Three-Dimensional Electroanatomic Mapping Systems in Catheter Ablation of Atrial Fibrillation

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Atrial fibrillation (AF) is the most common tachyarrhythmia, with a prevalence of 5% in people over the age of 65. Over the past decade, catheter ablation of AF has emerged as an important management choice for drug-refractory symptomatic paroxysmal or persistent AF. Three-dimensional (3D) electroanatomic mapping systems were introduced into catheter ablation of AF more than a decade ago. The 3D tool has the benefit of reducing the radiation exposure time, as well as voltage and fractionation mapping in order to identify the critical substrate during the ablation, prevent the formation of gaps, guide the ablation of post-ablation atrial tachycardia or flutter, and integrate images to improve the safety and long-term success rate. The 3D systems successfully enable safe and tailored radiofrequency ablation of AF in individual patients. (Circ J 2010; 74: 18–23)

Key Words: Ablation; Atrial fibrillation; Atrium; Mapping; Substrate

Atrial fibrillation (AF) is the most common tachyarrhythmia, with a prevalence of 5% in people over the age of 65 years.1 Over the past decade, catheter ablation of AF has emerged as an important management choice for drug-refractory symptomatic paroxysmal or persistent AF. The pulmonary veins (PVs) have been recognized as the dominant source of AF and the elimination of these triggers is important as the first step during AF ablation.2,3 Substrate modification is frequently required in those subjects with long-standing persistent AF.4

Owing to individual variations in the PVs/left atrium (LA), complex fractionated atrial signals in those with chronic AF, and development of complex arrhythmias after primary AF ablation, a 3-dimensional (3D) electroanatomic mapping system should be used.5 Currently, the Ensite NavX (St Jude Medical, Minnetonka, MN, USA) and Carto (Biosense Webster Inc, Diamond Bar, CA, USA) systems are the most popular 3D mapping systems used worldwide because they provide accurate visualization of the atrial anatomy and identification of the atrial substrate properties for catheter ablation of atrial arrhythmias. Here, the clinical experience and advantages of the 3D mapping systems used in AF ablation will be discussed.

Development and Clinical Use of the Electroanatomic Mapping Systems

The 3D mapping systems were introduced into clinical use 10 years ago when Gepstein et al performed an accuracy study with a non-fluoroscopic, catheter-based, endocardial mapping system.6 The highly reproducible and accurate results were demonstrated in both in vitro and in vivo studies. Gornick et al7 also demonstrated the ability to place separate catheters at any site within the mapping chamber. They also reported the resolution of the 3D mapping system could be as small as 2.3 mm in distance. The mapping system facilitates the difficult interventional ablation procedure, and can accurately navigate to a predefined site. It also shortens the fluoroscopic time and has a favorable spatial resolution. In addition, after calculating and displaying the electrical activation sequence, the operator can visualize the activation sequence (activation mapping) and easily obtain the voltage information (voltage mapping).

Advantage of 3D Electroanatomic Mapping Systems

Reduction of Radiation Exposure

Standard radiofrequency ablation procedures can be time-consuming and may require significant exposure to radiation, which can cause a small increase in the lifetime risk of fatal malignancy for both the patient and electrophysiologist.8 In a prospective randomized study, Kottkamp et al first demonstrated a significant reduction (~82.3%) in the exposure to fluoroscopy while maintaining a high efficacy during radiofrequency ablation of typical atrial flutter.9

During AF ablation, there is a significant prolongation of the fluoroscopic time during PV isolation with or without additional atrial substrate modification. After the introduction of the 3D systems, Sporton et al reported a substantial reduction in the fluoroscopic time and radiation dose (Carto system).10 Rotter et al also demonstrated a fluoroscopic time...
progressive remodeling of the atrial substrate in voltage and prolongation of the atrial activation time. Lo et al also demonstrated a worsening of the inflammatory markers (e.g., C-reactive protein and B-type natriuretic peptide). Chang et al also showed that the preexistence of a LA scar in patients undergoing PV isolation was a powerful, independent predictor of a procedural failure.

Providing a Guide for Atrial Substrate Modification

During AF, the diseased atrial myocardium causes an increased number and duration of double and fractionated potentials, and also exhibits a lower regional and global atrial voltage. The double potentials represent conduction block, whereas fractionated potentials indicate slow conduction. Most importantly, the result of voltage mapping from the electroanatomic mapping system is a guide to the severity of the atrial cardiomyopathy.

