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Real-time Dominant Frequency Mapping and Ablation of Dominant-Frequency Sites in Atrial Fibrillation with Left-to-Right Frequency Gradients Predicts Long-Term Maintenance of Sinus Rhythm

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Abstract

Background—Spectral analysis identifies localized sites of high-frequency activity during atrial fibrillation (AF). We determined the effectiveness of using real-time dominant frequency (DF) mapping for radiofrequency ablation of maximal DF (DFmax) sites and elimination of left-to-right frequency gradients in the long-term maintenance of sinus rhythm (SR) in AF patients.

Methods—DF mapping was performed in 50 pts during ongoing AF (32 paroxysmal, 18 persistent), acquiring a mean of 117±38 points. Ablation was performed targeting DFmax sites, followed by circumferential pulmonary vein isolation.

Results—Ablation significantly reduced DFs (Hz) in the LA (7.9±1.4 vs 5.7±1.3, p<0.001), CS (5.7±1.1 vs 5.3±1.2, p=0.006) and RA (6.3±1.4 vs 5.4±1.3, p<0.001) abolishing baseline left-to-right atrial DF gradient (1.7±1.7 vs 0.2±0.9; p<0.001). Only a significant reduction in DFs in all chambers with a loss of the left-to-right atrial gradient after ablation was associated with a higher probability of long-term SR maintenance in both paroxysmal and persistent AF pts. After a mean follow-up of 9.3±5.4 months, 88% of paroxysmal and 56% of persistent AF pts were free of AF (p=0.01). Ablation of DFmax sites was associated with a higher probability of remaining both free of arrhythmias (78% vs 22%; p=0.001) and free of AF (88% vs 30%; p<0.001).

Conclusions—Radiofrequency ablation leading to elimination of LA-to-RA frequency gradients predicts long-term SR maintenance in AF patients.

Keywords

atrial fibrillation; spectral analysis; catheter ablation; adenosine

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The recognition of the critical role of the pulmonary veins-posterior left atrial wall (PV-PLAW) region in paroxysmal atrial fibrillation (AF) initiation and maintenance has led to the widespread use of the circumferential pulmonary vein isolation (CPVI) ablation procedure.¹ However, this anatomically based approach is limited by its inability to successfully restore sinus rhythm (SR) in large groups of AF patients. Thus, two alternative strategies have emerged: 1) *extensive anatomical ablation procedures* combining CPVI with additional linear lesions along the left atrial (LA) roof, mitral annulus and other atrial structures;^{2,3} and 2) *electrogram-guided ablation procedures* consisting of either mapping and ablating localized reentrant sources driving AF⁴ or targeting complex fractionated electrograms (CFAEs).⁵ However, systematic ablation of CFAEs has led to conflicting results.^{5,6}

Spectral analysis of the bipolar signal enables rigorous characterization of the spatial distribution of excitation frequency at multiple locations of the atria and may also provide insight into the mechanisms responsible for AF in specific patients.⁷ Dominant frequency (DF) mapping is aimed at identifying localized sites of maximal DF (DFmax) during AF.⁷⁻⁹ Retrospective analyses have shown that radiofrequency (RF) ablation at such DFmax sites results in slowing and termination in a significant proportion of paroxysmal AF patients, indicating their role in AF maintenance.^{8,9}

We have previously demonstrated that adenosine infusion during ongoing AF may be used to highlight DFmax sites driving paroxysmal AF.⁹ Here we have combined for the first time the use of real-time DF mapping with RF ablation to conduct a feasibility study and prospectively evaluate the safety and long-term outcome of targeting DFmax sites. In addition, to search for predictive insight, we determined the effects of RF ablation of DFmax sites on AF spectral characteristics (i.e. left-to-right atrial frequency gradients) and its relation to the long-term SR maintenance.

