Clinical & Experimental Cardiology

Kette et al., J Clin Exp Cardiolog 2014, 5:1
http://dx.doi.org/10.4172/2155-9880.1000285

Research Article Open Access

What is Ventricular Tachycardia for Automated External Defibrillators?

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Rec date: Nov 06, 2013, **Acc date:** Jan 25, 2014, **Pub date:** Jan 28, 2014

Abstract

Aim: Assessment and comparison of different algorithms that Automated External Defibrillators (AEDs) use to recognize as shockable monomorphic and polymorphic Ventricular Tachycardia (VT).

Method: Engineering bench tests for a descriptive systematic evaluation in commercially available AEDs. AEDs were tested through an electrocardiographic (ECG) simulator that is capable to generate different kind of monomorphic and polymorphic VT. All tests were performed at the engineering facility of the Lombardia Regional Emergency Service (AREU, Azienda Regionale Emergenza Urgenza).

Results: The tests showed marked differences among the AEDs when a Monomorphic Ventricular Tachycardia was simulated. The AED recognized the Monomorphic Ventricular Tachycardia (MVT) as shockable rhythm above a value ranging from 140 to 230 beats per minute (BPM). For Polymorphic Ventricular Tachycardia (PVT) not all AEDs delivered a shock when pre-determined types of VT were selected.

Keywords: Ventricular tachycardia; Automated external defibrillators; Defibrillation; Hypotension; Dyspnoea

Introduction

The electrical treatment of cardiac arrest relies on a prompt defibrillation when a shockable rhythm is detected which can be either a ventricular fibrillation (VF) or a ventricular tachycardia (VT). This treatment differentiates from the non-shockable rhythms constituted by asystole and pulseless electrical activity (PEA) [1]. However, unlike ventricular fibrillation, VT does not always require an electrical defibrillation as only the absence of a pulse characterizes a cardiac arrest condition requiring prompt defibrillation. Ventricular tachycardia may instead require a synchronized electrical cardioversion when the patient is hemodynamically unstable but is not in cardiac arrest or may not require electrical treatment at all if the patient is only poorly symptomatic or can tolerate the arrhythmia without too much discomfort.

It is worthy to remember that clinical hemodynamic instability is defined when a single or an association of the following signs and/or symptoms coexist: altered mental status, dyspnoea, chest pain, hypotension and/or other hypoperfusion signs (low urine output, marbled and cold skin). The effects on the hemodynamic conditions, however, depend on many factors such as heart rate, age, duration and coexisting diseases. There is no a single defined heart rate value above which the patient becomes unstable.

Also, a monomorphic ventricular tachycardia can be more tolerated than a polymorphic tachycardia, because the PVT determines a poorer fillings volume to the heart with consequent decreased cardiac output. On the other hand, polymorphic VT may also resemble a VF not only under the clinical point of view but also as per the electrical waveform characteristics.

AEDs have been widely spread in the clinical setting in order to shorten the time frame between cardiac arrest and a prompt defibrillation, whenever required. Significant increases in survival rate have been documented following their introduction in the clinical setting [2-6]. The sequences of approach, stemming from the Guidelines, have been incorporated into the analysis algorithms such as to guide the operators toward the proper treatment. Accordingly, based upon the recognition of the underlying rhythm, the AEDs can provide effective defibrillation in those cases in which a shockable rhythm exists. Their sensitivity has reached values greater than 90% for VF and greater than 75% for VT [7,8].

Since VT underlies different clinical conditions, an AED may not recognize all ventricular tachycardia as shockable rhythm. The indication to defibrillate only relies on the electrical characteristics of the waveforms. Our own group recently performed a large investigation on several technical features of AEDs [9]. It was in this setting that we decided to test the behaviour of 18 automated external defibrillators with specific regard to the criteria whereby the AEDs can identify and consequently shock a VT.

Method

This study is part of a larger investigation on the technical and electrical features on AEDs performed by our own group at the Engineering Laboratory of the Lombardia Regional Emergency Service [9]. Basically, the overall assessment dealt with the main features such as energy and current delivered, shape and duration of the first and second phase of the biphasic waveforms and their relationship to different levels of impedance. For the purpose of the present manuscript preliminary results were presented in abstract form [10].

