ATRIAL FIBRILLATION

INNOVATIVE & EMERGING TECHNIQUES

Approaches for Focal Impulse and Rotor Mapping in Complex Patients: A US Private Practice Perspective

HAROON RASHID, MD, FACC and AMY SWEENEY, RN, BSN

Virginia Heart, Heart Rhythm Center, Falls Church, VA

ABSTRACT. The long-term clinical success of atrial fibrillation (AF) ablation remains relatively low in certain difficult-to-treat patient groups such as those with persistent AF. As a result, pulmonary vein isolation with substrate-based ablation approaches are being utilized in an effort to improve long-term outcomes in such patients. In hopes of improving long-term clinical outcomes in complex AF patients, focal impulse and rotor mapping (FIRM)-guided rotor ablation was incorporated in our practice over 1 year ago. Our purpose is to present some practical considerations from a series of patients with primarily persistent AF and repeat ablation after failed pulmonary vein isolation with additional ablation undergoing their first FIRM-guided procedure. Our experience from 56 consecutive patients who underwent FIRM-guided rotor ablation over a period of approximately 1 year is described. The majority of patients consisted of those with persistent AF (34%), long-standing persistent AF (43%), large atria, and complex co-morbidities. AF rotors were identified with FIRM mapping in all patients (a mean of 3.4 ± 1.2 per patient). Non-paroxysmal AF was associated with a significantly higher number of rotors in both atria, and patients with either a failed prior ablation or enlarged left atrial volume had a significantly higher number of right atrial rotors. With a mean follow up of 7.7 ± 3.0 months, 82.1% of patients remained free of AF recurrence. Among the patients with non-paroxysmal AF, 79.1% remained free of AF recurrence. The mean procedure time was similar to other substrate-based ablation approaches. It is feasible to incorporate FIRM-guided rotor ablation in a non-academic community hospital setting for the treatment of complex AF in patients with good medium-term clinical outcomes and minimal impact on procedure time compared with other substrate-based ablation approaches.

KEYWORDS. Ablation, atrial fibrillation, FIRM, rotor, spiral wave.

Background

Although pulmonary vein isolation (PVI) has been considered the “cornerstone” of ablation for atrial fibrillation (AF) in patients particularly with paroxysmal AF,1,2 Ablation for AF beyond PVI for any connected PVs in patients who have failed previous PVI or have persistent AF with dilated left atrium remains a challenge. With no consensus regarding the ideal approach. In fact, the recently published data from the STAR-AF 2 trial demonstrates that empiric linear lesions and ablation of complex fractionated atrial electrograms (CFAEs) provide no benefit over standard PVI alone.3 Another approach has been to apply stepwise ablation with the goal of AF termination to sinus rhythm or atrial tachycardia (AT) by ablating different targets (e.g., PVI, CFAE, other triggers, etc.) in a stepwise manner, often performed over multiple procedures. Unfortunately, long-term success in these difficult to treat patients has often been below 50% despite vigorous ablation attempts4,5 that included PVI, combined with linear lesions and CFAE in many instances. Even with aggressive stepwise approaches,
FIRM mapping in atrial fibrillation

recent publications have suggested varied single-procedure results.\textsuperscript{4,5} Recent clinical studies, based upon animal and ex vivo human models suggest that rotors/focal sources are the mechanism for sustaining AF\textsuperscript{6–8} indicating that focal impulses and rotor mapping (FIRM) and ablation may be able to better treat atrial fibrillation in these patients.\textsuperscript{9,10}

In order to treat these complex AF patients better, we incorporated FIRM-guided ablation in our practice a year ago. Here we present some practical considerations and follow-up from a series of patients with primarily persistent atrial fibrillation and repeat ablation after failed PVI with additional ablation undergoing their first FIRM-guided procedure.

**Methods**

We describe our experience from 56 patients who underwent FIRM-guided ablation over a period of approximately 1 year since our first procedure. Table 1 details the characteristics of these patients. At the start of our experience, we selected patients we considered ablation refractory, specifically those who had failed previous ablations via other approaches including convergent surgical catheter-based ablation and remained refractory to anti-arrhythmic medications. As our experience developed, we also treated patients undergoing first procedures but who were considered complex due to drug-refractory persistent or long-standing persistent AF, large atria, and complex co-morbidities.

