**Sites with Small Impedance Decrease During Catheter Ablation for Atrial Fibrillation are Associated with Recovery of Pulmonary Vein Conduction**

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**Running Title**: Impedance Decrease During AF Ablation

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**Abstract**

**Objective**: To correlate impedance decrease during atrial fibrillation (AF) ablation with lesion durability and PV conduction recovery demonstrated during redo procedures.

**Background**: Markers of successful ablation beyond acute conduction block are needed to improve durability of pulmonary vein (PV) isolation. Local impedance decrease resulting from ablation is a real-time marker of tissue heating and is correlated with lesion creation.

**Methods**: Impedance changes associated with point-by-point radiofrequency ablation in the PV antra were recorded during 167 consecutive first-time AF ablations. During clinically indicated redo procedures, sites of recovered PV conduction were identified, and were correlated with the impedance change achieved during ablation at these locations during the initial procedure.

**Results**: Redo procedures were performed in 28 patients, in whom 19 sites of recovered PV conduction were documented. Most sites of PV reconnection (58%) occurred along the posterior PV antra. Ablation resulting in impedance decrease <10 ohms during the initial procedure was present in 89% (17/19) of sites with conduction recovery. Regions with adjacent ablation resulting in impedance decrease <10 ohms were associated with a higher rate of conduction recovery (37% vs. 1.5%, $p<0.001$). Likewise, patients with PV conduction recovery demonstrated during redo procedure (Group 1) had larger regions where ablation resulted in <10 ohm impedance decrease than patients without PV conduction recovery (Group 2) ($21.9 \pm 15.5$ mm vs. $11.5 \pm 2.1$ mm, $p<0.01$).

**Conclusion**: Recovered PV conduction occurs predominantly in regions where adjacent ablation applications result in impedance decreases <10 ohms. Impedance-guided ablation strategies may improve durability of PV isolation.

**Keywords**: atrial fibrillation; catheter ablation; impedance decrease; impedance-guided ablation; pulmonary vein conduction recovery; pulmonary vein isolation

**Introduction**

Pulmonary vein (PV) isolation (PVI) is the standard goal of ablation for atrial fibrillation (AF). However, PV conduction recovery continues to be considered the primary factor responsible for the development of recurrent atrial arrhythmias, despite acute PVI achieved at the time of ablation.(1,2) Acute conduction block is therefore an insufficient endpoint for catheter ablation of AF.(3,4) Ablation strategies that promote more durable PVI are expected to improve outcomes.

Transient conduction block in the PVs after initial ablation, either due to stunned atrial myocardium resulting from inadequate local energy application or edematous tissue,(5) may mask the need for further ablation to achieve permanent conduction block. Real-time markers of adequate lesion creation would be useful to guide effective radiofrequency (RF) delivery, avoid recovery of PV conduction, and thereby improve the long-term efficacy of AF ablation.

Impedance decrease resulting from RF delivery is a real-time marker of tissue heating. As tissue temperature rises during RF ablation, ions within the tissue being heated become more mobile, resulting in a decrease in impedance to current flow.(6) Lesion diameter and depth have been shown to correlate well with impedance decrease, with an even more direct relationship than measured temperature.(7-9) We have recently reported the feasibility of performing PVI guided by close impedance monitoring with an irrigated RF ablation catheter; by ensuring an impedance decrease of at least 5 ohms in the first 10 seconds of ablation at each ablation site, 84% of patients with paroxysmal AF remained free of recurrent atrial arrhythmias after 431±87 days.(10) Based on further experience and observational data that additional lesion maturation may occur even after the initial impedance attenuation is observed,(11) we have subsequently determined that an impedance decrease of 10 ohm during ablation for up to 30 seconds at a stable location is a reasonable goal for adequate lesion creation and is associated with acceptable safety.

In this study, we hypothesized that lesions with an impedance decrease of <10 ohms during initial AF ablation would correlate with sites of PV conduction recovery during clinically indicated redo procedures. Conversely, we sought to demonstrate that greater impedance changes during ablation correlate with durable conduction block.

**Methods**

***Study population***

A total of 167 consecutive patients undergoing first-time AF ablations for paroxysmal or persistent AF performed over a 2-year period between October 2012 (when impedance measurements began being routinely recorded in our laboratory) and October 2014 were retrospectively evaluated. The patients underwent electrophysiologic study and catheter ablation after providing written informed consent. The study protocol was approved by the institution's Human Subject Protection Committee. Patients with prior left atrial ablation or surgery for AF were excluded. All patients who demonstrated recurrence of AF or atrial tachycardia after the initial 3-month blanking period were offered a repeat procedure (redo). Only patients who had their initial and redo ablation procedure at our institution were included.

