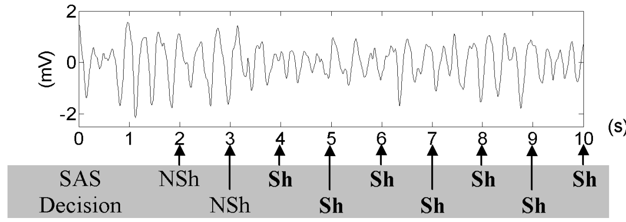

Figure 3. VF from file 614 with slow rate – analysis of at least 4s is required to accumulate mean rate above the threshold for 'Shock' decision.

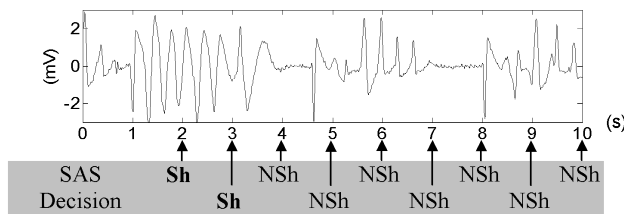

Figure 4. ECG strip from file 609 with non-sustained VThi. Although this strip is not included in the test set, because of intrinsic inconsistency of the rhythm, it illustrates the immediate adaptation of the SAS decision following the rhythm change. Shock is advised on 2nd and 3rd second during the VThi rush and immediately after its end the decision is changed to 'No Shock'. This case illustrates that longer analysis might be appropriate for non-consistent rhythms.

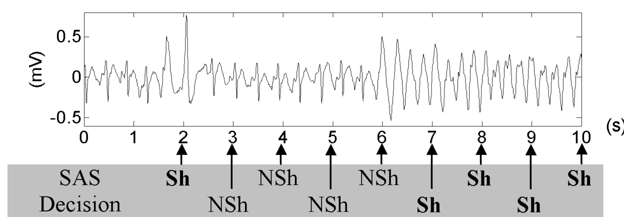

Figure 5. ECG strip from file 424 presenting transition from ONS to VThi at the 6th second. Although this strip is not included in the test set because of rhythm inconsistency, it illustrates the influence of different analysis durations on the SAS decision during unstable rhythm. For example, burst of ventricular ectopic beats could mislead short analysis of 2s but their influence is not meaningful for longer analysis durations. The spontaneous transition to VThi at the 6th second is immediately recognized so that 'Shock' is advised one second later up to end of the strip.

The four basic SAS criteria (HR, SU, SE, SM) are calculated for analysis durations from 2s to 10s. Considering all strips in the test dataset, statistical analysis of the criteria, expressed as mean ± standard deviation (SD), is presented for the different arrhythmia categories (NSR, ONS, VF, VThi) - Figure 6.

