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Atrial Electrogram Discordance During Baseline versus Re-Induced Atrial Fibrillation: Potential Ramifications For Ablation Procedures

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Abstract

Background—There are scant data comparing the electrogram (EGM) signal characteristics of AF in the baseline versus electrically induced states during ablation procedures.

Objective—The purpose of this study was to use novel intracardiac signal analysis techniques to gain insights into the effects of catheter ablation and AF re-induction on AF EGMs in patients with persistent AF.

Methods—We collected left atrial EGMs in patients undergoing first ablation for persistent AF at three time intervals: i) AF at baseline; ii) AF after pulmonary vein isolation (PVI) and; iii) AF after post-PVI cardioversion and subsequent re-induction. We analyzed the following two EGM spectral characteristics: 1a) dominant frequency (DF) and 1b) spectral complexity; and the following two EGM morphologic characteristics: 2a) morphology variation, and 2b) pattern repetitiveness.

Results—There were no differences in AF dominant frequency, dominant amplitude, spectral complexity, or metrics of EGM morphology or repetitiveness at baseline versus after PVI. However, dominant frequency, dominant amplitude, and spectral complexity differed significantly after DC cardioversion and re-induction of AF.

Conclusions—The frequency, spectral complexity and local EGM morphologies of AF do not significantly change over the course of a pulmonary vein isolation procedure in patients with persistent AF. However, re-induction of AF after DC cardioversion results in different DF and spectral complexity, consistent with a change in the characteristics of the perpetuating source(s) of the newly induced AF. These data suggest that AF properties can vary significantly between

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baseline versus re-induced AF, with potential clinical ramifications for outcomes of catheter ablation procedures.

Keywords

Atrial Fibrillation; Electrogram Analysis; Dominant Frequency; Linear Prediction

INTRODUCTION

Substrate-based electrogram (EGM) mapping and ablation of atrial fibrillation (AF) is often used along with pulmonary vein isolation (PVI) during AF catheter ablation procedures. Such mapping is based on various EGM characteristics that include morphology [e.g., complex fractionated atrial electrograms (CFAE)] and/or activation patterns (e.g., dominant frequency, rotor-based targets). Reports of success rates using EGM-based techniques vary, and possible causes of discrepancies include lack of standardization of EGM collection as well as analytical methods.

Little clinical data exist regarding whether spectral or morphologic AF EGM characteristics differ when EGMs are collected at different time points during ablation procedures, including: baseline, after PVI ablation, and when AF is converted to sinus rhythm and subsequently re-induced by electrical stimulation. It is clinically important to understand better the potential limitations of EGM-based treatment strategies during these procedures. For example, if AF dominant frequency values from a given site change over time, then frequency-based targeting of atrial sites may be neither rational nor effective.

The aim of this study was to compare these quantitative parameters of atrial EGMs in patients with persistent AF (i.e., at baseline, after PVI, and after DC cardioversion and AF re-induction), in order to determine the effects of ablation and DC cardioversion on atrial electrical activation patterns and provide mechanistic insight into AF maintenance over the course of a catheter ablation procedure.

METHODS

Study population

Intracardiac atrial EGMs were collected from a consecutive series of 35 adult patients at Columbia University Medical Center who underwent an electrophysiology study (EPS) for persistent AF requiring treatment with radiofrequency ablation (RFA). The Institutional Review Board of Columbia University Medical Center approved EGM data collection and analysis.

Electrophysiology Study

Patients underwent an initial evaluation that included history, physical examination, ECG, and echocardiogram. All 35 patients had a history of persistent AF and their baseline cardiac rhythm was AF in the laboratory. All membrane-active antiarrhythmic medications were held for at least 5 half-lives prior to the catheter ablation procedure, except for one patient who stopped amiodarone within 1 week prior to the procedure. RFA ablation consisted of

PVI + linear ablations (cavotricuspid isthmus, left atrial roof, and/or mitral) + CFAE ablation.

Figure 1 details the EGM sampling protocol for this study. All patients underwent PV isolation as the first step demonstrated by entry block or lack of any signals at all Lasso catheter poles. AF did not terminate by PV isolation in any of the 35 patients. All underwent DC cardioversion before any further ablation was carried out. After 10 minutes of atrial pacing at cycle length of 700 or 800 msec and during which time PVI was re-confirmed and hemodynamic parameters remained stable, AF re-induction was attempted using the following uniform protocol: left atrial burst pacing for at least 15 beats at each pacing cycle length, down from 300 msec to a minimum of 200 msec using interrupted pacing decrements of 10 msec.