***Index Ablation Protocol***

Ablation was performed under general anesthesia using either the Thermocool SF catheter or Thermocool SmartTouch contact-force sensing catheter (Biosense Webster, Diamond Bar, CA), delivered via a steerable sheath (Agilis NxT, St. Jude Medical, St. Paul, MN). Electroanatomic 3-dimensional mapping was performed using the Carto 3 system (Biosense-Webster, Diamond Bar, CA) with integration of intracardiac ultrasound (Carto Sound). A double transseptal approach was used with a mapping catheter positioned within the PV ostium during antral ablation. Detailed left atrial geometry was collected with a multispline (PentaRay NAV, Biosense Webster) or circular (Lasso NAV, Biosense Webster) mapping catheter. Ablation lesions were delivered in a power controlled mode (Stockert, Freiburgy, Germany). Power delivery was typically set at 30 Watts during ablation in the left atrium and was reduced to 15-25 Watts for ablation on the posterior wall in lesions adjacent to the esophagus. The location of the esophagus relative to the pulmonary vein antra was determined based on ultrasonographic reconstruction of the esophagus on the electroanatomic map and/or appreciation of esophageal temperature rise > 0.2 degrees Celsius during ablation on the posterior left atrial wall.

Real-time impedance was monitored using a dedicated window on the Carto 3 mapping system, with a scale ranging 50 ohm centered around the starting impedance, in order to accurately evaluate impedance changes with ablation. Impedance, power, and temperature were continuously recorded with a sampling frequency of every 100 milliseconds, and were later exported for data processing. Fluctuations in impedance relating to respiratory motion were accounted for by using impedance values measured in the same phase of the respiratory cycle at the start and end of ablation application. Ablation applications were delivered in a sequential, point-by-point fashion, and efforts were made to avoid "dragging" lesions at consecutive sites without interruption of ablation. All ablation applications were guided primarily by close monitoring of impedance changes with ablation, with the goal of achieving a ≥10 ohm impedance decrease during ablation at each catheter location, regardless of electrogram amplitude or measured contact force (contact force sensing catheters were used in only 13 of 167 initial ablations). Ablation was continued for a total RF application duration of up to 30 seconds until plateauing of the impedance curve was observed. Ablation was performed in the PV antra until both entrance and exit conduction block was demonstrated in all pulmonary veins.

RF ablation applications were tagged on the electroanatomic map with round markers 2 mm in diameter. Sequential lesions were applied in the PV antra with the goal to place the center of adjacent ablation marker within 3 mm. Visual gaps in the line were defined as a space between the edges of ablation lesions in the PV antra greater than 2 mm (i.e., the diameter of a single ablation marker) without any intervening ablation marker. Gaps were retrospectively measured on the electroanatomic map as the distance between the centers of adjacent ablation markers.

Ablation lesion markers were color-coded based on the impedance decrease achieved during ablation: a red ablation marker represents ≥10 ohm impedance decrease in ≤ 30 seconds of ablation, a pink lesion marker represents an impedance decrease of 5-9 ohms, and a white marker represents an impedance decrease < 5 ohms (**Figure 1**). Efforts were made to terminate low impedance lesions (<10 ohms) and re-orient the catheter to achieve better tissue contact. Lesions with impedance decrease between 5 and 10 Ohms were later tested with pacing (10 mA @ 2 ms) to determine whether additional lesions should be applied to render the ablation line unexcitable. Because of the proximity of the esophagus to the LA posterior wall, no further ablation was performed at some lesion sites on the posterior wall that continued to demonstrate low impedance and pace excitability.

***Redo Ablation***

During clinically indicated redo procedures, sites of recovered PV conduction were identified based on activation mapping into the PVs during sinus rhythm or atrial pacing, or by the location of ablation resulting in successful re-isolation of the PV. In order to categorize the site of recovered PV conduction, each ipsilateral pair of PVs was segmented by visual inspection into 4 sections along the PV antra (anterior, superior, posterior and inferior) as shown in Figure 2. In the case of a common ostium, segmentation was performed along the antrum in the same manner. Patients with non-interpretable electroanatomic maps on retrospective analysis were excluded.

**Correlation of Impedance Decrease with Lesion Durability**

Patients demonstrating any PV conduction recovery at the redo procedure were labeled Group I, and were compared to patients in whom all PVs remained electrically isolated during the redo procedure, as confirmed by entrance and exit block demonstrated prior to any ablation (Group II). Among patients in Group I, the locations of recovered PV conduction were correlated with the impedance decrease achieved during ablation at these locations during the initial procedure. The initial procedure maps, from patients in both groups I and II, were reviewed to identify regions of ablation in the PV antra with impedance decrease <10 ohms (indicated from index ablation map by white or pink markers) and any visual gaps > 2 mm between adjacent ablation lesions. Analysis of the sites of PV reconnection in Group I patients was performed independently and blinded to impedance analysis.

***Statistical Analysis***

Continuous variables are presented as mean ± standard deviation. Categorical variables are presented as numbers and percentages. Continuous variables were compared with the Mann-Whitney U test, and categorical variables using the Pearson chi-square test, or the Fisher's Exact test in cases where the expected value was less than 5 in any cell. All hypothesis testing was two-tailed and a p-value of less than 0.05 was considered statistically significant. All statistical analyses were performed using SPSS for Windows (SPSS Inc., Chicago, IL).