Methods

Patients

The study included drug-refractory paroxysmal and persistent AF patients admitted for RF ablation. Self-terminating AF lasting <48 hours was defined as paroxysmal; sustained AF lasting >1 week before the procedure or requiring external cardioversion to SR was defined as persistent. All antiarrhythmic drugs except amiodarone (n=7) were withheld >5 half lives before the study.

Real-Time Frequency Mapping

Definitions and standard electrophysiological protocols are presented in the Online Supplement. The protocol was approved by the Institution Research and Ethics Committee. All patients gave informed consent.

After the catheters were in place and sustained AF was induced in paroxysmal AF patients, 3D reconstruction of the atrial chambers and real-time DF determination was created using the CARTO navigation system with embedded spectral analysis capabilities (CARTO XP version 7.7, Biosense Webster) described in the Online Supplement.⁷⁻⁹ Color-coded DF maps in real-time during ongoing AF were superimposed on the atrial shell geometry, displaying low frequencies in red and high frequencies in purple (Figure 1).⁹ Sites demonstrating DFs that were at least 20% higher than their surrounding points were identified as primary and secondary DFmax sites; i.e., the primary DFmax site was that with the highest DF throughout the atria. Once a primary DFmax site was identified, an adenosine bolus was given and the DF was measured again at that site during peak adenosine effect.⁹

Radiofrequency Ablation

The endpoint of the procedure was ablation of DFmax sites plus CPVI (see Online Supplement for ablation protocol and setting details). Once the primary DFmax site was identified, ablation started at that site creating a circumferential set of lesions (Figure 1). After all DFmax sites were ablated, CPVI was performed in all patients. In case of SR conversion during the ablation protocol, AF inducibility was evaluated by repeating the stimulation protocol that previously induced AF. AF was considered inducible if it persisted for >10 minutes. For ethical reasons, due to the observational nature of the study and the a priori unknown outcome of DFmax sites ablation, CPVI was performed in all patients after DFmax sites ablation.

Post-ablation DF assessment

Post-ablation DF measurements were obtained at stable recording sites (RA appendage [RAA], CS) and the LA posterior wall. Measurements were performed prior to cardioversion in patients not converting to SR during the ablation protocol. In patients that converted to SR and became non-inducible, recordings were acquired at the last recording site prior to termination. Post-ablation DF maps were obtained again prior to cardioversion in 7 patients that remained in AF after ablation.

Follow-up

All patients were followed at the outpatient clinic at 3, 6 and 12 months after the procedure. A blanking period of 2 months was considered to define recurrences. A repeat procedure using the previously described protocol was indicated in all patients with recurrent atrial arrhythmias. Procedural success was defined as lack of AF or atrial arrhythmia recurrence in the absence of antiarrhythmic medication. Only AF recurrences were considered when analyzing the effect of the proposed ablation method on spectral characteristics and its relation to the long-term outcome.

Statistical Analyses

Continuous variables are reported as mean $\pm$ SD and assessed for normality using the Shapiro-Wilk test. Baseline characteristics comparisons were made using Student's *t*-test and the Fisher's exact test, as appropriate. In case of non-normally distributed continuous variables, non-parametric tests were used. The effect of ablation at each atrial region was compared using a mixed-model ANOVA design with Bonferroni correction. Analyses were performed with SPSS (V14.0.2) and statistical significance was established at $p < 0.05$.

Results

Patients

Fifty consecutive patients (52 $\pm$ 11 years, 37 (74%) male) admitted for AF ablation (32 paroxysmal, 18 persistent) were included. Table shows the patients' demographic and clinical characteristics. Five (16%) paroxysmal AF patients were in AF on arrival at the electrophysiology laboratory. AF was induced during catheter manipulation in 7 (22%) and by incremental pacing in 16 (50%) patients; 4 patients (12%) required isoproterenol infusion and CS pacing to induce sustained AF.