Patients underwent EGM collection from the left atrial posterior wall at the following times: 1) Prior to any ablation, including PVI; 2) After confirmation of PVI; 3) After DC cardioversion and if at least 5 minutes of AF was re-induced (n=9 patients). No linear ablation or CFAE ablation had been performed prior to the DC cardioversion and AF re-induction.

Atrial Fibrillation Electrogram Measurements

The distal ablation pole of the mapping/ablation catheter (Thermocool SF, Biosense Webster, CA), was used to record bipolar atrial EGMs from the same tagged site in the mid-posterior wall of the left atrium (LA), outside electrically-isolated antral areas, as identified by three-dimensional mapping. Digitized, bipolar posterior LA EGMs were collected in 8.4 second recording periods, filtered (30–500 Hz), sampled at 977 Hz, and stored on a digital recording system (CardioLab, GE, WI, USA).¹ A coronary sinus bipolar electrode (i.e., CS 3–4 or CS 5–6) was used to record simultaneous EGMs for comparison of spectral characteristics at the three time periods. In addition, after QRS subtraction was performed, lead aVF was used to record simultaneous surface atrial waves at the three time periods.

Electrogram Characteristics

AF EGMs were analyzed for signal characteristics related to their frequency and morphology using previously validated techniques.^{2, 3} The dominant frequency (DF) is defined as the largest fundamental periodic component in the frequency range of interest (3–12 Hz). The amplitude of this dominant peak is defined as the dominant amplitude (DA). The dominant amplitude is therefore the spectral magnitude of the largest fundamental peak in the frequency spectrum, for the electrophysiologic range of interest. The frequency of this peak is the dominant frequency. The magnitude (ordinate) axis of the power spectrum is then normalized to a range of 0–1. The mean spectral profile (MP) is defined as the average level of the normalized spectrum. The standard deviation of the mean spectral profile is depicted as the SP.

Morphologic (electrogram shape) characteristics were also measured by previously validated techniques.⁴ Each electrogram was characterized by detecting all electrogram deflections and measuring peak amplitude, width, and upslope and downslope of each deflection, which were expressed as mean $\pm$ standard deviation for all EGMs. The uniformity of amplitude

peaks was expressed as the mean sum of absolute values of EGM morphologies. As previously reported, electrograms with uniform sharp peaks have a higher sum of absolute values, whereas electrograms with meandering deflections have a lower sum of absolute values. Finally, the degree of repetitiveness of any patterns present in CFAE, whether periodic or not, was estimated using linear prediction and signal reconstruction methodology, a method that estimates, without filtering or distortion, future signal values from adaptively weighted past values, with an increased level of regularity in CFAE signals defined as a decrease in linear prediction error.⁵

These three different types of measurements describe the complexity of CFAE in different ways.^{2, 4, 5} Greater complexity in EGMs is indicative of a greater degree of randomness in the atrial electrical activation pattern, and is expressed as:

1. Spectral Characteristics:
 - a. Lower Dominant Amplitude
 - b. Higher Mean Spectral Profile
2. Morphologic Characteristics:
 - a. More variable EGM peak amplitude, width, upslope, and downslope
 - b. Lower sum of absolute EGM amplitudes
3. Repetitiveness Characteristics:
 - a. Higher error in repetition

Temporal Variation of Atrial Fibrillation

In order to assess temporal variability of AF EGMs, sequential 5-second time segments of 5-minute continuous recordings were collected and analyzed to calculate each metric's mean coefficient of variation (CoV=standard deviation/mean), CoV standard deviation (SD), and CoV range. A coronary sinus bipolar electrode was used to assess the following EGM metrics in a cohort of thirteen patients for whom such data were available: i) Spectral- DF, DA, MP, SP; ii) Morphologic- peak amplitude, width, upslope, downslope, mean sum of absolute values; iii) Repetitiveness- linear prediction error.

Statistical Analysis

Demographic characteristics were reported as mean $\pm$ standard deviation. Comparisons of continuous variables were analyzed by the Student paired *t*-test. Analysis of variance was used to assess group differences in the measured variables and post-hoc group comparisons were performed using Tukey's procedure. A *p*-value of <0.05 was considered to be statistically significant. Statistical analysis was performed using SAS 8.2 (SAS Institute, Cary, NC).

