Study on Atrial Fibrillation Recidivity After Electrical Cardioversion Through Fibrillatory Waves Time-Frequency Analysis

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Abstract

Electrical cardioversion (ECV) is a well-established therapy for atrial fibrillation (AF), which is the most common cardiac arrhythmia in clinical practice. However, conventional ECV protocols cannot manage whether to stop or to continue delivering shocks to the patient after an unsuccessful tentative. To this respect, the present contribution analyzes the ability of the fibrillatory waves amplitude (fWA) and the dominant atrial frequency (DAF), extracted non-invasively from the atrial activity (AA) signal, to predict the effectiveness of every single shock in ECV protocols. Results showed that the effects of the first ineffective shock were notably reflected in the fWA. Indeed, by considering the fWA values after, instead of before, the first ineffective attempt, the diagnostic ability was increased from 79.37% to 85.71%. For the remaining ECV attempts, non-significant changes for the analyzed time-frequency metrics were observed. As a consequence, fWA and DAF could provide valuable information to improve the effectiveness of conventional ECV protocols, in which the effect of the first unsuccessful shock is crucial to elucidate the procedure effectiveness.

1. Introduction

Atrial fibrillation (AF) is the most common sustained supraventricular arrhythmia encountered in diary clinical practice [1]. It affects 1–2% of the general population, its prevalence increasing with age, from <0.5% at 40–50 years, to 5-15% at 80 years [2]. Although AF itself does not represent a life-threatening condition, a patient with this arrhythmia has twice the risk of death than a healthy person [3]. Hence, an important goal of clinicians is to restore normal sinus rhythm (NSR). In this respect, electrical cardioversion (ECV) is a well-established strategy of AF therapy [4]. However, although its success rate is high, AF recurrence is common during the first year after the procedure, even when the patients are under pharmacological therapy [4]. More precisely, approximately 40–60% of cardioverted patients revert back to AF within three months following ECV and around 60–80% within one year [5]. Therefore, the ECV success prediction could improve candidate selection for the procedure, thus reducing risks for the patient and costs for the health care provider.

To this respect, we have recently presented a non-invasive method able to predict external ECV outcome. The algorithm considered a discriminant model based on a time feature of the atrial activity (AA), as the fibrillatory (f) waves amplitude (fWA), and a spectral characteristic of the f waves, as the dominant atrial frequency (DAF) [6]. However, the method has only been used to predict ECV outcome before the procedure is attempted, i.e., when no electrical shocks have been applied yet to the patient. Hence, given that f waves tracking after unsuccessful and consecutive electrical shocks can reveal clinically interesting information to understand the mechanisms underlying successful AF termination, the present work focuses in analyzing the capability of the fWA, the DAF, and their discriminant combination [6], to follow-up the AF pattern evolution under successive attempts of ECV.

It is interesting to note that in conventional external ECV protocols, the effects of unsuccessful shocks are unconsidered to decide wether to stop the procedure or to continue delivering additional shocks to the patient [5]. Although the costs and patient's suffering associated to the delivery of one or several shocks are minimal, the risks are increased. In this sense, the application of every single shock could induce ventricular arrhythmias and cause cerebrovascular accidents [5]. In addition, the delivery of excessive energy to the heart could damage its structure and lead to new cardiac pathologies that were not present before the shock [7]. Hence, information about the evolution of AF after each electrical shock could help in the development of more effective atrial defibrillation protocols [8].

2. Materials

Sixty-three patients (20 men and 43 women) with persistent AF lasting for more than 30 days, undergoing ECV were followed during four weeks. All the selected patients in the database were under antiarrithmic drug treatment with amiodarone (200 mg/day) before the procedure and during the whole follow up after ECV. Moreover, all of them were also under anticoagulant treatment with acenocumarol (INR between 2.5 and 4). A standard 12–lead ECG was acquired during the entire ECV procedure. The signals were digitized at a sampling rate of 1024 Hz with 16–bit resolution.

The electrical energy used for cardioversion followed the increasing sequence of 200, 300, 360 and 360 J for the first, second, third and fourth attempt, respectively. In 35 patients (55.56%), only one electrical shock with a energy of 200 J was needed to revert AF back to NSR. After ECV, in 21 patients (60%) NSR duration was below one month, whereas in the remaining 14 (40%) NSR was maintained. On the other hand, between 2 and 4 shocks were needed to revert AF in 18 patients (28.58%). In this case, 10 patients (55.56%) relapsed to AF, whereas the other 8 (44.44%) remained in NSR during the whole study follow up. In only 10 patients (15.87%), NSR was not restored after 4 consecutive electrical shocks.