Baseline spectral characteristics: Spatial distribution of DFmax sites

We acquired a mean of 117 $\pm$ 38 points (LA: 101 $\pm$ 24; RA: 44 $\pm$ 8; CS: 17 $\pm$ 9) during DF mapping of ongoing AF. In most paroxysmal AF patients, only LA maps were obtained. However, 3-D maps were also obtained ($n=4$) from the CS and RA when the operator presumed the presence of a DFmax source at either location by cycle length (CL) analysis,

or in the absence of SR conversion after ablation of DF sites on the LA. DF maps from LA, CS and RA were obtained in most persistent AF patients ($n=12$; 67%). The mean mapping protocol duration and fluoroscopy times were 62.7 ± 21.5 and 65 ± 17.6 minutes, respectively. The overall duration of the procedure was 248 ± 68.6 minutes.

In Figure 2, we show data from four regions: PV-PLAW, LA, RA, and CS. In paroxysmal AF patients, 83% of DFmax sites were located at the PV-PLAW region, with 12% being located at other sites in the LA; 4% at the RA and 1% at the CS. In contrast, permanent AF patients had a significantly lower incidence of DFmax sites in the LA-PLAW region (39%), and were more likely to have DFmax sites at non-PV locations of the LA (39%), RA (16%) and CS (6%) compared with paroxysmal AF patients (Figure 3). Interestingly, in persistent AF more than one third (36%) of DFmax secondary sites were found in the left or right atrial appendages.

RF ablation: AF termination and inducibility

AF terminated during ablation in 23 (72%) paroxysmal and 2 (11%) persistent AF patients ($p<0.001$). AF terminated after ablating the primary DFmax site in 17 paroxysmal AF patients. In paroxysmal AF patients, 92% of DFmax sites whose ablation led to successful AF termination were located at the PV-PLAW region; the reminder 8% sites were in the LA. In 2 persistent AF patients, ablation of a DFmax site at the PV-PLAW region and at the LA roof, respectively terminated AF.

RF ablation effect on AF spectral characteristics

Overall, RF ablation significantly reduced DFs (Hz) in the LA (7.9 ± 1.4 vs 5.7 ± 1.3 , $p<0.001$), CS (5.7 ± 1.1 vs 5.3 ± 1.2 , $p=0.006$) and RA (6.3 ± 1.4 vs 5.4 ± 1.3 , $p<0.001$), effectively abolishing LA-to-RA DF gradient (1.7 ± 1.7 vs 0.2 ± 0.9 ; $p<0.001$).

Among patients with paroxysmal AF, RF ablation significantly reduced regional DFmax in LA (7.8 ± 1.4 versus 5.2 ± 1 Hz; $p<0.001$) and RA (5.7 ± 1.3 versus 4.8 ± 0.8 Hz; $p<0.001$), but did not modify CS DFs (5.3 ± 0.9 versus 5.1 ± 1.2 Hz; $p=ns$). Consequently, the LA-to-RA DF gradient was abolished after ablation (2.1 ± 1.7 vs 0.4 ± 1.1 Hz; $p<0.001$). Similarly, among patients with persistent AF, RF ablation significantly reduced DFmax in the LA (7.9 ± 1.3 versus 6.5 ± 1.3 Hz; $p<0.001$), RA (7.3 ± 0.9 versus 6.5 ± 1.5 Hz; $p=0.006$) and CS (6.4 ± 1 versus 5.8 ± 1.3 Hz; $p=0.004$). Consequently, the LA-to-RA DF gradient that was present at baseline was also abolished after ablation (1 ± 1.5 versus 0.1 ± 0.7 Hz; $p=0.02$).

Long-Term Outcome

After a mean of 9 ± 5 months of follow-up, 24 (75%) paroxysmal and 9 (50%) persistent AF patients were free of arrhythmias in the absence of antiarrhythmic therapy ($p=0.07$). Freedom from AF was achieved in 28 (88%) of paroxysmal and 10 (56%) persistent AF patients ($p=0.02$). A repeat ablation procedure was performed in 3 (9%) paroxysmal and in 6 (33%) persistent AF patients ($p=0.05$).