Much evidence for identifying the substrate properties has been provided by both contact and noncontact mapping systems. Using the contact mapping system, it was reported by Sanders et al that slowing of atrial regional conduction with a greater number of electrograms with fractionation and areas of low voltage occurred in patients with congestive heart failure and sinus node disease. Verma et al reported that the preexistence of a LA scar in patients undergoing PV isolation was a powerful, independent predictor of a procedural failure. In addition, LA scarring is associated with a lower ejection fraction, larger LA size, and increased inflammatory markers (e.g., C-reactive protein and B-type natriuretic peptide). Chang et al also demonstrated a worsening of the atrial voltage, as well as prolongation of the atrial activation time, as the AF progressed from paroxysmal to chronic. There is a good correlation between the decrement in LA voltage and prolongation of the atrial activation time. Lo et al also found progressive remodeling of the atrial substrate in patients with recurrent AF (Figure 1).

Using a noncontact mapping system, Lin et al demonstrated that the substrate properties of activation and cycle-length-dependent voltage reduction may be related to the development of atrial flutter and AF. Higa et al also beautifully delineated the preferential conduction of focal atrial tachycardia from a small area in the atrium, reporting that two-thirds of the atrial tachycardias originated from low-voltage zones, or border zones near the low-voltage zone, and could safely be eliminated by radiofrequency ablation.

Substrate modification is important during the ablation procedure for chronic AF. It was first proposed by Nademanee et al in 2004 that areas with complex fractionated atrial electrograms (CFE) represent a defined electrophysiologic substrate and are ideal targets for ablation to eliminate AF. During a 1-year follow-up, 73% of the patient with chronic AF and 79% of the patient with paroxysmal AF were free of any arrhythmias after a single ablative session. The 3D electroanatomic mapping systems also provide an automatic detection algorithm for CFE mapping. Both Lin et al and Stiles et al showed proof of the consistency of the automatic detection algorithms using the electroanatomic mapping systems. The assessment of the CFEs requires a recording duration of ≥5 s at each site in order to obtain a consistent fractionation (Figure 2). Ablation of continuous CFEs, in addition to PV isolation and LA linear ablation, has a better long-term efficacy based on the results of a single ablation procedure. Lo et al also reported that the origin of the non-PV ectopics was the same location as that of the atrial continuous CFEs: AF could be effectively eliminated by limited ablation targeting those atrial continuous CFEs. Persistent CFE sites play an important role in the maintenance of AF and the 3D mapping system is a useful tool for substrate mapping during AF.
Prevention of Gap Formation and Activation Mapping to Guide the Catheter Ablation

Post-ablation atrial tachycardia and flutter have been reported in patients undergoing catheter ablation of AF. Gerstenfeld et al reported that persistent focal atrial tachycardia occurred after segmental PV isolation, with the reentrant circuit located at the PV ostium. Chae et al also reported that approximately 90% of the atrial tachycardias that develop after circumferential PV isolation have a reentrant mechanism and they considered that gaps might be related to prior ablation lines. However, it may not be easy to identify such gaps. Entrainment is a conventional technique for localizing the circuit of reentrant tachycardia, but there are some disadvantages with using this technique to identify post-ablation tachycardias. It may terminate the tachycardia during the pacing maneuvers or cause the organized tachycardia to deteriorate into fibrillatory conduction. Moreover, there are extensive low-voltage zones and scars in these AF patients, which may cause difficulty in capturing the atrium during entrainment. The 3D electroanatomic mapping systems provide an effective alternative to mapping and localizing post-ablation atrial tachycardias. Using the 3D mapping system, Chang et al found that post-ablation reentrant atrial tachycardia had a higher incidence of gaps in the LA appendage ridge, whereas focal atrial tachycardia had a higher incidence of gaps in the PV carina. Those reentrant tachycardias frequently terminated during mitral and roof linear ablation. An excellent outcome with only a 0.6% recurrence was demonstrated during a 21-month follow-up. Furthermore, Kumagai et al used the noncontact mapping system to guide the Box isolation and the system could detect the conduction gaps as well as analyze the mechanism of atrial tachyarrhythmias.

