BRIEF REPORT

Spectral Analysis of Sustained and Non-Sustained Ventricular Fibrillation in Patients With an Implantable Cardioverter-Defibrillator

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The mechanisms responsible for the maintenance and termination of ventricular fibrillation (VF) are poorly understood. The aim of this study was to compare the spectral characteristics of the electrical signal during sustained and non-sustained VF in patients with an implantable cardioverter-defibrillator. The study included 51 patients who had had at least one episode of sustained VF (ie, duration >5 s and requiring shock administration) and non-sustained VF (ie, duration >3 s and spontaneously terminated) that were recorded by the device set in a unipolar configuration. Spectral analysis of the first 3 s of each episode was performed. The dominant frequency was higher in sustained VF (4.6 [0.7] Hz) than in non-sustained VF (4.3 [0.6] Hz; *P*=.01), while the other parameters were similar. Although the spectral characteristics of sustained and non-sustained VF were similar, differences were observed during the first 3 s that could be used in algorithms for the early detection of non-sustained VF.

Key words: *Ventricular fibrillation. Implantable defibrillator. Spectral analysis.*

Análisis espectral de la fibrilación ventricular sostenida y no sostenida en portadores de desfibrilador implantable

Los mecanismos de mantenimiento y finalización de la fibrilación ventricular (FV) son poco conocidos. El objetivo del estudio es comparar las características espectrales de la señal eléctrica de la FV sostenida y no sostenida en pacientes portadores de desfibrilador implantable. Se incluyó a 51 pacientes con al menos un episodio de FV sostenida (de más de 5 s y que precisara choque) y no sostenida (de más de 3 s y terminación espontánea) registrados por el dispositivo en configuración monopolar. Se realizó un análisis espectral de los primeros 3 s de cada episodio. La frecuencia dominante fue mayor en las FV sostenidas (4,6 ± 0,7 frente a 4,3 ± 0,6 Hz en las no sostenidas; p = 0,01), y los demás parámetros fueron similares. Durante los primeros 3 s, si bien las características espectrales son parecidas, hay diferencias utilizables en algoritmos de detección precoz de FV no sostenida.

Palabras clave: *Fibrilación ventricular. Desfibrilador. Análisis espectral.*

INTRODUCTION

Ventricular fibrillation (VF) is normally a sustained condition, and electrical shock is required to end it. However, we do sometimes see rhythms that appear to be VF on the electrocardiograph, but which stop spontaneously. These rhythms have been described as polymorphic ventricular tachycardia or non-sustained VF,[1] and their definition is a question of semantics, since from a clinical point of view and according to the electrocardiograph, they are nearly indistinguishable. The reasons that determine the prolongation or spontaneous termination of these arrhythmias are unknown but profoundly interesting, since they could provide information regarding VF mechanisms and aid in the development of new algorithms in implantable cardioverter defibrillators (ICDs) to avoid treating self-resolving fibrillations. The purpose of this study is to evaluate the spectral characteristics of sustained and non-sustained VF episodes in patients fitted with an ICD.

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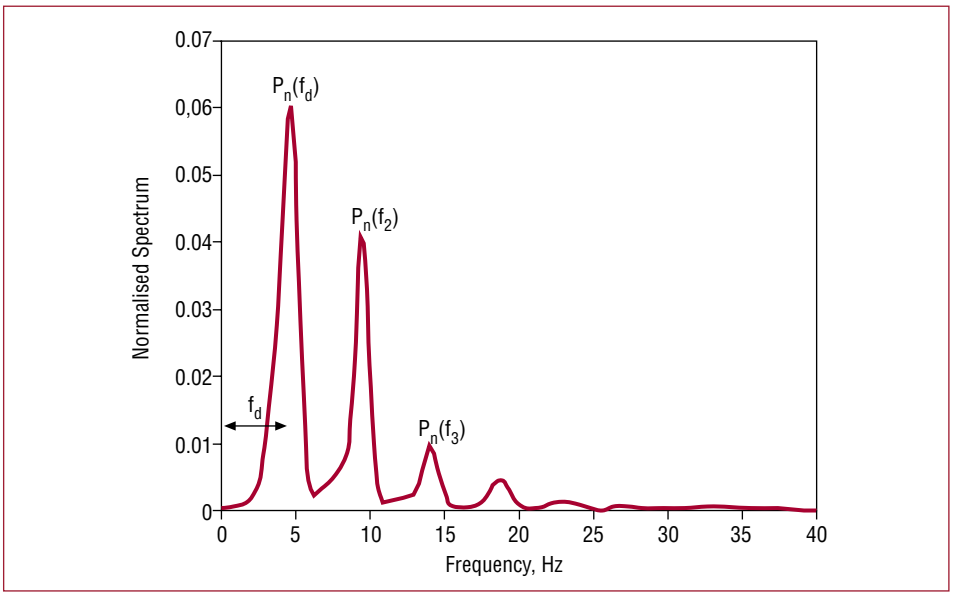

Figure. Schema of the spectrum of the ventricular fibrillation signal and the calculated spectral parameters.

METHODS

Patients and Episodes

We reviewed the information from all of the patients whose defibrillators were being monitored in 2 tertiary hospitals. The study includes those patients who had logged at least one sustained fibrillation episode and another non-sustained fibrillation episode, whether it was spontaneous or induced. VF[2] is defined as ventricular tachyarrhythmia with changeable and irregular morphology and a mean cycle length <300 ms. VF is considered to be sustained when it is present during at least 5 s and when a shock is required to end it; it is non-sustained when it lasts >3 s and terminates spontaneously (the duration >3 s is required to permit a reliable mathematical analysis of the signal oscillations). The electrical signal analysed during VF is obtained from the digital electrogram stored in the device.