In our procedures, we have always used single plane fluoroscopy with three-dimensional (3D) electroanatomic mapping (NavX, St. Jude Medical, St. Paul, MN). Two transseptal punctures are then performed using long transseptal sheaths. Once therapeutic activated clotting time (ACT) levels are achieved (>300), the traditional mapping and ablation workflow for FIRM-guided ablation is performed as shown in Figure 1a, starting with placement of a direct contact multi-electrode (64 poles) basket (FIRMap, Abbott Electrophysiology, Topera, Menlo Park, CA) in the right atrium (RA) with RA rotor mapping (RhythmView, Abbott Electrophysiology, Menlo Park, CA) and ablation (Tacticath\textsuperscript{TM} – Quartz Contact Force Ablation Catheter), followed by moving the basket to the left atrium (LA) and performing LA rotor mapping and ablation. The FIRM mapping software utilizes an advanced computation approach to create activation trails focused on identifying sources of the arrhythmia such as rotors or focal sources (Figure 1c,d).\textsuperscript{11,12} After all sources in the RA and LA were sequentially eliminated via ablation, any necessary PVI was performed utilizing a circular mapping catheter (Achieve, Medtronic, Minneapolis, MN or Reflexion, St. Jude Medical, St. Paul, MN) for any veins electrically connected to the LA. In 17/56 (30.4\%) patients, where all four pulmonary veins demonstrated pulmonary vein potentials, Cryoballoon (Arctic Front, Medtronic) ablation was performed to isolate the pulmonary veins. Cavotricuspid isthmus (CTI) ablation was performed in patients who either had CTI flutter or had intact CTI conduction in order to minimize repeat procedures for typical flutter in patients who otherwise are free of AF. Finally, coronary sinus (CS) ablation was performed in those patients where AF had remained inducible with predefined induction protocol or had persisted after veins had been isolated and rotors had been eliminated in both the RA and the LA. This was done to eliminate any potential rotors from the CS that could not be mapped.

**Altered workflow in patients undergoing re-do ablations**

In our laboratory, after our initial experience with five patients, as illustrated in Figure 1b, we altered the FIRM workflow for greater efficiency in re-do patients. Rather than always performing FIRM mapping in the RA immediately, we would assess for PV reconnection immediately upon placement of the first transseptal sheath. If PVI was necessary, it was performed at this time, carrying out both assessment and PVI. The basket catheter was then placed into the LA for FIRM mapping and ablation before placement in the RA. Finally, FIRM mapping and ablation was performed in the RA until no further sources were identified. If AF was still present or inducible at this point, we would ablate the CS empirically to eliminate any potential rotors from the CS that could not be mapped. The reason we adopted this modified workflow was that it allowed us to efficiently proceed (e.g. PVI) while waiting for the ACT to reach full therapeutic levels that are required prior to basket catheter insertion. The basket catheter was not inserted before achieving an ACT of 300 s. and no ablation was performed in the LA when ACT levels were normal or low.

**Practical considerations: basket catheter sizing**

Because of the complexity of atrial anatomy, selecting the right basket for wide area mapping is essential to getting the best FIRM maps. Our approach has been to utilize both transesophageal echo (TEE) and intracardiac echocardiography (ICE). We focus on LA sizing as that is more complex and obtain measurements in two different

**Table 1: Patient characteristics of patients undergoing FIRM-guided ablation**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All patients (n = 56)</th>
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<tbody>
<tr>
<td>Age, years</td>
<td>65.7 ± 9.0</td>
</tr>
<tr>
<td>Male gender</td>
<td>42 (75)</td>
</tr>
<tr>
<td>LA volume (ml)</td>
<td>76.8 ± 26.7</td>
</tr>
<tr>
<td>LA volume index (ml/m(^2))*</td>
<td>36.7 ± 12.8</td>
</tr>
<tr>
<td>Type of AF</td>
<td></td>
</tr>
<tr>
<td>Paroxysmal</td>
<td>13 (23.2)</td>
</tr>
<tr>
<td>Persistent</td>
<td>19 (33.9)</td>
</tr>
<tr>
<td>Long-standing persistent</td>
<td>27 (48.2)</td>
</tr>
<tr>
<td>Patients with prior ablation</td>
<td>27 (48.2)</td>
</tr>
<tr>
<td>CHA\textsubscript{2}DS2-VASc</td>
<td>2.1 ± 1.0</td>
</tr>
<tr>
<td>Body mass index (kg/m(^2))</td>
<td>28.7 ± 5.1</td>
</tr>
<tr>
<td>Left ventricular ejection fraction</td>
<td>55.9 ± 8.5</td>
</tr>
<tr>
<td>Obstructive sleep apnea</td>
<td>28 (50.0)</td>
</tr>
<tr>
<td>Previously failed amiodarone</td>
<td>21 (37.5%)</td>
</tr>
</tbody>
</table>

