Shock Timing on High Power Spike of the Morphology Electrogram Improves Shock Outcome: The Study in Defibrillator Patients

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Abstract

Previous studies have demonstrated that pulse delivery timed on upslope of morphology electrogram (ME) during high voltage phase significantly improved shock outcome. However this mechanism is poorly understood. We hypothesized that the upslope in ME may indicate the activation in the obtained segment of myocardium. Recently we found that reliable identification of local depolarization in the atrial fibrillatory signal can be achieved using adaptive estimation of the instantaneous signal power (P). The spikes of P reflected local activation in the mapped atrial site.

The aim of this study was to investigate the relation of high power spikes of ME to ventricular shock outcome and to the upslope. 575 VF episodes recorded and stored during ICD implantation in 77 patients were used for analysis.

1. Introduction

Previous studies [1] have shown that DC-pulse delivery during the higher voltage phase of the ventricular fibrillation (VF) obtained from surface ECG improves the probability of successful defibrillation. However these studies were contradicted by the study of Jones and Klein [2], who demonstrated that changes in the surface ECG did not necessarily correspond to those seen in the endocardial leads during VF. Later, W. Hsu et al. [3] have suggested that the electrical signal between ICD defibrillation electrodes (morphology electrogram (ME)) is more appropriate for characterization of the electrical activity in the ventricular myocardium than the surface ECG. In this study, it was found that shock delivery coordinated with the upslope of fibrillation electrogram during the higher voltage phase improves the probability of successful defibrillation, whereas the higher voltage phase alone did not indicate the optimal time for DC-pulse delivery.

Griezbach et al [4] suggested the descriptor of the wave form termed instantaneous signal power (P) reflecting upstroke velocity in the signal. The figure 1 demonstrates normalized ME and P of two induced VF episodes .

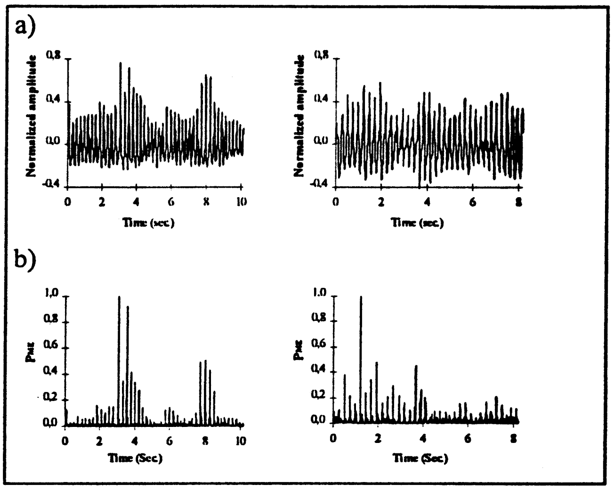

Figure 1. a) the diagrams present examples of morphology electrograms (ME) recorded during ventricular fibrillation. Two high voltage periods are clearly seen in the left diagram.; b) while the instantaneous power (P_{ME}) correlates with the ME voltage in the case presented on the left, no correlation between P_{ME} and voltage of ME depicted on the right can be seen. The apparently organized segments are seen in both P_{ME} diagrams

The aim of the present study was primarily based on retrospective analysis of induced VF episodes to test whether the probability of defibrillation increases by shock delivered after large power spikes.
Secondary we investigated the relationship between up/downslope and power of the ME.

2. Methods

2. 1. Data acquisition

For detecting the defibrillation threshold (DFT), a total of 575 VF episodes was induced in 77 patients (n= 7.47 ± 2.55). All shock deliveries were performed using a biphasic pulse.

The intraoperative electrophysiological tests were performed after the endocardial lead (Endotak C, CPI/Guidant) was placed in the right ventricular apex. The distal shock electrode was placed as close as possible to the ventricular septum and as far as

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possible into the right ventricular apex. The proximal electrode was located outside of heart at the vena cava superior. The leads were tripolar with endocardial cardioversion and defibrillating/pacing leads. Transvenous leads were implanted with a defibrillation electrode spacing of 16.8 cm. VF was induced by AC delivery (50 Hz) for 5 seconds. Approximately after another 10 seconds the shock delivery was performed via an external cardioverter/defibrillator (ECD, CPI). The DFT was determined by applying decreasing energy steps (20,15, 10, 8, 5, 3 J) until the first ineffective termination was obtained. Between two inductions of VF a pause of 5 minutes was set. The ME was recorded between the distal (cathode) and the proximal shock electrode (anode).