**Results**

Among 167 consecutive ablations for AF (mean 60.1 years, 68% male, 61% paroxysmal), redo procedures were performed in 28 patients (17%) who experienced symptomatic recurrent atrial arrhythmias. Of these, 6 patients (4 with recurrent PV conduction and 2 without) were excluded from analysis due to unavailable electroanatomic maps (3), poor quality map at redo precluding identification of the region of reconnection (1), incomplete PVI at the initial procedure (1), or inability to assess impedance decreases at the initial procedure due to deviation from a point-by-point ablation technique (1). Of the remaining 22 patients, 15 patients (68%) had recovered conduction into at least one PV documented at redo procedure (Group I), and 7 patients (32%) had no recovery of PV conduction (Group II). Patients in both groups had similar baseline characteristics, though patients in Group II underwent more extra-PV substrate ablation during the initial procedure, consistent with the presence of non-PV sources of arrhythmia recurrence in Group II patients (**Table 1**).

**Location of Pulmonary Vein Conduction Recovery**

Among 15 patients included for analysis in Group I, 19 sites with recovered conduction into the PVs were documented during redo procedures (1.3 sites per patient). Recovered PV conduction most commonly occurred in the posterior antrum of the PVs 58% (11/19), including 8 sites in the posterior right PV antrum, and 3 sites in the posterior left PV antrum). The remaining sites of PV reconnection were in the anterior antrum of the right PVs (3), superior antrum (roof) of the left PV (2), roof of the right PV (1), and anterior antrum of the left PVs (1), **Figure 2**.

**Correlation between Impedance Fall and Sites of Pulmonary Vein Reconnection**

Among patients in Group I, sites of recovered conduction into the PVs correlated with low impedance decrease achieved at the initial ablation. Local ablation applications with an impedance decrease < 10 ohms were present at 89% (17/19) of sites with conduction recovery. Impedance decrease < 5 ohms were observed in 74% (14/19) of these sites. Analysis of ablation performed during initial procedures at sites of subsequent conduction recovery typically showed >1 adjacent ablation applications resulting in impedance decrease <10 ohms (mean 5.6, range 1-12, adjacent RF applications), creating a distance of 21.9 ± 15.5 mm between lesions with ≥ 10 ohm impedance decrease at the site of conduction recovery (**Figure 3**). In addition, visual gaps between ablation lesions were present at or adjacent to (within 3mm) the site of conduction recovery in 4 patients, with an average length of gaps of 7.5 ± 1.3 mm.

Regions in the PV antra with >1 adjacent ablation resulting in impedance decrease < 10 ohms had significantly higher likelihood of PV conduction recovery in that region. When initial AF ablation lesions were evaluated by segmented region of ablation in the PV antra (i.e. 4 sections per ipsilateral pair of PVs, 8 sections per patient, see **Figure 2**), 46 of 176 sections (26%) were found to have adjacent RF applications with less than 10 ohm impedance decrease during the initial ablation. Among these, 17 of 46 (37%) had recovered PV conduction within these regions identified during redo procedures, compared to only 2 sites with recovered PV conduction among 130 sections (1.5%) without consecutive sites of ablation with impedance decrease <10 ohm ($p<0.0001$). Accordingly, the positive predictive value for consecutive ablations with impedance decrease < 10 ohms correlating with PV conduction recovery in that region was 37%, and the negative predictive value was 98%, indicating ablation with impedance decrease ≥ 10 ohm had a predictive value over 98% for the absence of pulmonary vein conduction recovery in our study (Table 2). The 2 sites of conduction recovery despite ablation with impedance decrease > 10 ohms occurred on the interatrial septum along the anterior right PV antrum, as discussed below.

**Comparison of Ablation Lesion Characteristics Between Groups**

In Group II, no PV conduction recovery was seen at redo procedure. As shown in **Table 3**, patients in Group II had either absent or smaller regions with impedance decrease <10 ohms during the initial ablations compared to patients in Group I (see example **Figure 4**). Among patients in Group I, there were 3.2 ± 2.4 regions with impedance decrease <10 ohms per patient, with an average distance of 18.0 ± 11.2 mm between adequate lesions. In contrast, among patients in Group II, there was an average of 2.4 ± 1.7 regions per patient in which ablation resulted in suboptimal impedance falls, spanning a distance of 11.5 ± 2.1 mm per region ($p<0.01$ for length of region with adjacent ablations with <10 ohm impedance falls).

There was no difference between the groups in the presence of visual gaps, in which a separation of at least 2 mm was present between adjacent ablation lesions. Visual gaps were observed between noncontiguous lesions in 1.2 ± 1.6 regions spanning a distance of 8.5 ± 2.6 mm per region in Group I, compared to 1.0 ± 1.2 spanning an average distance of 9.3 ± 0.6 mm per gap in Group II ($p=0.77$ for number of visual gaps; $p=0.41$ for length of gaps).

**Anatomic Considerations Associated with Impedance Changes**

The posterior PV antrum was the most common location of recovered PV conduction in this study. As presented on Table 3, among patients in Group I, the posterior right and left PV antra were also the most common locations where the target impedance decrease >10 ohms was not achieved during the initial ablation. At all of the posterior wall sites of conduction recovery, an impedance decrease <10 ohms was documented during the initial procedure (example, **Figure 5**). In most cases (7/11, 64%) where PV conduction recovery occurred in the posterior wall, the esophagus was in close proximity to ablation in that region, as determined by either direct visualization of the esophageal course on intracardiac echo (CARTOSound®) or by acute esophageal temperature rise >0.2 degrees during ablation.