As shown in Figure 3A, paroxysmal AF patients that remained free from AF had significant maximal DF reduction at all recording sites (LA: 7.9 ± 1.4 versus 5.2 ± 1 Hz, $p<0.001$; RA: 5.8 ± 1.3 versus 4.7 ± 0.8 Hz, $p<0.001$; CS: 5.3 ± 0.9 versus 4.9 ± 0.9 Hz, $p=0.03$). Consequently, as shown in Figure 3B, the LA-to-RA gradient was abolished (2.2 ± 1.8 versus 0.4 ± 1.3 Hz, $p<0.001$). In contrast, in patients with recurrent AF (left), DFmax was significantly reduced only in the LA (7.1 ± 1.3 versus 5.4 ± 1.4 Hz, $p=0.02$) with no significant changes in RA (5.5 ± 1 versus 5.2 ± 1 Hz, $p=ns$), or CS (5.5 ± 0.9 versus 6.1 ± 2.4 Hz, $p=ns$) or in the LA-to-RA gradient (1.4 ± 1.2 versus 0.3 ± 0.5 Hz, $p=ns$).

As shown in Figure 4A, persistent AF patients that remained AF-free (right) had a significant reduction in DFmax in the LA (8.3 ± 1.4 versus 6.3 ± 1.4 Hz, $p < 0.001$) and RA (7.4 ± 1 versus 6.2 ± 1.7 Hz, $p < 0.01$), abolishing LA-to-RA DF gradient (Figure 4B, right). In contrast, in patients with recurrent AF (panel A), DFmax was significantly reduced only in the LA (7.5 ± 0.9 versus 6.6 ± 1.3 Hz, $p = 0.04$) and CS (6.4 ± 1.2 versus 5.5 ± 0.8 Hz, $p = 0.04$), with no significant change in the RA (7.1 ± 0.8 versus 6.7 ± 1 Hz, $p = \text{ns}$), or the LA-to-RA gradient (0.4 ± 0.6 versus -0.14 ± 0.6 Hz, $p = 0.05$).

Predictors of arrhythmia recurrence

The presence of a LA-to-RA gradient prior to ablation was predictive of a better outcome in patients with persistent AF (Figure 4B). Ablation of DF sites was associated with a higher probability of remaining both free of arrhythmias (78% vs 20%; $p = 0.001$) and free of AF (88% vs 30%; $p < 0.001$). The proportion of AF recurrences was higher in patients in whom there remained untargted DFmax sites after the procedure (50% vs 77%; $p = 0.05$). Untargted DFmax sites were more common in persistent compared to paroxysmal AF patients (28% versus 61%; $p = 0.02$). The most common locations of untargted DFmax sites were: atrial appendages in 13, LAPW in 7, CS in 2, RA in 2 and LA septum in 1 patient. The number of patients with untargted DFmax sites located at the appendages was significantly higher in persistent compared to paroxysmal AF patients (33% versus 9%, $p = 0.03$). All univariate predictors of AF recurrence, together with other relevant variables (i.e. SR conversion during ablation; radiofrequency applications duration), were introduced into a stepwise logistic regression model. The only independent predictors of freedom of AF were ablation of DF sites (OR: 0.144 (CI 0.025–0.833); $p = 0.002$) and paroxysmal AF (OR: 0.051 (CI 0.008–0.338); $p = 0.03$). There was a significant interaction between ablation of DF sites and LA-to-RA gradient, which explains why the latter variable was not selected (see Online Supplement).