2. 2. Study patients

We studied 77 patients (60 male, age 60.8±10.4 years) with a mean left ventricular ejection fraction (LVEF) of 32.8±8.7% referred for an ICD implantation. Indications for implantation of an ICD were: aborted sudden death (n=44); poorly tolerated sustained polymorphic ventricular tachycardia (n=33). Underlying cardiac pathology was coronary artery disease (CAD; n=48), dilated cardiomyopathy (DCM; n=21), right ventricular dysplasia (RVD; n=2), and idiopathic VF (n=6).

2.3. Signal analysis

Recently, we have developed an algorithm allowing the identification of the organized periods in fibrillatory atrial signals [5]. This algorithm is based on adaptive estimation functions suggested by Griezbach et al. [4]. The adaptive estimation function of the mean value (M) of the signal (X), which is a fundamental statistical parameter, can be constructed by a simple recursive formula:

$$M_0=X_0;\ M_{i+1}=M_i+D_1 * (X_{i+1}-M_i) \qquad (1)$$

with $0<D_1<1$ as an adaptation constant. The value of D_1 has to be found during validation of the algorithm. Based on adaptive mean estimation function (1) the effective value of signal (P) can be defined:

$$P_0=0;\ P_{i+1}=P_i+D_1*((X_{i+1}-M_{i+1})^2-P_i) \qquad (2)$$

This effective value estimation function P describes the instantaneous power of the signal at each point of time and is shown to have properties of an adaptive high-pass filter [4]. The intra-cardiac electrogram is a summation recording of group of cells and depolarization occurs sequentially over time. In our study in patients with atrial fibrillation (AF) we demonstrated that the calculation of P allowed to distinguish organized AF periods and regions characterized by large power spikes reflecting depolarization in the obtained area and baseline intervals between them from the disorganized AF phases within which no base line could be seen [5].

This approach was applied to the analysis of ME during VF. In our previous work [5] we found the adaptation constant $D_1=0.75$ to be appropriate for identification of depolarization events during atrial fibrillation. Due to the fact that frequencies of AF and VF are in the same spectrum this value of D_1 was chosen for the VF analysis in the present study.

During validation of algorithm we observed segments with diastolic intervals following by large monophasic power spikes and segments with small and biphasic spikes (Fig. 2,3). Thus the value of spike of P_{ME} prior to shock (P_{shock}) can be used as a parameter of the ME wave form at time of pulse delivery.

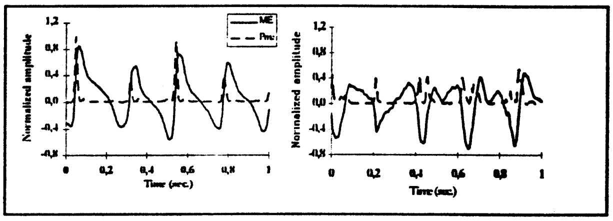

Figure 2. Left) the diagram presents an example of coordination between power spike (P_{ME}) and upslope in the morphology electrogram (ME). Right) the power spikes are seen during upslope and during downslope, 9% of VF episodes

The relation of power spike to up/down slope ME was tested by examination of the incidence of various combination between the power spike and morphological property of the ME using the χ^2 test.

P_{shock} and defibrillation outcome were registered for shock every strength in each patient. The differences between two continuous variables were tested using non-parametric Mann-Whitney-U test. This test was used due to not requiring a normal distribution of the variables to be analyzed

For each patient the median of P_{shock} (P_{med}) was calculated to obtain an individual value. The relationship of (P_{med}), LVEF and age of patients to DFT was tested using the multi-group Kruskall-Wallis test.

The differences were considered as significant by an error probability value of $p< 0.05$.

3. Results

Powers spikes were observed during upslope of ME in 85% cases (χ^2-test, $p<0.001$) (Fig. 2). However, in 9 % of cases the power spikes were obtained on the upslope and on the downslope within the same episode of VF and in 6% on the downslope of ME.

In 40% of records we observed that the sequences of large power correlated with the increased voltage of ME, whereas in other cases such a correlation could not be found (Fig. 1). As depicted in figure 1.b the amplitude range did not show significant changes depending on time, while the instantaneous power drastically decreased in the last part of the episode. Segments with large power spikes separated by base were found in all obtained electrograms (Fig. 1,2). The first such apparently organized segment was found within first 5 seconds episode in all episodes. Number and length of other high power segments varied from episode to episode and from patient to patient. During DFT testing shock was delivered manually so that mean duration of VF episode was 10 ±2 sec. In all VF episodes with duration not less than 10 seconds and in 65% of episodes with a shorter duration at least two apparently organized segments were found (Fig. 1 a). However in 35 % of VF episodes with duration less than 10 seconds the organized phase was obtained only in the first part of the VF episode (Fig 1.b). In the episodes where two organized phases were found the mean amplitude of P spikes in the first organized phase was significantly higher than in the second (0.85 ±0.33 vs. 0.6 ±0.25, $p<0.001$) (fig 1.a).