Two sites of PV conduction recovery occurred in the anterior right PV antrum despite >10 ohm impedance decrease during the index ablation and no visual gap. One possible explanation may be thick atrial myocardium in the septum, in which a 10 ohm fall did not correlate with a transmural lesion. In one of these patients, the septal thickness at the site of conduction recovery was measured to be 7.2mm (based on distance between adjacent right and left atrial ablation markers), and conduction block at this site during the redo required a long duration lesion from the right atrial septum (30W, 72 seconds, achieving 20 ohm impedance decrease, **Figure 6**).

**Discussion**

This study demonstrates that recovered PV conduction occurs almost exclusively in areas where adjacent RF applications result in impedance decreases <10 ohms, and these regions are significantly more likely to have PV conduction recovery than regions in which ≥ 10 ohms impedance decrease was consistently achieved. Furthermore, patients with durable PVI had smaller regions with low (<10 ohm) impedance decreases with ablation compared to patients with recovered PV conduction. In contrast, small visual gaps between lesion markers had no correlation with PV conduction recovery in this study, assuming the surrounding ablation applications resulted in > 10 ohm impedance decrease. Though not all sites with lesser impedance decreases correlated with PV conduction recovery, in the presence of an impedance decrease >10 ohms conduction recovery was rare. These findings indicate that an impedance decrease ≥ 10 ohms during radiofrequency delivery may represent a specific marker of durable lesion formation in thin atrial tissue, allowing an operator to alter modifiable factors such as contact force, catheter orientation, or power in order to achieve this end point.

In this series, the only 2 sites of PV conduction recovery that did not correlate with an impedance decrease < 10 ohm were found in the interatrial septum along the anterior aspect of the right PVs where the thickness of atrial myocardium can be substantial. In such locations a 10 ohm impedance decrease may not reliably indicate sufficient tissue heating to create a transmural lesion.

The most common site of PV conduction recovery identified during redo procedures was found to be in the posterior antra of the right and left PVs. Due to the close vicinity of the esophagus and esophageal temperature rise with ablation, RF ablation is often delivered more conservatively with lower power or duration, and may be prematurely terminated, at such posterior wall locations. Restricted ablation application may explain the lower impedance decreases achieved in this region. Indeed, in most cases (7/11, 64%) where PV conduction recovery occurred in the posterior antra, the site of ablation was demonstrated to be in close proximity with the esophagus, either by intracardiac echocardiography or by the observation of esophageal temperature rise with local ablation. Ablation strategies to facilitate more durable and safe lesion formation in these precarious sites, such as short duration or repetitive ablation application with higher contact force, need further evaluation.

As PV conduction recovery remains common despite achievement of acute PVI, additional procedure endpoints beyond acute conduction block are needed to create durable PVI. Commonly used surrogates for lesion creation such as electrogram amplitude diminution and catheter tip temperature do not correlate well with durable lesion formation, particularly with irrigated ablation catheters.(8) Ensuring non-excitability to pacing along the ablation line has been shown to be a useful parameter to lower the risk of AF recurrence after PVI,(12) but despite this non-excitability cannot reliably distinguish tissue that has been stunned from tissue that will be permanently scarred.(5) In contrast, impedance decrease is a quantifiable real-time measure of tissue damage. Experimental studies have shown that an impedance decrease at least 10 ohm is associated with tissue temperature of at least 60 degrees Celsius, with a specificity of over 70%, and even higher specificity for greater impedance falls. Impedance decrease has also been directly correlated with lesion diameter and depth,(8) as well as with effective lesion creation during ablation.(8,13) As demonstrated by this study, impedance decreases <10 ohms at adjacent ablation sites may indicate the need for further ablation to avoid early conduction recovery, if it is safe to do so relative to collateral structures such as the esophagus.

The routine use of contact force sensing catheters now allows optimization of the catheter-tissue interface and has improved clinical outcomes and safety.(14) Indeed, increased catheter-tissue contact has been associated with a larger impedance decrease during RF ablation,(7,9,15,16) and in the absence of catheter-tissue contact, an impedance decrease of 10 ohms cannot be achieved.(7) However, contact force is only one of several factors associated with lesion creation (in addition to ablation power, duration, surface area, etc), and when measured in isolation may not indicate effective tissue destruction. Furthermore, measurement of average contact force alone may actually be misleading when catheter stability or tip orientation is poor (unpublished data, G Michaud). A recent study found a significant difference in impedance decrease, but not contact force or force-time integral, between adequate and inadequate ablations.(17) Since contact force is modifiable prior to ablation delivery using available force-sensing catheters, applied contact may be considered an important predictor of adequate tissue heating, whereas a ≥10 ohm resultant impedance decrease indicates that such heating has occurred and a durable lesion is likely.