AF: atrial fibrillation; FIRM: focal impulse and rotor mapping; LA: left atrium. Values are n (%), mean ± SD.

*Calculated from data available for 48 patients.
dimensions (septum to lateral LA and anterior to posterior LA with both TEE and ICE) (Figure 2a,b). The basket that is incrementally the next largest size than the largest dimension is chosen. For example, if the dimensions of LA are 5.6 and 5.3 cm we use the 60-mm basket. Similarly for LA measurement between 6 and 7 cm we would use a 70-mm basket.

**Practical considerations: basket deployment and transseptal puncture site**

It is important that the transseptal puncture site is at the mid-septum as confirmed with a view on ICE of the left-sided veins (Figure 3). We used a deflectable sheath (typically Agillis, St. Jude Medical, St. Paul, MN) for deploying the basket. When deploying the basket, its tip is brought to the antrum of left superior pulmonary vein (LSPV), carefully confirming that it is not at the left atrial appendage (LAA), and then the sheath is pulled back to the transseptal puncture site. It is critical to withdraw the sheath rather than advance the collapsed basket to minimize risk of patient injury. This maneuver reproducibly deploys the basket into the LA with good coverage of the posterior wall as well as the rest of the chamber.

**Practical considerations: sustained AF and FIRM mapping**

A requirement to perform FIRM mapping is to have the patient in sustained atrial fibrillation for at least 5 min. For those patients presenting in AF after the start of the procedure, nothing further is required. For those who are not in atrial fibrillation, AF is induced via pacing, typically from the CS catheter, with a pre-set protocol on our stimulator. This protocol is different from just pacing rapidly at a fast rate. The protocol in our laboratory is as follows: burst pacing from the CS starting at 400 ms, with a 10-ms decrement until either AF is induced or we arrive at a cycle length of 190 ms. Each drive train constituted 25 beats. Once AF has been established for at least 5 minutes, the FIRMap catheter is inserted into the RA or LA and a 60-s time frame of data is recorded. While in most laboratories, the RA is recorded first, we found that our workflow was better with LA maps first, with rare exceptions. The 60-s data “epoch” is saved on the electrophysiology laboratory recording system and then transferred to the RhythmView system. This system then further processes the data and creates a 3D electrophysiologic (not anatomic) video map showing the electrical conduction in the mapped chamber.
Follow-up and statistical analysis of data

Follow-up for arrhythmia recurrence followed HRS/EHRA/ECAS guidelines. Arrhythmia recurrence was detected by symptoms and event monitors to coincide with clinic visits as well as event monitoring at the time of reported symptoms. Recurrence of AF or AT was defined as AF or AT (excluding typical atrial flutter) >30 s on intermittent monitors. Comparisons between groups were made with a two-tailed Student’s t test and reported with means and standard deviations. Nominal values are expressed as n (%). A p value of <0.05 was considered statistically significant.

Results

We performed FIRM-guided procedures in 56 consecutive patients. Seventy-five percent (42/56) were males with a mean age of 65.7 ± 9.0 years. Persistent AF was present in 34% (19/56) of the patients, long-standing persistent AF (>2-year duration) was present in 43% (24/56) of patients, and paroxysmal AF was present in 23% (13/56) of patients. Regarding previous ablation procedures, 48% (27/56) of patients had one or more previous AF ablation procedures, 22% (6/27) of which had more than two procedures, and one patient had also previously undergone a maze procedure. Prior ablation included wide-area antral PVI verified using a circular catheter. Additional ablation included a left atrial roof line in most of the persistent AF patients, and ablation of observed clinically relevant atrial tachycardias or flutters. Table 1 further describes patient demographics and characteristics.