RESULTS

Patient Characteristics

Summary characteristics of the patients' demographics are listed in Table 1. The study population included 35 patients (27 men/8 women; mean age 57 + 11 years) who underwent a catheter mapping and ablation procedure. Average duration of AF was 28 months (range=3–168 months, median=15 months).

Atrial Fibrillation Electrogram Measurements

1) Spectral Characteristics—PVI was the first phase of catheter ablation in all patients. AF did not terminate as a result of PVI alone in any of the 35 patients. There were no significant atrial EGM spectral differences between baseline AF versus ongoing post-PVI AF, but there were significant differences in the AF re-induced after DC cardioversion AF compared to baseline and post-PVI uninterrupted AF for the following parameters:

- i. Dominant frequencies decreased
- ii. Dominant Amplitudes increased
- iii. Mean spectral profiles decreased

Figure 2 is a representative example of the AF EGMs and their phase plots in a sample collected at baseline and then after DC cardioversion to sinus and re-induction to AF with atrial burst pacing.

- i. Dominant Frequency (Figure 3): DF remained unchanged over the course of PVI, but was significantly decreased during re-induced AF: $p=0.22$ for baseline (6.19 Hz) versus post-PVI AF (5.93 Hz), $p<0.01$ for baseline (6.19 Hz) versus re-induced AF (5.24 Hz), and $p=0.02$ for post-PVI (5.93 Hz) versus re-induced AF (5.24 Hz).
- ii. Dominant Amplitude (Figure 4A): DA remained unchanged during the PVI procedure, but then was higher during re-induced AF, $p=0.61$ for baseline (1.75) versus post-PVI AF (1.83), $p=0.03$ for baseline (1.75) versus re-induced AF (2.44), and $p=0.02$ for post-PVI (1.83) versus re-induced AF (2.44). These EGM values during post-cardioversion, re-induced AF were consistent with a more homogeneous, less complex, perpetuator(s) of AF compared to the baseline AF.
- iii. Spectral Complexity (Figure 4B): Values for the mean spectral profile of the AF EGMs were not significantly changed over the course of the PVI, but was significantly lower after AF re-induction: $p=0.85$ for baseline (0.36) versus post-PVI AF (0.35), $p=0.05$ for baseline (0.36) versus re-induced AF (0.27) and $p=0.02$ for post-PVI (0.35) versus re-induced AF (0.27). Thus, spectral complexity remained unchanged until DC cardioversion and AF re-induction, when it was decreased.

Spectral analyses obtained from bipolar coronary sinus EGMs were consistent with those obtained from the posterior LA wall: (i) Dominant Frequency and (ii) Dominant Amplitude were unchanged between baseline vs. post-PVI AF, but significantly different after AF re-induction. For DF: $p=0.14$ for baseline (6.31 Hz) versus post-PVI AF (5.96 Hz), $p=0.02$ for

baseline (6.31 Hz) versus re-induced AF (5.64 Hz); for DA: $p=0.58$ for baseline (1.55) versus post-PVI AF (1.59), $p<0.01$ for baseline (1.55) versus re-induced AF (2.28). (iii) Mean spectral profile was also unchanged between baseline vs. post-PVI AF, with a non-significant trend for lower value after AF re-induction: $p=0.64$ for baseline (0.39) versus post-PVI AF (0.40), $p=0.06$ for baseline (0.39) versus re-induced AF (0.34).

Spectral analyses of baseline versus post-induction AF obtained from surface lead aVF were also consistent with those obtained from the posterior LA wall: (i) Dominant Frequency and (ii) Dominant Amplitude were significantly different after AF re-induction (DF: $p<0.001$ for baseline (6.01 Hz) versus re-induced AF (5.34 Hz); DA: $p=0.05$ for baseline (1.82) versus re-induced AF (2.23). (iii) Mean spectral profile had a non-significant trend for lower value after AF re-induction: $p=0.07$ for baseline (0.31) versus re-induced AF (0.26).

2) Morphologic Characteristics—Table 2 lists the mean values and p-values for comparisons of the following morphologic parameters of local AF EGMs: Sum of Absolute Values; Amplitude; Width; Upslope, and Downslope. There were no significant EGM signal differences among the baseline, post-PVI, and re-induced AF groups when comparing these morphologic parameters.

3) Repetitiveness Characteristics—Linear repetition of EGMs remained unchanged through the course of the PVI ablation, as well as after re-induction of AF: $p=0.31$ for baseline (0.39) versus post-PVI AF (0.37), $p=0.12$ for baseline (0.39) versus re-induced AF (0.37), and $p=0.96$ for post-PVI (0.37) versus re-induced AF (0.37).