Repeat DF mapping and ablation

Repeat ablation procedures were performed in 10 patients 6 ± 4 months after the initial procedure. The reasons for the repeat procedure were: recurrent AF in 6 patients, focal atrial tachycardia in 1 patient and macro-reentrant tachycardia in another. Atrial tachycardias were successfully treated. In 2 additional patients AV nodal ablation was performed. In the 6 persistent AF patients undergoing repeat procedure, there had been reconnection of all 4 PVs ($n = 4$) or left PVs ($n = 2$). As seen in Figure 5 for one patient, compared to the initial procedure (Panel A), primary and secondary DFmax sites in the redo procedure (Panel B) were located at the same posterior LA area (purple). Similar results were obtained in 4 patients. Moreover, there was no significant difference between primary (7.4 ± 0.6 vs 8 ± 1.2 Hz; $p = \text{ns}$) and secondary (7.2 ± 0.6 vs 7.6 ± 1 Hz; $p = \text{ns}$) DFmax sites when both procedures were compared.

A second DF map was obtained immediately after the ablation protocol in 7 patients (3 paroxysmal, 4 persistent) in whom there was no SR conversion after ablation. Compared to the pre-ablation map, DF was reduced significantly after ablation at both primary (10 ± 2 vs 7.6 ± 1.4 Hz; $p = 0.02$) and secondary sites (9.1 ± 1.9 vs 6.8 ± 1.6 Hz; $p = 0.05$). As illustrated in Figure 6 for one case, in patients with paroxysmal AF, the DFmax after ablation became slower and its location shifted from the PVs to the base of the posterior wall, LA appendage (LAA) and RA. A similar post-ablation shift was observed in persistent AF patients in whom DFmax sites were located at the PVs prior to ablation (Figure 7). In contrast, persistent AF patients in whom DFmax was located at sites other than the PVs, such as the LAA base or the CS, they either remained at that site or became slower and shifted to a contiguous LA site.

Safety Analysis

After a total of 60 ablation procedures there were 3 minor and 1 major complications: PV stenosis occurred in a paroxysmal AF patient that was successfully treated with PV angioplasty; 2 patients presented vascular problems at the access site that resolved without surgical treatment; one patient presented transient phrenic nerve paralysis spontaneously resolved.

Discussion

We demonstrate for the first time that real-time DF mapping is feasible and can be safely performed as a complement to conventional AF ablation procedures. Real-time spectral analysis of AF enables identification and elimination of DFmax sources responsible for AF maintenance. Most important, targeting DFmax sites followed by CPVI results in long-term SR maintenance in 75% paroxysmal and 50% persistent AF patients.

Online determination of spatial distribution of DFmax sites

DF analysis of the bipolar signal of atrial activity during AF provides an objective characterization of the spatial distribution of excitation frequency.⁷ Previously, retrospective analyses showed that ablation at DFmax sites terminated a significant proportion of paroxysmal AF cases.^{8,9} Here we demonstrate that real-time DF mapping is a safe and useful aid to routine AF ablation. Total procedure duration, fluoroscopy times and rate of major complications were similar to previously reported studies.^{2,4,6}

The different distribution of DFmax sites in paroxysmal vs persistent AF patients after mapping with online spectral analysis resembles that obtained by Sanders *et al.*⁸ who used offline DF mapping. Together, the data from both studies demonstrate our ability to differentiate paroxysmal versus permanent AF patients. Once DFmax sites were identified, we performed adenosine infusions to confirm their role in driving AF,⁹ and eliminated DFmax sites by creating a circumferential set of lesions around them. All DFmax sites, including those located at the PVs and those at other atrial structures were selectively ablated. Nevertheless, some DFmax sites, particularly those in the atrial appendages, were not targeted mainly due to safety concerns or inability to reach those sites. The higher AF recurrence rate in patients with non-ablated DFmax sites at the end of the procedure supports the important role of extra-pulmonary sites in persistent AF maintenance.