The significant differences in P_{shock} between successful and failed defibrillation were confirmed for each shock energy (fig. 3, 4).

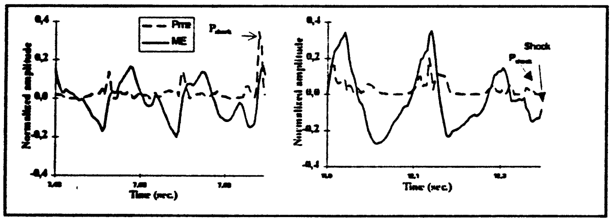

Figure 3. Theleft figure presents morphology electrograms (ME) and instantaneous power (P_{ME}) of VF episode prior to successful shock of 10 J. Power spikes during the upslope of ME are clearly seen. The shock follows the power spike (P_{shock}) with the value of 0.4.The right diagram presents the next VF episode of the same patient with failed shock of 10 J. Compared to the example depicted above shock follows a diffuse structure with a maximal value of 0.05.

While the successful defibrillations were observed in the whole spectrum of instantaneous power, the failed defibrillation occurred, if shock has been delivered after low P_{shock} (Fig. 4). Thereby shock outcome depends only on the value of power spike but not upon concordance of the spike with up/down slope of the ME.

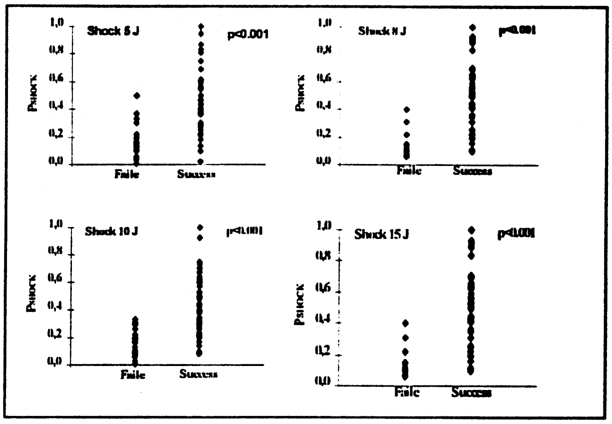

Figure 4. The figure presents the distribution of instantaneous power of morphology electrogram prior to shock (P_{shock}) for successful and failed shocks of several energies. Independent on shock strength the successful defibrillation was observed in a whole spectrum of instantaneous power. The failed defibrillation occurred, if shock has been delivered during low power phase. For the energy of 15 J only few pulses delivered at very small P_{shock} failed to defibrillate.

4. Discussion

In our study the successful defibrillation was observed in the whole spectrum of signal power, while the unsuccessful shocks were strongly associated with deliveries after power spike of a low value. The shocks in patients with higher DFT were delivered mainly after a small power spike (Fig 3). The overlap between P_{med} among DFT values can be explained due to other factors defining individual defibrillation threshold, such as dilatation of the heart,, location of infarct scars.

This result suggests that the probability of successful defibrillation increases if the shock is delivered after a large power spike (Fig 2,3). As it was mentioned above the instantaneous power has properties of a high pass filter. Therefore, the power spike indicates high frequency phase of the ME characterizing depolarization. Regarding P_{ME} trace we could distinguish segments with large power spikes separated by baseline and segments with small spikes without clear separation between them (Fig. 2, 3). Based on analysis of morphology electrogram only it's impossible to make conclusion about spatiotemporal organization of VF. However, the ME reflects electrical activity in the large segment of myocardium and our results suggest that successful defibrillation is more probably if shock is delivering during organized phase of ME. Recently C. Callaway at al. [6] calculated fractals of wave form of ECG during VF and found improved defibrillation success by shock delivered by lower fractal. This study also supports our result.

5. Study limitations

Several limitations of the present study have to be acknowledged. In contrast to experimental studies in animals our conclusions are based on the statistical analysis of the relationship between P_{shock} and defibrillation outcome and between DFT and P_{med}. The definition of E50 is impossible due to ethical reasons. A prospective study similar to that performed by Hsu et al. [3] also cannot be performed in humans.

Other factors that may influence the success rate of defibrillation, such as dilatation of the heart, location of infarct scars etc. have not been evaluated in the present study.

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