Temporal Variation of Atrial Fibrillation

Table 3 notes that when calculating coefficient of variation (CoV) for consecutive 5-second EGM samples over a total of 5 minutes, there was variation of measured spectral metrics (Table 3A) ranging from 8.9–16.8%, and of morphologic and repetitiveness metrics (Table 3B) ranging from 2.9–9.7%. For the DF, DA, and MP metrics, a significant difference in these values was noted when comparing between measured patients. Lack of significant differences between patients for the morphologic and repetitiveness metrics reinforces the relatively more stable nature of local EGMs for those metrics, as compared to spectral characteristics.

DISCUSSION

EGM signal analysis reveals that local frequencies, spectral complexities, and local EGM morphologies, as recorded from the posterior wall of the LA, do not significantly change over the course of PVI ablation procedures in patients with persistent AF. While prior findings have reported the temporal variability of sequential DF and CFAE maps over the course of a mapping procedure,^{6, 7} the current data suggest a degree of stability in certain *local* EGM characteristics, such as spectral complexity as well as morphology. Comparison of baseline versus re-induced AF shows significant, quantitative differences in EGMs obtained from three different locations: the posterior LA, the coronary sinus, and the surface ECG lead. Notably, AF EGMs manifest the following spectral changes after re-induction with DC cardioversion: 1) a decrease in dominant frequency; 2) an increase in dominant

amplitude; 3) a decrease in the mean of the normalized power spectrum. Thus, while the *morphology* and *repetitive* nature of local AF EGMs do not significantly change over time, there are significantly different *spectral* characteristics of EGMs that are present after AF re-induction.

Comparison to Prior Studies

Temporal variability is present for the measured metrics over 5 minute sampling periods, and observation that is in agreement with prior analysis by Habel et al., who noted that “brief periods of comparison are inadequate to detect temporal variability” of EGM DFs.⁶ However, even after taking into account the practical limitation that brief periods of comparison may not be able to detect temporal variability in EGMs, our post-induction data are nevertheless still significantly different from baseline data and point out that re-induction of AF does lead to significant changes in local EGM spectral parameters, including DF, DA, and MP.

Prior studies have also noted that the posterior wall of the LA possesses the highest frequency regions and activation patterns consistent with AF maintenance, including rotors.^{8,9} Thus, these findings expand our understanding of the role of the LA posterior wall, support the well-established findings of variable and relatively low success rates of PVI-only ablation in persistent AF patients, and reinforce the long held impression that there are sources external to the pulmonary veins perpetuating the fibrillation process that are not necessarily affected by PVI in patients with persistent AF.

We believe these findings indicate the possibility of different sources and mechanisms being activated by AF re-induction following PVI. Thus, the process of PVI, conversion to sinus and then re-induction of AF (e.g., by burst pacing techniques), may result in patients manifesting AF with dissimilar activation properties from ‘baseline’ AF. These data suggest that the process of cardioverting and re-inducing AF can change circuits responsible for maintaining AF to different frequencies and spectral profiles. The possibility that AF activation properties can change after cardioversion and re-induction may therefore pose methodological problems with potential clinical consequences, especially when EGM-based substrates are targeted and when repeated DC cardioversions and re-inductions are used to guide the ablation process.

Prior studies have noted that AF spectral characteristics can change during the course of radiofrequency ablation. Atienza et al. note that ablation at highest DF sites, followed by circumferential PVI, led to elimination of left-to-right atrial frequency gradients.¹⁰ Similarly, Hocini et al. performed stepwise ablation in the right as well as right atria and documented AF cycle length prolongation.¹¹ These studies differ from the present study because both the locations and extent of ablation were more extensive than that of PVI alone. Our findings add to these prior studies by comparing and contrasting not only properties of pre- vs. post-PVI AF, but also of baseline versus post-induction AF.