AF spectral characteristics and long-term ablation outcome

Globally, DFmax site ablation and CPVI results in significant decreases in regional DF and reduction of LA-to-RA DF gradients in both paroxysmal and persistent AF patients. However, the degree of regional DFmax reduction differed in terms of long-term outcome. Only those patients with a pre-existing LA-to-RA DF gradient at baseline in whom there was a significant reduction in both LA and RA DFs with abolition of the gradient, remained free from AF during long-term follow-up. We found no relationship between acute AF termination during ablation and long-term freedom from recurrent AF in paroxysmal AF patients. Our results are in agreement with prior studies in patients with chronic AF that demonstrated a clinically successful outcome despite the absence of AF termination during the ablation procedure.^{3,6,10}

The prevalent findings in persistent AF with recurrences that required repeated procedure are 1) recovered PV conduction¹⁰ and 2) DFmax site location and maximal DF values similar to baseline prior to ablation. DFmax site ablation in the atria leading to a significant DF reduction is required for a successful outcome. This can be achieved with CPVI in the

majority of paroxysmal AF patients. However, in patients with persistent AF, ablation of extrapulmonary sites is required since half of DFmax sites are located outside the PV region.

Prior studies

Randomized studies have shown the superiority of isolating a large area around ipsilateral veins.^{1,11} Currently, most ablation strategies for AF use a standardized anatomical approach of CPVI with or without additional ablation lines. However, because a single predefined ablation schema is not equally effective across patients with AF the technique has evolved towards 2 different strategies: 1) *extensive anatomical ablation procedures* that combine CPVI with linear lesions,^{2,3} and 2) *electrogram-guided ablation procedures* aimed at either mapping and ablating localized re-entrant sources or targeting CFAEs.⁴⁻⁶ In the first case, very extensive lesions are performed that may involve more ablation than necessary in some patients, specifically when isolation of the posterior wall is attempted.⁴ In the second approach other authors have proposed targeting CFAEs.^{5,6} However this approach is also limited because it is not systematic, based on qualitative inference of electrogram morphology and/or cycle length, and thus its results are difficult to interpret.⁶ Moreover, a recent study using CFAE ablation as the only ablation strategy reported suboptimal results in chronic AF.⁶

Two other studies have analyzed the effects of ablation strategies on atrial DFs, but important differences exist.^{13,14} In both cases, DF analysis was retrospective and used a limited mapping and different ablation strategies. Prior to ablation, Lazar *et al.*¹³ did not find a significant LA-to-RA gradient in persistent AF patients, probably due to lower mapping resolution. Nevertheless, in agreement with our results, individual persistent AF patients demonstrating LA-to-RA DF gradients had a better outcome with PV isolation. Lemola *et al.*¹⁴ found that both CPVI and CFAE ablation, reduced DFs in the LA and the CS. However, only a significant frequency reduction in both atria (as assessed by DFs measurement on lead V1) following CFAE ablation was associated with long-term freedom of AF. These results emphasize the need for extensive atrial mapping to detect and ablate extra-pulmonary DFmax sites in persistent AF.

Clinical implications

The strategy of combining CPVI and DFmax site ablation may be particularly useful in two situations. First, in persistent AF patients, this pathophysiologically-based strategy enables selective ablation of sites responsible for AF maintenance, reducing the risks imposed by extensive empirical ablation procedures. Second, in paroxysmal AF patients it facilitates source identification when an extra-pulmonary source is suspected. Nevertheless, newer mapping and ablating techniques are still needed to enhance DFmax site identification and facilitate ablation at challenging anatomical sites (e.g., LAA).

Limitations

This work is limited by being an observational single center study. Further studies will be needed to confirm the impact of DF gradient elimination on AF ablation outcomes regardless of the strategy. Yet, our results may serve as the basis for a future randomized clinical trial comparing our strategy versus standard CPVI. Second, the sequential data point acquisition prolonged mapping and procedure time may raise concerns regarding spatio-temporal stability. However, results in repeat procedures point to an acceptable long-term stability of DF. A better outcome after *all* DFmax sites ablation would be required to confirm role of DF sites in AF maintenance. Finally, we cannot rule out the presence of DFmax sites outside the mapped regions but this may only have an impact in persistent AF cases.^{8,9}

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Figure 1.