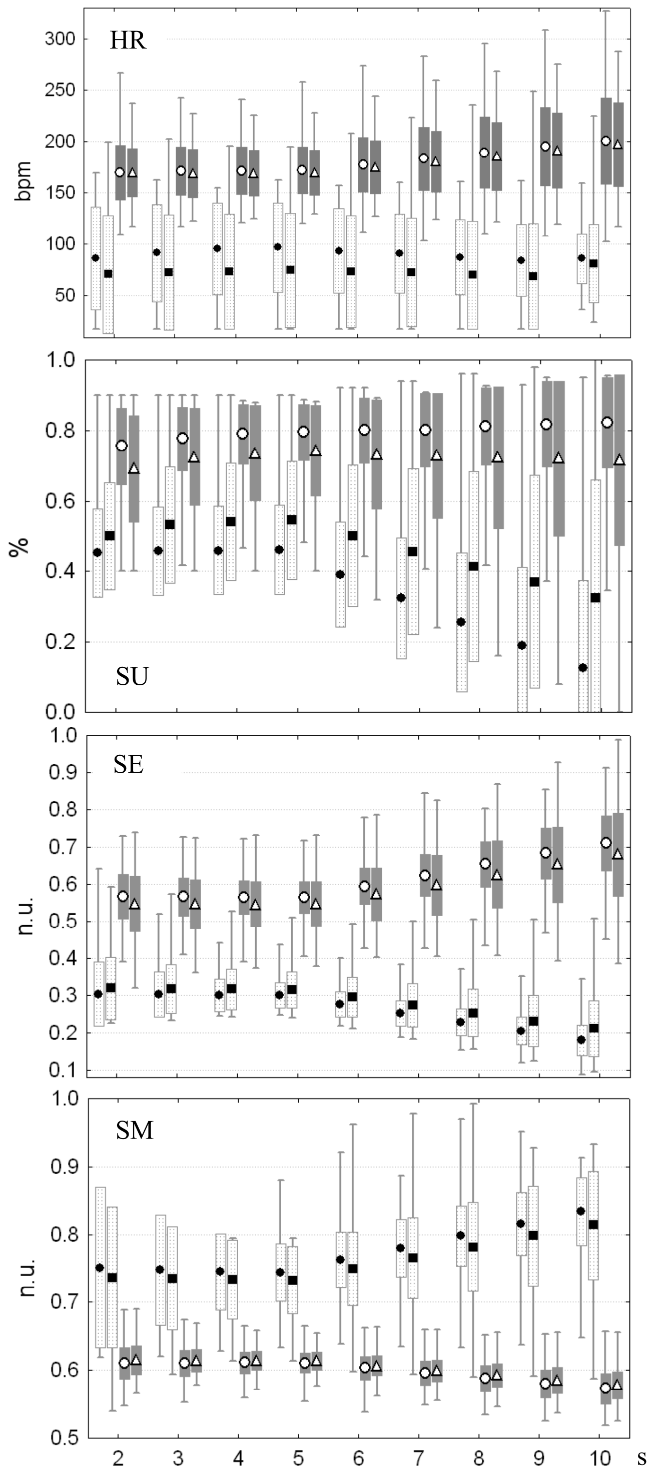

Figure 6. Distribution of SAS criteria values over time for the different rhythm categories, presented as box-plots (mean, ±SD, non-outlier range).
● NSR ■ ONS ○ VF △ VThi

Analysis of variance (one-way ANOVA) confirms that the non-shockable rhythm groups (NSR, ONS) are significantly distinguishable from the shockable rhythms (VF,VThi) comparing the values of each criterion at 2s up to 10s of analysis ($p<0.05$).

Using all samples in the test database, the SAS 'Shock'/'No Shock' decisions for different durations of the ECG analysis are recorded and compared to the related ECG annotations to derive specificity (Sp) for NSR, ONS and sensitivity (Se) for VF, VThi. The results are compared to the AHA performance goals in Table 1. A bilateral t-test evaluating differences between two proportions is applied to find any significant degradation in accuracy of alternative analysis durations compared to the reference at 10s (validated in AED [19]). *P-value* <0.05 is highlighted as statistically significant in Table 1.

Table 1. SAS accuracy for analysis durations from 2s to 10s fully complies with the AHA goals [12] set for NSR, ONS, VF, VThi rhythms. The test sample size (TestSS) extracted from MIT-vfdb is above the minimal sample size (MinSS) defined by AHA.
* $p<0.05$ – significant drop in accuracy for analysis duration <10s compared to the reference at 10s.

	NSR	ONS	VF	VThi
	Sp	Sp	Se	Se
2 s	99.5 % *	97.1 % *	93.8 % *	92.1 % *
3 s	99.5 % *	98.0 % *	97.1 %	94.6 % *
4 s	99.5 % *	97.6 % *	98.1 %	96.0 %
5 s	99.9 %	97.8 % *	99.0 %	95.5 % *
6 s	100 %	97.9 % *	99.4 %	95.5 % *
7 s	100 %	97.8 % *	99.7 %	98.0 %
8 s	99.9 %	97.7 % *	99.4 %	98.0 %
9 s	99.8 %	97.8 % *	99.4 %	98.0 %
10 s	100 %	99.2 %	98.7 %	99.0 %
AHA Goal	>99 %	>95 %	>90 %	>75 %
TestSS	1023	1425	308	202
MinSS	100	30	200	50

4. Limitations

- Due to access to a limited amount of data, this study concerns multiple samples from single patients.
- Asystoles could not be tested because of their absence in the MIT-vfdb database.

5. Discussion and conclusions

This study indicates that measuring ECG features of rate and morphology for at least 2s can provide reliable criteria for significant separation between shockable and non-shockable rhythms (Figure 6). When SAS is built based on these criteria, the accuracy for 'Shock'/'No

Shock' decision at 2s to 10s fully complies with the recommended performance goals [12] (Table 1). This result allows management of faster AED analysis process during hands-off pause in accordance to the AHA 2010 Guidelines [5] for limiting CC interruptions to less than 10s. In this respect, the 2s analysis presents high Sp, allowing safe and early triggering of shock if a shockable rhythm is detected, thus shortening the pre-shock pause.

Since higher accuracy is observed for longer analysis durations, we tested the shortest duration without significant degradation of Sp/Se compared to the maximal reference values at 10s. The shortest duration without significant degradation depends on the ECG rhythm, starting from 3s for VFs (Se=97.1% vs. 98.7%, p=0.17), 5s for NSR (Sp=99.8% vs. 100%, p=0.15), 7s for VThi (Se=98% vs. 99%, p=0.41). However results are significantly degraded at 9s for ONS (Sp=97.8% vs. 99.2%, p=0.021), which can be explained by the inconsistency of the ONS rhythms. In this respect, we conclude that the best duration/performance balance for Se could be achieved from 4s to 7s, however 10s are required to derive the maximal Sp, especially for the mixed group with non-shockable arrhythmia varying in rate and QRS morphology.