Overall, eighteen AEDs from twelve different companies were tested:

1) SaverOne (Ami Italia, Napoli, Italy);

2) G3 Pro (Cardiac Science, Bohtell, Washington, USA);

3) G5 Pro (Cardiac Science, Bohtell, Washington, USA);

4) Lifeline AED (Defibtech, Guilford, Connecticut, USA);

5) Responder AED (General Electric, Schenectady New York, USA);

6) Sam300P (HeartSine, Belfast, Ireland);

7) Lifepak 1000 (Physio Control, Redmond, Washington, USA);

8) Lifepak Express (Physio Control, Redmond, Washington, USA);

9) Cardiolife 2100 (Nihon Kohden, Shangai, China);

10) FR2+ (Philips, Eindhoven, Netherlands);

11) FRx (Philips, Eindhoven, Netherlands);

12) FR3 (Philips, Eindhoven, Netherlands);

13) RescueSAM (Progetti, Trofarello, Italy);

14) AED HeartSave (Primedic, Rottweil, Germany);

15) FRED Easy (Schiller, Baar, Switzerland);

16) FRED Easyport (Schiller, Baar, Switzerland);

17) AED Plus (Zoll, Chelmsford, UK);

18) AED Pro (Zoll, Chelmsford, UK).

Tests were performed by using a defibrillator analyser (Impulse 7000D, Fluke Biomedical, Everett) which allows three different functions: defibrillation, ECG, pacing. We used the ECG mode to simulate different cardiac rhythms. All tests were made by a single biomedical electronic engineer who consistently performed all evaluations. All but one test were conducted between January 2012 and May 2012, with the exception of a newly introduced device which came out on the market in summer 2012. The analysis for this device was performed at the end of September 2012 with the same consistency as the previous ones. In order to obtain consistent observations our engineers maintained a systematic method of assessment which yielded highly consistent behaviourby each AED when a pre-determined rhythm was chosen.

For each model, the pads of the disposable electrodes were cut, replaced with suitable plugs and connected to the defibrillator analyser.

Tests consisted in verifying the AEDs' capability to recognize the following shockable rhythm:

1) Monomorphic Ventricular Tachycardia (MVT), for which there was a choice of selection of the simulated heart rate from 120 to 300 Beats per Minute (BPM) at an amplitude of 1 milliVolt (mV). For monomorphic VT, we set the BPM at the minimum value of 120. Stepwise increases of 5 BPMs were applied until we identified the cut-off level, a value above which the VT was recognized as a shockable rhythm (Figure 1).

2) Five types of Polymorphic Ventricular Tachycardia: PVT1, PVT2, PVT3, PVT4, PVT5 (Figure 2). All these rhythms had amplitude of 1 mV but they differed in the BPM value, which had the following values:

3) PVT1: 150 BPM; PVT2: 180 BPM; PVT3: 200 BPM; PVT4: 240 BPM;

4) PVT5: 280 BPM.

For each arrhythmia, we verified the ability of AED to properly recognize a shockable or non shockable rhythm. Measurements were repeated three consecutive times.

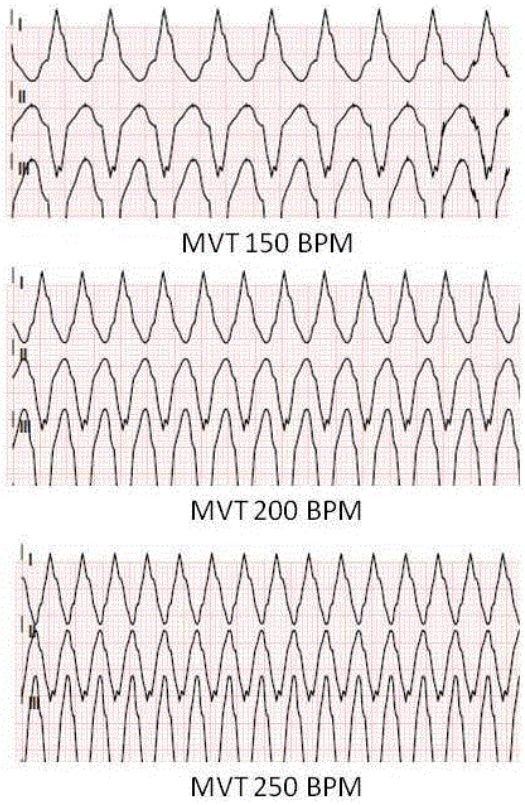

Figure 1: Monomorphic Ventricular Tachycardia

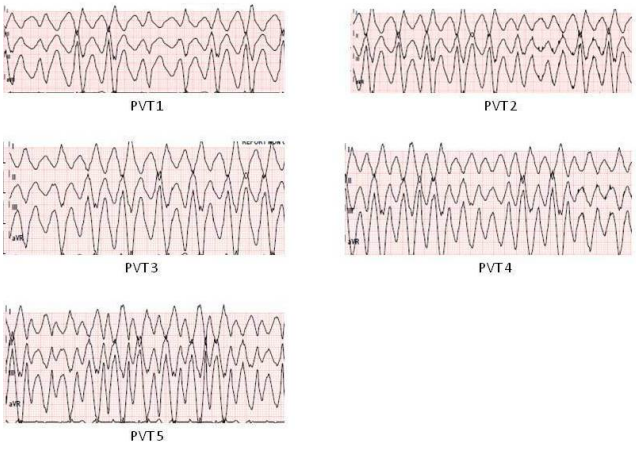

Figure 2: Polymorphic Ventricular Tachycardia.