**Limitations**

This retrospective evaluation did not systematically evaluate all factors that may be associated with durable lesion creation. Other ablation related markers, such as electrogram diminution or catheter tip stability by intracardiac echo were not evaluated at sites with eventual conduction recovery. Furthermore, index ablations evaluated in this study were almost universally performed with non-contact force sensing catheters, making correlation of impedance change and contact force applied at sites of reconnection unavailable. Impedance measurements may be influenced by several factors beyond local tissue characteristics including individual characteristics in the chest, indifferent electrode position and hemodynamic conditions, and measurable impedance change may be seen with a large rise in tissue temp at a small contact area and a small rise in temp at a larger tissue contact;(18) however, the decrease in impedance during RF ablation is almost entirely due to variation in local tissue impedance.(19) While impedance changes with ablation are not correlated to AF recurrence rates in this retrospective analysis, the identification of PV conduction recovery during redo procedures provides an objective method to assess the technical success of this ablation strategy.

**Conclusion**

Despite acutely successful PVI, recovery of PV conduction remains commonly identified during redo procedures, and typically occurs at sites in which adjacent RF applications result in impedance decrease of <10 ohms during the initial ablation. Although several factors such as energy application, catheter tip contact and local tissue properties at the site of ablation may affect lesion creation, an impedance decrease ≥10 ohms indicates local tissue heating has occurred, and is a specific marker for durable ablation success in most atrial tissue. Impedance decrease with ablation may be used as an additional endpoint beyond acute conduction block in order to predict durability of PVI.

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**Figure Legend**

**Figure 1.** During AF ablation procedures, ablation markers were applied on the electroanatomic map in a color-coded fashion indicating magnitude of impedance decrease with ablation. Red markers indicate ≥10 ohm impedance decrease, pink 5-9 ohm decrease, and white <5 ohms decrease. In the presented graphs, impedance during ablation is shown in green, with impedance scale (green text) presented on the Y-axis, and time on the X-axis. Dashed white lines represent starting and ending impedance values, and the change in impedance during ablation (starting impedance – ending impedance) is also specified. Catheter tip temperature (in degrees Celcius) is presented in the Y-axis in red.

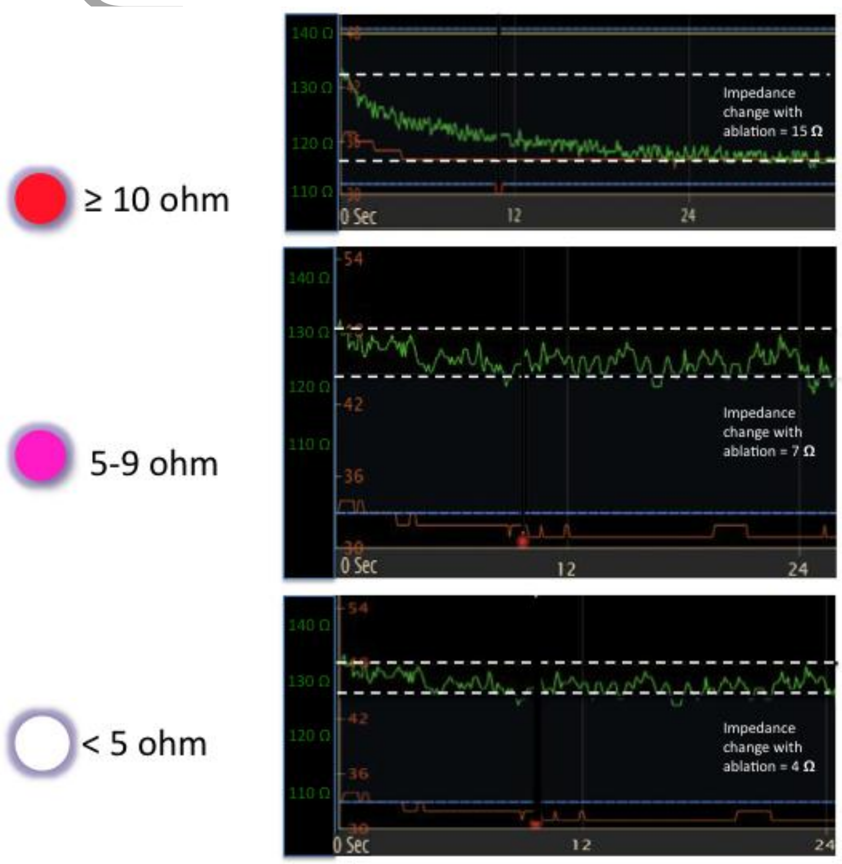

**Figure 2**. Locations of PV conduction recovery identified during redo procedures. Each ipsilateral pair of pulmonary veins are divided into 4 sections: superior, posterior, inferior, and anterior.