AF EGMs have not only been noted to change characteristics during the course of EP mapping and ablation procedures, but also with administration of antiarrhythmic agents. For example, in a previous study, atrial activation patterns changed during the course of ibutilide

administration, including an increase in the variability of AF EGM amplitudes and morphologies, as well as a decrease in AF EGM pattern repetitiveness.¹² In addition, we have also noted that CFAE patterns differed between paroxysmal and persistent AF patients. Notably, in persistent AF patients the dominant frequencies (DF) are higher and more uniform at multiple recording locations compared to paroxysmal AF patients.⁵ These findings may be explained by noting that while patients with paroxysmal AF are thought to manifest drivers of AF that originate in and around the pulmonary veins, as well as relatively more normal atrial substrate that manifests more heterogeneous EGM characteristics, the concomitant atrial remodeling in persistent AF patients results in a more homogeneous, or stable, atrial substrate with less variability in electrophysiological properties, resulting, for example, from AF drivers possessing relatively similar characteristics due to stable sources.¹³

Clinical Implications

Both CFAE sites and sites manifesting high frequency of activation have been targeted as potential sources of AF perpetuation or maintenance.^{4, 14–18} However, a limitation of using DF to characterize CFAEs is that it provides little information regarding other characteristics of signals, including potential periodic components of the signal. For example, when multiple frequencies arise from independently firing sources,¹⁹ DF analysis can be limited to one spectral peak and miss sources that are driving the arrhythmia. Similarly, continuous electrical activity in paroxysmal as well as persistent AF patients has been reported to be a nonspecific marker of potential target sites for AF ablation.²⁰ These observations point out the need to use broader spectral characteristics when analyzing AF EGMs.

In conclusion, the improved understanding of the properties of less traditional EGM signal indices are required for the selection of patients more likely to benefit from ablation procedures. Changes in these EGM metrics may reflect different underlying mechanisms driving or maintaining the arrhythmia. Prior study has shown that AF recurrence and stability, as well as higher measures of frequency organization, have been shown to correlate with AF termination during ablation, and after antiarrhythmic medication treatment.^{21–23} In addition, EGM recurrence patterns, as measured by morphology recurrence plot analysis, have more recently been postulated to be critical for sustaining AF.^{24, 25} Thus, the search for other EGM indices as tools for finding ablation targets continues, and further analysis is required to understand the significance of these differences and to define their role during ablation procedures.

Limitations

The study was limited by EGM collection from a single endocardial site in the posterior LA in a relatively small number of patients with AF; data were not collected from the right atrium. However, data were collected in a consecutive manner in a homogeneous patient population with longstanding persistent AF, in a previously noted part of the LA with important characteristics for AF maintenance.^{8, 9} In addition, spectral analyses from the coronary sinus and ECG support endocardial EGM findings. Different AF re-induction protocols may lead to AF with different signal characteristics. While our pacing protocol was standardized for patients, further studies of different protocols to assess this possibility

are warranted. Finally, the characteristics of AF were not evaluated after the more extensive ablation which followed DC cardioversion and re-induction, so data about possible further changes in spectral frequency and complexity are not available. Further studies with larger numbers of patients can provide more insight into whether the use of novel EGM indices can help to guide and improve upon catheter ablation for AF.

CONCLUSIONS

Novel EGM signal analytical techniques reveal that the frequency, spectral complexity and local EGM morphologies of AF do not significantly change over the course of a pulmonary vein isolation procedure in patients with persistent AF. However, re-induction of AF through DC cardioversion results in different DF and spectral complexity, suggesting a change in the perpetuating source(s) of the newly induced AF. Although the significance of these measurable differences is not yet known, these data suggest that AF properties can vary significantly between baseline versus re-induced AF, with potential ramifications for catheter ablation procedures.

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Abbreviations

AF	atrial fibrillation
CFAE	complex fractionated atrial electrogram
CoV	coefficient of variation
DA	amplitude of dominant peak
DC	direct current
DF	dominant frequency
ECG	electrocardiogram
EGM	electrogram
EPS	electrophysiology study
LA	left atrium
MP	mean spectral profile
PVI	pulmonary vein isolation

RFA	radiofrequency ablation
SP	standard deviation of mean spectral profile

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Clinical Perspectives

Novel EGM-based signal analyses reveal that local AF metrics do not change significantly over the course of pulmonary vein isolation ablation in patients with persistent AF. However, spectral characteristics of AF, such as dominant frequency, dominant amplitude, and mean spectral profile, do change significantly after DC cardioversion and AF re-induction. Therefore, our findings indicate the possibility of different sources and mechanisms being activated by AF re-induction following PVI. That AF properties may change after re-induction poses potential limitations on ablation procedures, especially when substrate targeting is used to guide the ablation procedure. More analyses are required to understand the significance of these differences during ablation procedures.

Figure 1.
Protocol for EGM sampling in AF patients.

Figure 2.