Results

All eighteen AEDs recognized both VF and non shockable rhythms with sensitivity and a specificity of 100%. Instead, marked differences among the devices were seen when the VTs were simulated.

Table 1 summarizes the results of the MVT recognition tests. Overall the AED recognized the MVT as shockable rhythm above a value ranging from 140 to 230 BPM. However, within these results two main different behaviours were identified. In the first group (15 AEDs) the devices had their own cut-off value above which VT was systematically considered as shockable. In a second group (3 AEDs) the MVT was recognized as shockable only in those rhythms that were comprised within a narrower BPM range (between 225 and 250 for Philips FR2, between 230 and 250 for Philips FR3 and between 150 and 280 for Primedic HeartSave). Below and above these levels the devices did not indicate to shock.

Device	NWT (BPIVI)
Ami Italia Saver One	>140
Cardiac Science G3	>150
Cardiac Science G5	>150
Defibtech Lifeline AED	>135
GE Responder	>160
HeartSine Sam300P	>180
Nihon Kohden Car &elite 2100	>180
Philips FRx	>225
Physic, Control Lifepak 1000	>150
Physic, Control Lifepak Express	>150
Progetti ReseneSam	>150
Schiller FRED easy	>200
Schiller FRED easyport	>200
Zoll AED Phis	> 155
ZollAED Pro	>160
Philips FR2	225-250
Philips FR3	230-250
Primedic HeartSave	150-280

Table 1: MVT recognition tests

The results of the PVT recognition tests are shown in Table 2. We observed marked differences among AEDs. Only four devices (Nihon Kohden Cardiolife 2100, Progetti Rescue Sam, Schiller FRED Easy, Zoll AED Plus) recommended the shock at every kind of PVT. The remaining 14 devices showed different behaviours. Six AEDs identified as shockable rhythms those PVTs characterized by BPM levels above 180 (PVT1). Four devices recognized as shockable the PVTs above 200 BPM (PVT2). The remaining group of four AEDs highlighted different patterns in which high heart values (above 240 BPM and 280 BPM) were identified as non shockable.

Device	PVT1	PVT2	PVT3	PVT4	PVT5
Nihon Kohden Cardiolife 2100	YES	YES	YES	YES	YES
Progetti RescueSam	YES	YES	YES	YES	YES
Schiller FRED easy	YES	YES	YES	YES	YES
Zoll AED Plus	YES	YES	YES	YES	YES
Zoll AED Pro	NO	YES	YES	YES	YES
Physio Control Lifepak 1000	NO	YES	YES	YES	YES
Ami Italia Saver One	NO	YES	YES	YES	YES
Cardiac Science G5	NO	YES	YES	YES	YES
Defibtech Lifeline AED	NO	YES	YES	YES	YES
Primedic HeartSave	NO	YES	YES	YES	YES
Physio Control Lifepak Express	NO	NO	YES	YES	YES
Cardiac Science G3	NO	NO	YES	YES	YES
GE Responder	NO	NO	YES	YES	YES
HeartSine Sam300P	NO	NO	YES	YES	YES
Philips FRx	YES	YES	YES	NO	NO
Philips FR2	NO	YES	YES	NO	NO
Philips FR3	NO	YES	YES	NO	NO
Schffier FRED eisyport	NO	YES	YES	YES	NO

Table 2: PVT recognition tests

Discussion

The introduction of the Automated External Defibrillation in the clinical market has allowed a widespread diffusion of these devices not only in the Emergency Services but also in public places like casinos, airport, airplanes and others locations with a high risk of sudden cardiac arrest [2-6,11-13).

This campaign has produced significant improvement in survival rate in presence of ventricular fibrillation although the overall impact of the AEDs as part of the Public Access Defibrillation (PAD) programs is still subject of ongoing researches [14-16].

VF, however, is often an evolution of a previous VT. This was found in hemodynamic laboratories where the sequence of the arrhythmia was documented [17,18]. It was then suggested that the lower proportion of VT and VF as presenting rhythms could be the natural evolution of a defibrillating rhythm into asystole by progressive depletion of energetic myocardial compounds in the absence of artificial support provided by chest compression. Nevertheless, in the last decade growing evidence toward a decreased proportion of defibrillating rhythms was documented [19-23].