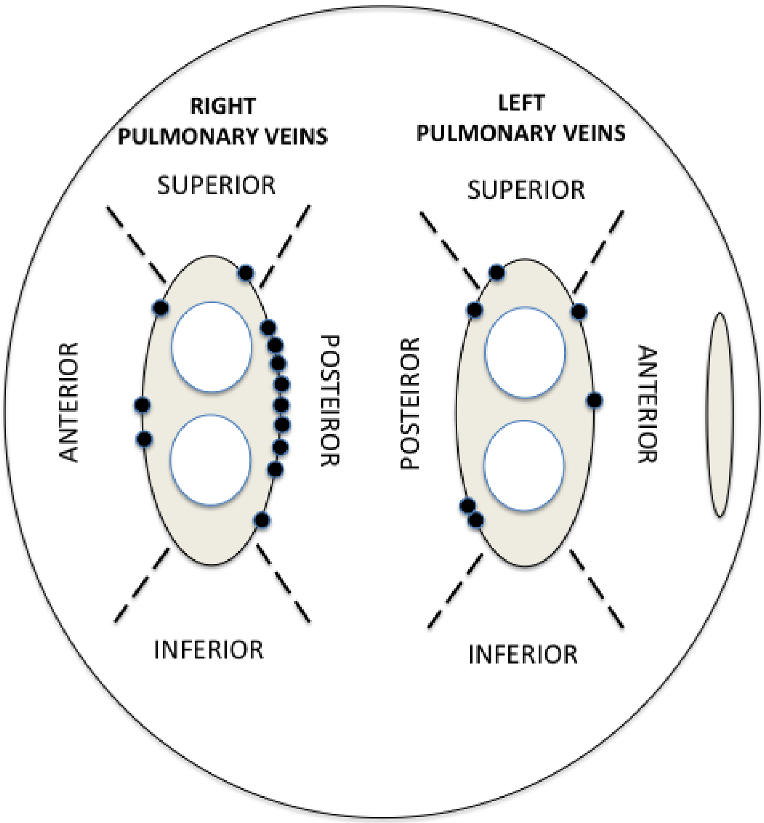


**Figure 3. A**: Example of an electroanatomic map from an initial AF ablation. Red ablation markers indicate where ablation resulted in impedance decrease ≥10 ohms, pink markers indicate locations where ablation resulted in a 5-9 ohm impedance decrease, and white markers indicate impedance decrease of <5 ohms with ablation. **B:** Activation map from the redo procedure on the same patient demonstrating recovered conduction along the posterior right PV antrum, correlating with the region of pink ablation markers from the initial procedure (indicating impedance decrease <10 ohms with ablation in this location).

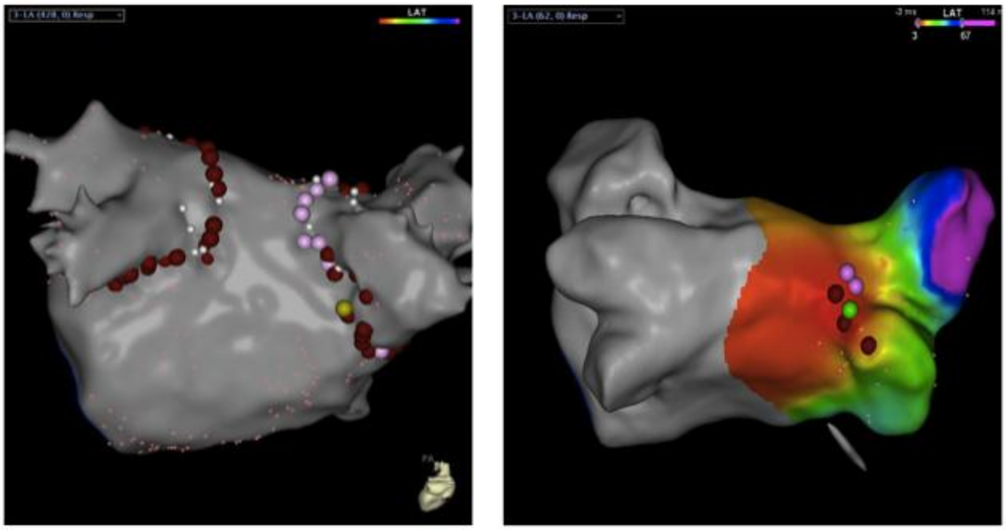


**Figure 4**. Example of the electroanatomic map from an initial ablation in a patient in Group 2, in whom persistent PV isolation was found during the redo procedure. During the initial ablation, all ablation applications in the PV antra had a ≥10 ohm impedance decrease, indicated by red ablation markers. Arrow points to one such lesion along the anterior right PV antrum. The impedance curve (green line) from ablation at this location is shown below; the impedance scale (in ohms) is presented on the Y-axis on the right side of the graph (green text). Dashed white lines represent starting and ending impedance values, and the change in impedance during ablation is specified. Duration of ablation is presented on the X-axis, and catheter tip temperature (in degrees Celcius) is also presented in the Y-axis in red.