Signal Processing

The analysis period spanned the 3 initial seconds of the VF and its onset was established as the moment when the recorded signal became free from interferences produced by the shock or the 50 Hz current employed in induction. Monopolar configuration was used to register the potential difference between the active ICD case and the electrode tip, as this is an electrical source that is not as limited as the distal bipole. Each episode that the device classified as VF was visually analysed to confirm that it was indeed a fibrillation rhythm. $P_{(f)}$ spectral representation was obtained using Welch's periodogram cancelling the baseline, Hamming window (256 samples), a 50% overlap and 1024 resolution samples. The spectrum thus obtained was normalised in the module in order to have a unitary area. As frequency parameters, we estimated the dominant frequency (f_d), corresponding to the absolute maximum of the spectrum module, and the peak potentials for the f_d and the second and third harmonics: $P_n(f_d)$, $P_n(f_2)$, and $P_n(f_3)$, respectively. As a means of organisation we used the organisational index, defined as the quotient of the potential contained in the band corresponding to 75% of the dominant frequency and its harmonics and the total potential for the band in question (Figure).

Statistical Analysis

Variables are described as the mean (standard deviation). The Student t test was used to compare means for paired data (P<.05 being significant).

RESULTS

Of the 243 patients fitted with ICDs who were evaluated, 56 presented at least one episode of VF with spontaneous termination and one ended using shock; 5 received the shock before 5 s, for which reason their significance is doubtful and they were excluded from the study. The 51 remaining patients (44 males; aged, 61.7 [12.8]) constituted the analysed population. Two sustained VF episodes and 3 non-sustained VF episodes were spontaneous, and the rest were induced during implantation (by applying 50 Hz to 44 patients and shock on T to 2 others). Given that the number of patients whose VF was induced by shock on T is quite small, this variable was not analysed in this study. Ninety-four point one percent of the patients had ischaemic cardiopathy,

and in 24 the LVEF was <30%. The total duration of the episodes that were analysed was 8.7 (1.7) s for sustained episodes and 6.3 (2.5) s for those that ended spontaneously. The overlap in the duration of sustained and non-sustained episodes is due to the variations in condenser charging time according to the programmed level of energy, the state of the battery and the device make and model. Spectral parameters of both groups are shown in Table. The sustained episodes present a significantly larger f_d than the non-sustained ones (4.6 [0.7] compared with 4.3 [0.6] Hz respectively). Powers for f_d, the harmonics, and the OI were similar in both groups.

TABLE. **Spectral Characteristics From Sustained and non-sustained Ventricular Fibrillation Episodes**

	Sustained VF	Non-sustained VF	*P*
f_d, Hz	4.6 (0.7)	4.3 (0.6)	.001
$P_n(f_d)$ (×1000)	108.9 (36.3)	105 (36.9)	.61
$P_n(f_2)$ (×1000)	16.8 (12.3)	17.4 (10.7)	.76
$P_n(f_3)$ (×1000)	3.8 (3.1)	4.8 (4.4)	.12
OI	0.7 (0.1)	0.7 (0.1)	.70

f^d indicates dominant frequency; OI, organisational index; $P_n(f_d)$, $P_n(f_2)$, and $P_n(f_3)$, spectral powers for the dominant frequency and the second and third harmonics; VF, ventricular fibrillation.
Variables are presented as the mean (standard deviation).

DISCUSSION

Our results indicate that sustained VF episodes in patients fitted with an ICD have a higher f_d than non-sustained episodes in the first 3 s of arrhythmia. However, we did not find significant differences in either the potentials or the organisational spectral parameters.

Although polymorphic ventricular tachycardias can prolong and become VF, the episodes often end spontaneously. Classifying these episodes as polymorphic tachycardia, *torsades de pointes* or non-sustained VF is a problem of terminology, since there are no clear morphological or frequency criteria that would allow us to distinguish between these conditions using electrocardiography.[1] Spectral analysis of these rhythms indicates that there is a certain degree of underlying organisation that becomes translated as the appearance of defined spectral peaks.[3-5] Mäkikallio et al[2] analysed 7 patients fitted with similar ICDs to those used by our patients. The analysis employed non-linear dynamic methods and the team found better organisation in the first beats of self-resolving episodes compared with in sustained ones, although the mean cycle of the intervals, which corresponds to f_d, does not show significant differences. The low number of patients analysed, the use of bipolar electrograms and the different algorithms that were used could explain this discrepancy. In a preliminary analysis of 18 patients with ICD, using manual cycle measurement, it has been described that the non-sustained VF cycle was larger than that of sustained episodes, reaching statistical significance at the start of the sixth interval.[6] The present study confirms these findings in a higher number of patients by using spectral analysis.

Limitations of the Study

Although our study includes a larger number of patients than do similar studies described in the literature, it is still relatively small. It is possible that a larger sample would have shown significant differences in the organisation of the arrhythmia. On the other hand, most of the episodes were induced using a 50 Hz current that affects the EGM, for which reason it is not possible to determine the exact moment of VF induction, and its relation with the analysed period is only approximate. Thirdly, spectral analysis was limited to a single derivation, obtained from electrodes situated in the right ventricle, and so we did not have information about the characteristics of the VF signal in different zones. Obtaining simultaneous records from various spots on both ventricles could significantly improve the sensitivity of the analysis. Finally, some episodes that were included in the sustained VF group because treatment was received might have resolved spontaneously without applying shock. This limitation is inherent to the design of the study and can only be remedied by mapping fibrillation during extracorporeal circulation.

To conclude, during the first 3 s, although spectral characteristics of sustained and non-sustained VF episodes are similar, they do have differences that could be used in designing algorithms for the early detection of self-resolving VF in patients fitted with an ICD.

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