A, Real-time atrial DF map (posterior view; CARTO system) in a paroxysmal AF patient. Purple, primary DFmax site (red arrow) on right intermediate PV (RIPV). Red dots, circumferential ablation line. B, bipolar recording (top) of primary DFmax site and its power spectrum (bottom) prior to ablation. C, surface ECG leads and intracardiac lasso catheter electrograms within RIPV; ablation catheter in the encircled area, CS and HRA catheter during isolation of right-sided PVs. Catheters recording outside the encircled area (CS, HRA) show conversion to SR (star) whereas the lasso catheter inside RIPV demonstrates ongoing AF.

Figure 2. Spatial distribution of DFmax sites in paroxysmal and persistent AF patients grouped in four regions: PV-PLAW, LA, RA, and CS.

Paroxysmal AF

Figure 3.

Regional DFmax following ablation in paroxysmal AF patients in relation to long-term freedom from AF. A. DFmax in LA, RA and CS and LA-to-RA gradient were all significantly reduced in AF free (right) compared with recurrent AF patients (left). B. Right, LA-to-RA DF gradient disappeared following ablation. Left, in patients with recurrent AF, maximal regional DFs were significantly reduced in LA only, with no significant change in LA-to-RA gradient.

Figure 4.

Regional DFmax following ablation in persistent AF patients in relation to long-term freedom from AF. A. Right, AF-free patients had a significant reduction in maximal regional DF in both LA and RA. Left, in patients with recurrent AF, DF was reduced in LA and CS only. B. LA-to-RA DF gradient was abolished in AF-free patients (right) but not in patients with recurrent AF (left). The presence of a LA-to-RA gradient at baseline was predictive of freedom from AF.

Figure 5. DF maps in a persistent AF patient; LA posterior view. A, Prior to ablation. B, Prior to redo procedure. Purple, primary DF site on the LA posterior wall. Note close correlation between both maps regarding primary DF site location (posterior LA wall) and maximal DF values at primary DF site.

Figure 6. DF maps in paroxysmal AF patient. A, prior to ablation. A DFmax site was identified in LIPV. Significantly lower frequencies are recorded in the other chambers, confirming the LA-to-RA DF gradient at baseline. B, immediately after DFmax site ablation and CPVI. Note significant reductions in DFmax in all chambers, with shift in DFmax to LAA.

Figure 7.

DF maps in a persistent AF patient. A, prior to ablation. A DFmax site was identified in the right superior PV (red arrow). B, Immediately after DFmax site ablation and CPVI. Significant reduction in DF is observed in all chambers, with a shift in DFmax to the RAA. No electrical signals are recorded inside the encircled veins.

Table 1

Patient Characteristics

	Paroxysmal AF (n=32)	Persistent AF (n=18)	p-value
Age (years)	52.8±11.3	50.3±11	0.52
Male (%)	24 (75%)	13 (72%)	0.83
Body mass index (kg/m ²)	26.6±3.1	30.5±7.5	0.06
Structural heart disease	1 (11%)	8 (44%)	0.001
First AF episode			
<1 year	3 (9%)	2 (12%)	
1–3 years	3 (9%)	2 (12%)	
>3 years	26 (82%)	13 (76%)	0.92
Sustained AF duration (months)	NA	19.9±11	-
Left atrial size (mm)	40.7±6	47.5±6	<0.001
Left atrial area (cm ²)	18.8±3.1	26.3±7.2	<0.001
Right atrial area (cm ²)	16.4±2.7	22.4±8.5	0.004
LV ejection fraction (%)	59.2±7	48.8±12.4	<0.001
Number antiarrhythmic used	2.1±0.9	2±1	0.65

NA, not applicable; AF, atrial fibrillation; LV, left ventricle.