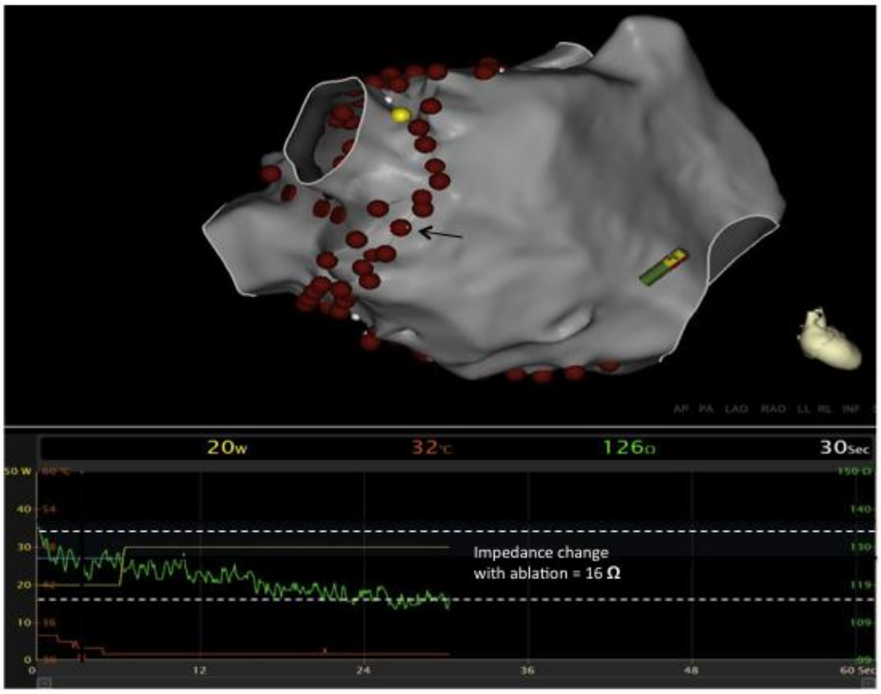


**Figure 5.** Electroanatomic map integrating intracardiac echocardiography to reconstruct the anatomy of the left atrium and esophagus (turquoise structure), demonstrating position of the esophagus overlying the posterior aspect of the right PVs. Ablation lesions in this region were applied with caution (20W, <20 seconds), and consequently adjacent lesions achieved impedance decreases <10 ohm (indicated by pink markers).

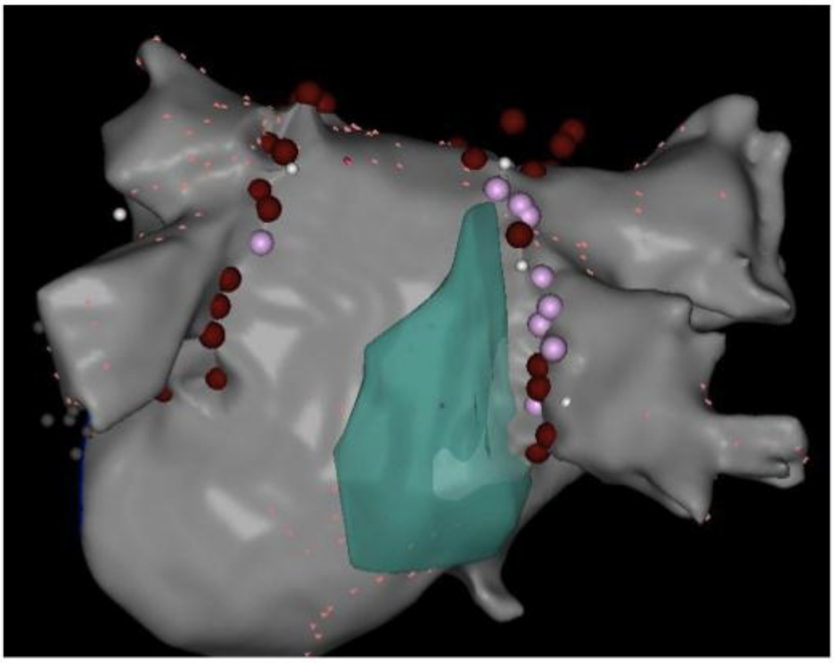



**Figure 6.** Electroanatomic map from an initial ablation in which isolation of the right PVs required ablation along both sides of the interatrial septum, with prolonged energy applications. The distance between ablation applications on the right and left side of the interatrial septum is 7.2 mm, indicating the thickness of the septum in this location. During the redo procedure in this patient, recovered conduction into the right PVs occurred at this thick region of the interatrial septum. The impedance graph from the initial ablation at this location shown below, demonstrating ablation with energy set at 30 Watts, duration 72 seconds, with an associated impedance decrease of 17 ohms. On the graph, impedance curve is shown in green, with the impedance scale (in ohms) presented on the Y-axis on the right side of the graph. Dashed white lines represent starting and ending impedance values, and the change in impedance during ablation is specified. Duration of ablation is presented on the X-axis, and catheter tip temperature (red) and ablation power (yellow) are also displayed on the Y-axis on the left side of the graph.