3. Methods

Several parameters relative to the f waves morphology have been analyzed recently to predict ECV outcome, before any shock was applied to the patient [6]. Some of these features were extracted from the AA time domain, such as the fWA or the AA mean power. The remaining features were obtained from the spectral characterization of the AA, such as the DAF, its first harmonic, its 3-dB bandwidth, etc. However, the results showed that the most significant single predictors for ECV outcome were the fWA and the DAF. Other tested single parameters also reported slight significant differences between patients who relapsed to AF, maintained NSR and had an ineffective procedure, but their discriminant power was notably lower than the one provided by the fWA and the DAF [6]. On the other hand, [6] also demonstrated that a forward stepwise discriminant analysis was able to provide a model based on these two metrics, which outperformed the discriminatory ability of each single parameter. It has the form $\mathrm{DF} = 34.917 \cdot \mathrm{fWA} - 0.683 \cdot \mathrm{DAF} + 1.156$.

Bearing this context in mind, with the aim to follow-up the AF pattern evolution among successive ECV attempts, fWA, DAF and DF were computed from a 10 seconds-length ECG segment preceding every single shock. Details on the fWA and DAF computation from the AA signal can be found in [6].

For each parameter, the thresholds to predict the shocks effectiveness and AF recurrence were obtained making use of the patients set in which several ECV attempts were applied. The maximum discrimination thresholds between effective and ineffective ECVs (Th1) and between patients who relapsed to AF and resulted in NSR, after the first month (Th2), were obtained by computing the receiver operating characteristic (ROC) curve, computed over the corresponding parameter after the first unsuccessful shock. The ROC curve is a graphical representation of the trade-offs between sensitivity and specificity. Sensitivity is the true positive rate while specificity is equal to the true negative rate. Other related metric is the accuracy, which quantifies the total number of ECVs precisely classified. The value that provided the highest accuracy in each case was selected as optimum threshold.

4. Results

As can be appreciated for the fWA analysis in Fig. 1(a), before any ECV attempt, most of the patients who relapsed to AF presented values overlapped with patients in which ECV was ineffective. However, after the first shock, the ineffective ECVs maintained similar amplitudes, whereas effective attempts presented higher values. The fWA was greater in those patients who maintained NSR than in those others who relapsed to AF. Additionally, the predictive ability after the first shock was increased from 64.29% to 89.29%, the statistical differences among groups being notably higher. Contrarily, for the DAF analysis, the diagnostic ability and the statistical differences among groups remained approximately constant after the first unsuccessful shock, such as Fig. 1(b) shows. Nevertheless, a higher DAF decrease was observed for effective cardioversions. Regarding the analysis with the discriminant function DF, no improvement in the classification into patients who resulted in NSR, relapsed to AF and presented an unsuccessful procedure was provided after the first shock, as can be observed in Fig. 1(c). However, considerably higher statistical differences among groups were noticed in this case.

The discriminant ability of the fWA, DAF and DF before any ECV attempt has been analyzed recently [6]. To check whether a higher diagnostic ability could be reached through these same parameters after, instead of before, the first unsuccessful shock, we also analyzed those other patients who only needed one shock to restore NSR. For these patients, a 10 seconds-length ECG segment preceding cardioversion was extracted and analyzed with the three parameters. Mean and standard deviation (std) values for the three metrics together with the classification results and the statistical significance values, considering jointly the patients who needed only one and several shocks, are shown in Table 1. It is noteworthy that, for the three metrics, the thresholds Th1 and Th2 were those obtained by