Use of EGM signal analysis to calculate the dominant frequency, dominant amplitude and mean of the normalized power spectrum in an AF ablation patient at baseline (A&C) vs. post-DC cardioversion and re-induction (B&D). After DC cardioversion, the dominant frequency decreases from (A) 6.22 to (B) 5.58 Hertz, the dominant amplitude increased from (A) 1.44 to (B) 1.77, and the mean of the normalized power spectrum (MP=dotted lines) decreases from (C) 0.36 to (D) 0.33, indicating lower frequency, less disparate source(s) contributing to the frequency power spectrum post-DC cardioversion.

Figure 3.

Comparison of the change in the dominant frequency in persistent AF patients at baseline, post-PVI, and after DC cardioversion and then re-induction of AF. There were no significant atrial EGM spectral differences between baseline AF and post-PVI AF, but there were significant differences when AF was re-induced. EGMs manifest a lower dominant frequency after re-induction, indicating more homogenous sources contributing to the frequency power spectrum post-DC cardioversion.

Figure 4.

Comparison of the change in the magnitude of the (A) dominant frequency amplitude and of the (B) power spectrum in persistent AF patients at baseline, post-PVI, and after DC cardioversion and then re-induction of AF. For both measures, there were no significant atrial EGM spectral differences between baseline AF and post-PVI AF, but there were significant differences when AF was re-induced. EGMs manifest higher dominant frequency amplitudes after re-induction and lower means of normalized power spectrum, indicating

more homogenous sources contributing to the frequency power spectrum post-DC cardioversion.

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Table 1

Patient Characteristics

Characteristic	Number (%)
Number of Patients	35
Female/Male Gender	8 (23)/27 (77)
Age (years)	57 ± 11 [Range 21–72]
Left Atrial Size (cm)	
- Normal (< 4.0)	2 (7)
- Mild-Moderately Enlarged (4.1–4.9)	21 (78)
- Severely Enlarged (> 5.0)	4 (15)
Left Ventricular Ejection Fraction (%)	
- Normal (> 55)	18 (64)
- Mildly Decreased (45–54)	5 (18)
- Moderately Decreased (35–44)	1 (4)
- Severely Decreased (<35)	4 (14)

Data are presented as mean ± SD, ranges, and percentages. Left atrial size not available for 8 patients; left ventricular ejection fraction not available for 7 patients.

Table 2

Morphologic Characteristics of AF EGMs

	Sum of Absolute Voltages	Peak Amplitude Mean	Upslope Mean	Downslope Mean	Width Mean
1) Baseline AF:	0.663	0.037	0.007	0.007	3.921
2) Post-PVI AF:	0.677	0.036	0.007	0.007	3.944
3) Post Re-induction AF:	0.644	0.035	0.007	0.007	4.054
p-value:	Type 1-3	0.50	0.47	0.46	0.66
	Type 1-2	0.43	0.92	0.91	0.89
	Type 2-3	0.24	0.57	0.54	0.59

More uniform sharp peaks have a higher sum of absolute values, while meandering peaks have a lower sum of absolute voltages.

Table 3

Temporal Variation of Atrial Fibrillation, as Measured by Coefficient of Variation

A. Spectral Characteristics			
Parameter:	Mean $\pm$ SD (%)	Range (%)	P-value (for comparison between patients)
Dominant Frequency (DF)	8.9 $\pm$ 6.8	1.7 – 25.9	0.027
Dominant Amplitude (DA)	11.8 $\pm$ 6.8	5.7 – 29.5	0.017
Mean Spectral Profile (MP)	16.9 $\pm$ 5.4	11.5 – 28.9	0.017
Standard Deviation of Mean Spectral Profile (SP)	10.9 $\pm$ 1.4	9.5 – 14.3	0.124

B. Morphologic and Repetitiveness Characteristics			
Parameter:	Mean $\pm$ SD (%)	Range (%)	P-value (for comparison between patients)
Sum of Absolute Values	3.3 $\pm$ 1.1	1.7 – 5.7	0.325
Peak Amplitude	8.0 $\pm$ 2.9	4.9 – 14.2	0.117
Upslope	9.7 $\pm$ 6.0	4.1 – 26.1	0.226
Downslope	9.3 $\pm$ 4.9	4.1 – 22.4	0.378
Width	2.9 $\pm$ 0.7	1.9 – 4.1	0.261
Linear Prediction (LP)	8.9 $\pm$ 2.6	4.2 – 12.9	0.296