Anatomical Identification and Integration of Non-Invasive Images in the LA

The complex anatomy of the LA makes it difficult to position ablation catheters using fluoroscopy alone. In the study by Ho et al, the myocardial architecture in the PVs was highly variable. In general, the myocardial sleeves were thickest in the inferior wall of the superior veins and the superior wall of the inferior veins. In addition, there are some anatomical variants (eg, right middle vein, roof pouch etc) and areas in which it is difficult to gain good catheter contact and stability (eg, LA appendage ridge). The electroanatomic mapping system can guide the ablation in those important structures or anatomical variants. The system can also provide simultaneous visualization of epicardial and endoscopic views of the LA and enable the ablation application to be performed more accurately and easily (Figure 3).

Udyavar et al reported that after 1 round of PV isolation, successful elimination of PV potentials was achieved in only approximately 60% of the patients. A PV carina ablation is advisable to substantially increase the elimination rate of PV potentials to 100%. By using a 3D mapping system, the PV carina can be visualized clearly from both the 3D shell and endoscopic view. In addition, Valles et al reported the importance of spontaneous PV triggers (accounting for 63% of all triggers) originating from the carina region in patients undergoing AF ablation. Wongcharoen et al also found that 15% of AF patients had roof pouches and a longer roof line. The location of the LA appendage and left PVs may affect catheter stability during the ablation, and an inferior LA appendage is more frequently observed in AF patients. Miyamoto et al used the noncontact mapping system to identify the location of the esophagus relative to the LA posterior wall. These findings are important for determining the strategy of AF ablation and use of the 3D mapping system can overcome those issues and avoid any procedure-related complications.

![Figure 2](image-url) Regional distribution of the sites of complex fractionated atrial electrograms (CFE) in the left atrium (PA view), recorded over 2.5 s (A) and 5 s (B). In (A), there are extensive CFEs including the left pulmonary vein and posterior wall areas. In (B), the CFE is localized to ostium of the left superior pulmonary vein.
Figure 3. Endoscopic (Upper) and fluoroscopic (Lower) views showing the catheter location during radiofrequency ablation application. The 3-dimensional mapping system enables simultaneous visualization of the epicardial and endocardial views. The axis and location of the catheter tip can be seen accurately by using both views. (Reproduced with permission from Lo LW, et al. J Cardiovasc Electrophysiol 2009 (in press).)

Figure 4. Reconstructed computed tomography image and 3-dimensional (3D) geometry of the left atrium and pulmonary veins (PV) in the PA view showing the abnormal location of the ostium of the RIPV according to the EnSite NavX system. (A) Reconstructed computed tomography image and abnormal posterior location of the RIPV. (B) NavX image shows the shell of the PV–left atrium. With the aid of the reconstructed computed tomography image, the 3D NavX shell can be constructed more accurately, preventing ignorance of the abnormal anatomy. LAA, left atrial appendage; LIPV, left inferior PV; LSPV, left superior PV; RIPV, right inferior PV; RSPV, right superior PV.
Both the Ensite NavX and Carto systems allow for integration of either CT or MRI images of the LA into the catheter display image of the mapping system. Anatomical variability can be identified after merging the CT anatomy into the reconstructed shell. Figure 4 is an example of an abnormally located right inferior PV ostium found after reconstruction of the CT image, which provided a guide to constructing the LA geometry and avoided ignorance of the ostium of the right inferior PV. Richmond et al evaluated CT image integration in the EnSite NavX Fusion system and successful results were shown in all patients, after a required learning curve for the physicians. The advantage of the CartoMerge system was also reported by Kistler et al, with improved visualization of the complex LA geometry. In a prospective randomized study, Della Bella et al further demonstrated the superior efficacy and long-term outcome of image-integration-guided ablation of AF over conventional fluoroscopy-guided ablation. Moreover, the integration also shortened fluoroscopy time, reduced the arrhythmia recurrence and increased the rate of restoration to sinus rhythm.

Conclusions

The 3D virtual anatomic mapping systems are increasingly used during the mapping and ablation of complex atrial arrhythmias. As a result of the growing patient population undergoing AF ablation, understanding the advantages of the 3D electroanatomic mapping systems is a fundamental and important step for every electrophysiologist. The 3D tools reduce the radiation exposure time, and the voltage and CFE mapping assist in identifying the critical substrate during the ablation, preventing gap formation and guiding post-ablation atrial tachycardia or flutter ablation, and image integration improves the safety and long-term success rate. The systems enable safe and successful tailored radiofrequency ablation of AF in individual patients.

Disclosure

The authors have no conflicts of interest to declare.

References