The current study shows compliance of any analysis duration from 2s to 10s with recommendations. Inconsistency of the rhythm along the strip is a limiting factor to assess the impact of shortening the analysis. Further implementation of such a process in an AED will allow validating the current results.

References

[1] Eftestol T, Sunde K, Steen P. Effects of interrupting precordial compressions on the calculated probability of defibrillation success during out-off-hospitals cardiac arrest. Circulation 2002;105:2270–3.

[2] Yu T, Weil M, Tang W, Sun S, Klouche K, Povoas H, Bisera J. Adverse outcomes of interrupted precordial compression during automated defibrillation. Circulation 2002;106:368–72.

[3] Wik L, Hansen T, Fylling F, Steen T, Vaagenes P, Auestad B, Steen P. Delaying defibrillation to give basic cardiopulmonary resuscitation to patients with out-of-hospital ventricular fibrillation: a randomized trial. JAMA 2003;289:1389–95.

[4] Cheskes S, Schmicker R, Christenson J, Salcido D, Rea T, Powell J, et al. Perishock pause: an independent predictor of survival from out-of-hospital shockable cardiac arrest. Circulation 2011;124:58-66.

[5] Travers A, Rea T, Bobrow B et al. 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Part4: CPR overview. Circulation 2010;122:S676–84.

[6] Eilevstjonn J, Eftestøl T, Aase S, Myklebust H, Husøy J, Steen P. Feasibility of shock advice analysis during CPR through removal of CPR artefacts from the human ECG. Resuscitation 2004;61:131–41.

[7] Aramendi E, de Gauna S, Irusta U, Ruiz J, Arcocha M, Ormaetxe J. Detection of ventricular fibrillation in the presence of cardiopulmonary resuscitation artefacts. Resuscitation 2007;72:115–23.

[8] De Gauna S, Ruiz J, Irusta U, Aramendi E, Eftestøl T, Kramer-Johansen J. A method to remove CPR artefacts from human ECG using only the recorded ECG. Resuscitation 2008;76: 271–8.

[9] Irusta U, Ruiz J, de Gauna S, Eftestøl T, Kramer-Johansen J. A least mean square filter for the estimation of the cardiopulmonary resuscitation artefact based on the frequency of the compressions. IEEE Trans Biomed Eng 2009;56:1052–62.

[10] Didon JP, Dotsinsky I, Jekova I, Krasteva V. Detection of shockable and non-shockable rhythms in presence of CPR artifacts by time-frequency ECG analysis. Computers in Cardiology 2009;36:817-20.

[11] Krasteva V, Jekova I, Dotsinsky I, Didon JP. Shock advisory system for heart rhythm analysis during cardiopulmonary resuscitation using a single ECG input of automated external defibrillators. Ann Biomed Eng 2010;38:1326–36.

[12] Kerber R, Becker L, Bourland J, Cummins R, Hallstrom A, Michos M, et al. Automatic external defibrillators for public access defibrillation: Recommendations for specifying and reporting arrhythmia analysis algorithm performance, incorporating new waveforms, and enhancing safety. Circulation 1997;95:1677–82.

[13] Rosado A, Guerrero J, Bataller M, Chorro J. Fast non-invasive ventricular fibrillation detection method using Pseudo-Wigner-Ville distribution. Computers in Cardiology 2001;28:237–40.

[14] Thakor N, Zhu YS, Pan KY. Ventricular tachicardia and fibrillation detection by a sequential hypothesis testing algorithm. IEEE Trans Biomed Eng 1990;37:837–843.

[15] Zhang X, Zhu Y, Thakor N, Wang Z. Detecting ventricular tachicardia and fibrillation by complexity measure. IEEE IEEE Trans Biomed Eng 1999;46:548–55.

[16] Throne R, Gupta S. Effects of short duration signal analysis for detecting ventricular fibrillation. Conf Proc IEEE Eng Med Biol Soc 1994;2:1312–13.

[17] Chen S, Thakor N, Mower M. Ventricular fibrillation detection by a regression test on the autocorellation function. Med Biol Eng Comput 1987;25:241–9.

[18] MIT-VFDB http://physionet.org/physiobank/database/vfib.

[19] Jekova I, Krasteva V, Ménétré S, Stoyanov T, Christov I, Fleischhackl R, et al. Bench study of the accuracy of a commercial AED arrhythmia analysis algorithm in the presence of electromagnetic interferences. Physiol Meas 2009;30:695–705.

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