The sensitivity for VT was demonstrated to be even lower in relationship to VT heart rate [24]. This statement implies by itself that AEDs have different “capability” to identify the VTs to be shocked. This may be related to the fact that a VT may be the underlying rhythm of a patient not in cardiac arrest. Of course, the device cannot identify the clinical conditions and the choice to defibrillate relies on

the internal algorithm of the AED. This capability is based on the several characteristics composing a waveform susceptible to be shocked. Indeed, beside the rate and the amplitude of the waveforms, the shape, the transition between the "QRSs", and the stability of the signal may all be parameters which can be taken into account to build an algorithm aimed to defibrillate a determined rhythm. For instance, a high frequency narrow QRS tachycardia is not recognized as shockable despite an underlying high rate. On the other hand, lower rate VTs may be considered as shockable when the algorithm identifies sudden morphological changes in QRS complexes.

Different engineering solutions may thus have been chosen by the manufacturers according to whether the treatment of a VT may be more or less conservative. This means that a more "aggressive" algorithm would prompt defibrillation for a greater number of VTs, thus increasing the sensitivity for VTs but reducing the specificity. This condition would increase the risk that a perfusing VT would be recognized as shockable rhythm. Therefore, the lower sensitivity for VTs reported by the Guidelines stems from the need not to defibrillate perfusing rhythms (i. e. patients not in cardiac arrest).

In our investigation monomorphic and polymorphic VT were taken into account. Firstly we tested the AEDs capability to recognize the monomorphic ventricular tachycardia as shockable rhythm. We observed that the cut-off values above which VT was considered shockable were quite different ranging from a minimum of 135 to 225 BPM. Three AEDs recognized shockable VTs only within a narrower heart rate range. While it can be speculated that the lower level was set according to the engineering algorithm, it is unclear why above a higher level the AED could not any longer recognize the MMVT as a shockable rhythm.

The behaviour of the tested devices with specific regard to polymorphic ventricular tachycardia was even more diverse. As previously described, we identified several patterns. The results highlighted in our observations are indeed surprising as we were expecting a more consistent behaviour among the AEDs. Even in the setting on PMVT two of the three AEDs which had a narrow range of shockability in MMVT had a comparable behaviour and recognized as shockable those polymorphic ventricular tachycardia whose heart rate ranged between 180 and 200 bpm (Philips FR2 and Philips FR3). An additional AED (Schiller FRED Easyport) had a comparable pattern although the range of shockability was wider ranging from 180 to 240 bpm. We do not have a clear explanation for that and we reasoned that this depended on the internal algorithms probably based on the several and different parameters belonging to the engineering solutions which are unknown to the users.

This issue represents undoubtedly a limitation in our study as we only had the possibility to vary the heart rate within a pre–defined rhythm selected in the simulator.

Another limitation of this study is related to a bench evaluation since the behaviour in the clinical setting or in an animal laboratory may differ. A study from real patients would provide evidence on the behaviours of the AEDs in the clinical setting but a very large series of patients would be required. Indeed, from preliminary analysis of more than 1000 traces of cardiac arrest in patients (subject of an ongoing study from our own group and as yet unpublished), VT as a first rhythm was observed in a very few instances. Likewise, in another observation stemming from additional preliminary unpublished assessment on out-of-hospital cardiac arrest in Lombardia region it was highlighted that VT as a presenting rhythm accounted only for less than 2% of the total cardiac arrest rhythms.

An additional limitation is that one may argue that AEDs should be placed on the chest of unconscious patients only. If this concept is systematically applied, conscious patients would not benefit the use an AED and therefore our observation would result in a potential limited usefulness for the clinical setting.

The issue of recognizing a VT, either monomorphic or polymorphic, may be even more challenging due to the clinical implications above described. Since the AEDs cannot identify the patient conditions it is clear that they can base their "choices" on their technological features only.

Nevertheless, despite the limitation of the bench evaluation, this systematic assessment allowed us to identify the AED behaviour in the setting of a variety of ventricular tachycardia. We therefore believe that our study may be useful to the AED manufacturers in developing a more consistent behaviour in shock decision since a more appropriate algorithm would prompt a more accurate diagnosis in the setting of adult and paediatric tachyarrhythmia [25,26].

Acknowledgements

We gratefully acknowledge the precious evaluation and expertise of Dr. Maddalena Branchi, Chief Engineer at the engineering facility of the "Papa Giovanni XXIII" hospital (Bergamo, Italy), for her further assessment of the methodology used in the present study.

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This article was originally published in a special issue, entitled: **"Cardiopulmonary Disorders-2nd Edition",** Edited by Dr. Guochang Hu, University of Illinois, USA