Patients were assessed for acute procedural results (Table 2). In short, FIRM mapping revealed rotors/focal sources in all patients, with a mean of 3.4 ± 1.2 rotors/focal sources per patient (2.4 ± 0.9 LA rotors/patient and 1.1 ± 1.0 RA rotors/patient), with 62.5% (35/56) of patients having right atrial rotors. The relationship between patient characteristics and rotor locations was also evaluated (Table 3). Of note, non-paroxysmal AF was associated with a significantly higher number of rotors in both atria, and patients with either a failed prior ablation or enlarged left atrial volume (defined as ≥ 59 ml/m²) had a significantly higher number of right atrial rotors. Acutely, 16/56 (28%) patients had termination of their AF into sinus rhythm with the rest undergoing cardioversion at the end of their procedure.

All patients (56/56) evaluated for long-term follow up were beyond the 90-day blanking period, with a mean follow up of 7.7 ± 3.0 months. Of these patients, 82.1% (46/56)
remained free of AF recurrence, and 78.6% (44/56) remained free of AF/AT recurrence, nine of which remained on antarrhythmic medication. Among the patients with non-paroxysmal AF, 79.1% (34/43) remained free of AF recurrence, and 76.7% (33/43) remained free of AF/AT recurrence, eight of which remained on antarrhythmic medication. Long-term freedom from AF was not predicted by whether the patients had acute AF termination during the ablation procedure.

Discussion

Our experience, in a non-academic community hospital setting, demonstrates a practical approach to the treatment of refractory and complex AF patients utilizing FIRM-guided ablation. We were able to incorporate FIRM mapping for our challenging patients without impacting the workflow of the AF ablation procedure, as evidenced by a total procedure time that is similar to findings reported in other studies utilizing standard substrate-based ablation techniques for complex patients. For example, a recently published large randomized controlled trial reported mean procedure times of 229 and 223 min for PVI + electrogram ablation, and PVI + lines (respectively), which is consistent with our mean procedure time of 221 min. Moreover, our initial experience is consistent with the findings of large single and multicenter studies that good results can be achieved when adding FIRM-guided rotor ablation to standard ablation approaches, particularly in patients in whom ablation had been previously unsuccessful or who may otherwise considered poor candidates for catheter-based ablation procedures. In Narayan et al., long-term (>3 year) outcomes of FIRM-mapping have been shown to be robust in a primarily persistent AF population. Similarly, numerous single-center experiences have been reported using FIRM mapping in independent studies of more complex patients with good success. These experiences are consistent with our findings that patients with persistent AF have a significantly higher number of rotors. Additionally, patients with enlarged atrial volumes or who have failed a previous AF ablation have a significantly higher number of right atrial rotors.

Recently, one study has questioned the success of FIRM-guided ablation, but the results of this investigation were complicated by the fact that half of the recordings that were analyzed showed cycle lengths of 250–500 ms (dominant frequency 2–4 Hz), which is more consistent with AT rather than AF, potentially resulting in algorithm or analysis problems in that study. Additionally, basket positioning in that study was difficult as noted by the authors due to using an older basket technology (Constellation, Boston Scientific, San Jose, CA) which was limited in ability to conform to the LA and limited in size such that they could not fully map larger LA sizes. Nevertheless, the mechanistic role of rotors in human AF has been recently validated utilizing elegant optical mapping studies in explanted donor hearts. This study noted relatively stable endocardial rotors with variable epicardial breakthrough. Validation of the FIRM approach with such gold-standard optical mapping studies would be valuable and are currently underway.

Limitations

Given that our follow-up is only approximately 8 months, additional follow-up is necessary to assess the long-term effectiveness of FIRM-guided rotor ablation at our center, which is currently underway. As a practical matter, although the procedure is cost-effective at our center, procedure cost should be evaluated, particularly when combined with multiple ablation technologies, as this may be challenging for some centers.

Summary

Successful maintenance of normal rhythm at a mean of 7.7 months of follow-up, in patients who have previously failed ablations or may otherwise be considered poor candidates for ablation, can be achieved with FIRM mapping combined with PVI in a private practice setting. Given the fact that a significantly higher number of right atrial rotors are present in patients who have failed prior ablations, FIRM mapping may be particularly important with patients undergoing a repeat AF ablation procedure.

References