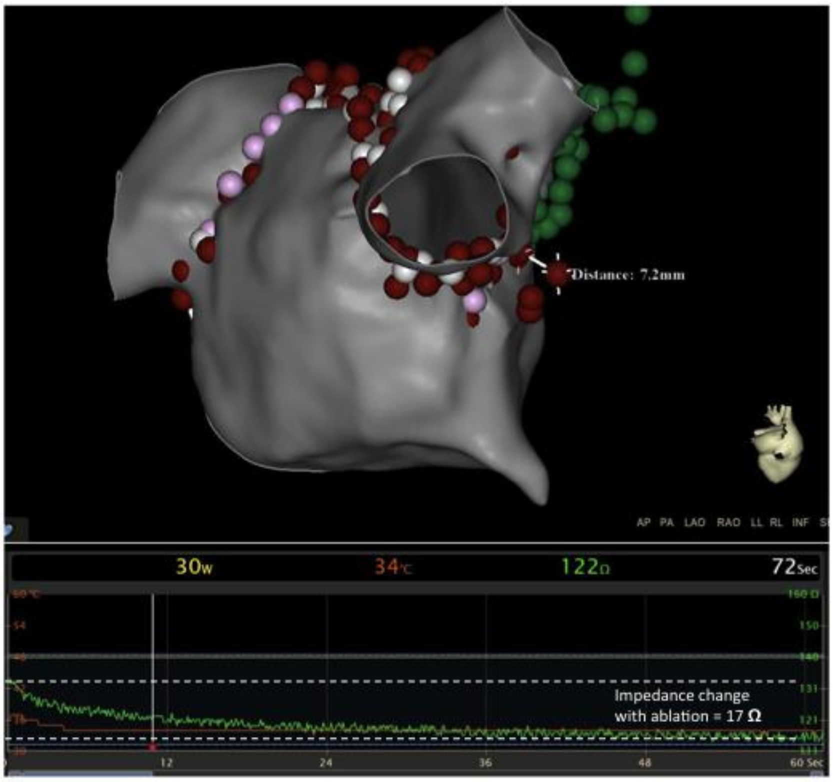




**Table 1**. Clinical characteristics

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| | Group I (n=15) | Group II (n=7) | p |
|---|---|---|---|
| **Clinical** | | | |
| *a)* Age | 55.1 ±12.3 | 63.6±8.9 | 0.12 |
| Male | 67% (10) | 43% (3) | 0.37 |
| Paroxysmal | 73% (11) | 57% (4) | 0.63 |
| Congestive heart failure | 14% (2) | 50% (3) | 0.13 |
| Hypertension | 60% (9) | 43% (3) | 0.65 |
| Dyslipidemia | 40% (6) | 14% (1) | 0.35 |
| Diabetes Mellitus | 0 | 14% (1) | 0.32 |
| Chronic Kidney Disease | 0 | 0 | 1.0 |
| Sleep apnea | 13% (2) | 14% (1) | 1.0 |
| Prior stroke or TIA | 7% (1) | 0 | 1.0 |
| Vascular disease | 7% (1) | 17% (1) | 0.52 |
| ***Imaging*** | | | |
| LVEF | 58.1±4.4 | 54.8±10.8 | 0.33 |
| LA enlargement | 53% (8) | 83% (5) | 0.65 |
| LA diameter | 4.0±0.6 | 4.9±1.0 | 0.06 |
| Mitral Regurgitation (> Mild) | 0 | 29% (2) | 0.09 |
| **Index Ablation Strategy** | | | |

| | | | |
|---|---|---|---|
| Acute PVI achieved | 100% (15) | 100% (7) | 1.0 |
| CTI line | 53% (8) | 43% (3) | 1.0 |
| Mitral isthmus line | 7% (1) | 57% (4) | **0.02** |
| LA roof line | 53% (8) | 100% (7) | 0.05 |
| CFAE ablation | 20% (3) | 29% (2) | 1.0 |
| Posterior wall isolated | 0 | 43% (3) | **0.02** |
| Cardioversion performed | 7% (1) | 29% (2) | 0.23 |
| **Clinical Recurrence/Redo ablation** | | | |
| Recurrent arrhythmia | | | |
| AF | 80% (12) | 43% (3) | 0.14 |
| AT | 20% (3) | 57% (4) | 0.14 |
| Time from index ablation to redo (days) | 320±159 | 273±165 | 0.53 |

**Table 2**. Contingency table correlating impedance decrease with pulmonary vein conduction recovery in each region. Positive predictive value for consecutive ablations with impedance decrease < 10 ohms correlating with PV conduction recovery = 37%, negative predictive value = 98%; sensitivity = 89%, and specificity = 82%.

| | **PV conduction recovery** | **No PV conduction recovery** | ***Total*** |
|---|---|---|---|
| **<10 ohm decrease with ablation** | 17 | 29 | *46* |
| **≥10 ohm decrease with ablation** | 2 | 128 | *130* |
| ***Total*** | *19* | *157* | *176* |

**Table 3.** Comparison of Ablation Lesion Characteristics Between Groups

| | Group I (n=15) | Group II (n=7) | p |
|---|---|---|---|
| | | | |
| *b)* | | | |
| Number of regions with <10 ohm impedance decrease ablations | 3.2 ± 2.4 | 2.4 ± 1.7 | 0.46 |
| Length of regions with low impedance decrease (mm) | 18.0 ± 11.2 | 11.5 ± 2.1 | **<0.001** |
| Number of gaps between adjacent ablation lesions | 1.2 ± 1.6 | 1.0 ± 1.2 | 0.77 |
| Length of gaps (mm) | 8.5 ± 2.6 | 9.3 ± 0.6 | 0.41 |
| Location of consecutive ablations with low impedance decrease | | | |
| Left PV Anterior | 33% (5) | 29% (2) | 1.0 |
| Left PV Superior | 7% (1) | 0 | 1.0 |
| Left PV Posterior | 60% (9) | 14.3% (1) | 0.07 |
| Left PV Inferior | 20% (3) | 29% (2) | 1.0 |
| Right PV Anterior | 13% (2) | 0 | 1.0 |
| Right PV Superior | 27% (4) | 43% (3) | 0.63 |
| Right PV Posterior | 73% (11) | 0 | **0.004** |
| Right PV Inferior | 13% (2) | 14% (1) | 1.0 |