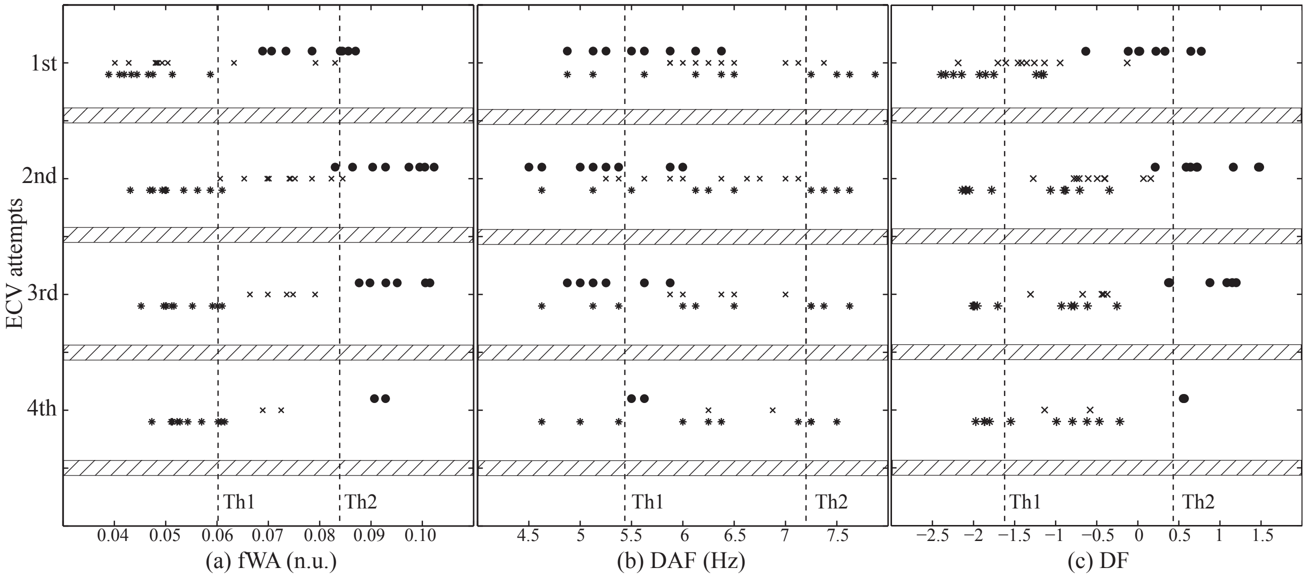

Figure 1. Analysis of the (a) fWA, (b) DAF and (c) DF for the patients who needed several ECV attempts. Symbols •, × and * represent patients who maintained NSR, relapsed to AF and presented an unsuccessful ECV, respectively.

Parameter	ECV result	Mean ± std	Accuracy	p
fWA	NSR maintenance	0.1025 ± 00232 n.u.	81.82%	
	AF recurrence	0.0717 ± 0.0100 n.u.	87.10%	1.81×10^{-7}
	Unsuccessful ECV	0.0516 ± 0.0056 n.u.	90%	
DAF	NSR maintenance	4.9943 ± 0.7564 Hz	77.27%	
	AF recurrence	5.9960 ± 0.7285 Hz	77.42%	5.42×10^{-3}
	Unsuccessful ECV	6.3875 ± 1.0581 Hz	40%	
DF	NSR maintenance	1.3164 ± 0.9590	86.36%	
	AF recurrence	-0.4372 ± 0.5547	100%	3.92×10^{-8}
	Unsuccessful ECV	-1.4042 ± 0.6914	50%	

Note: n.u. = normalized units

Table 1. Results of the fWA, DAF, and DF analyses considering jointly the patients who needed only one and several ECV attempts.

analyzing only the patients who needed several shocks. In the three cases, both Th1 and Th2 behaved as valid discrimination thresholds, because higher diagnostic abilities and statistical significances among groups than in previous works were obtained [6].

5. Discussion and conclusions

The application of the first shock in patients who needed several ECV attempts to restore NSR clarified considerably the ECV outcome prediction through fWA analysis, see Fig. 1(a). Indeed, by considering the fWA values after, instead of before, the first ineffective attempt, the diagnostic ability achieved with all the patients was increased from 79.37% [6] to 85.71%. In contrast, the effect of the first unsuccessful shock was reflected with limited impact in the results provided by the DAF and DF analyses. However, considering the values obtained after the first ineffective shock, the predictive ability of both metrics was notably improved in comparison to the values computed before any attempt [6]. Thus, for the DAF, the diagnostic accuracy increased from 65.08% [6] to 71.42% and, for the DF, from 82.54% to 87.30% .

Other important remark is that fWA and DF increased and DAF decreased notably after the first unsuccessful shock, see Fig. 1. For the remaining ECV attempts, similar values were observed before and after the corresponding shock. Thereby, it could be concluded that the first attempt plays the most important role in ECV and, as a consequence, in the possibility of restoring NSR after several shocks. This observation is in agreement with the results reported by two previous works where the most adequate initial shock energy was analyzed [9, 10]. Precisely, these studies reported that the higher the first shock energy, the higher the number of effective ECVs in which NSR is restored, the lower the number of needed shocks to restore NSR and, therefore, the lower the cumulative energy applied to the heart.

As a consequence, the information provided by the analyzed time-frequency metrics could contribute to improve the effectiveness of actual ECV protocols, which cannot manage whether to stop or to continue delivering shocks to the patient after the first unsuccessful tentative [5, 8].

Acknowledgments

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