

Electroanatomical Mapping Systems. An Epochal Change in Cardiac Electrophysiology

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Abstract In the last two decades new mathematical and computational models and systems have been applied to the clinical cardiology, which continue to be developed particularly to quantify and simplify anatomy, physio-pathological mechanisms and treatment of many patients with cardiac arrhythmias. The Authors report our large experience on electroanatomical mapping systems and techniques that are currently used to quantify and analyze both anatomy and electrophysiology of the heart. In the last 15 years the Authors have performed more than 15,000 invasive catheter ablation procedures using different non-fluoroscopic three-dimensional (3D) electroanatomical mapping and ablation systems (CARTO, Ensite) to safely and accurately treat many patients with different cardiac arrhythmias particularly those with atrial fibrillation with a median age of 60 years (IQR, 55-64). The Authors have also developed and proposed for the first time a new robotic magnetic system to map and ablate cardiac arrhythmias without use of fluoroscopy (Stereotaxis) in >500 patients. Very recently, epicardial mapping and ablation by electroanatomical systems have been successfully performed to treat Brugada syndrome at risk of sudden death in a series of patients with a median age of 39 years (IQR, 30-42). Our experience indicates that electroanatomic mapping systems integrate several important functionalities. (1) Non-fluoroscopic localization of electrophysiological catheters in three-dimensional space; (2) Analysis and 3D display of cardiac activation sequences computed from local or calculated electrograms, and 3D display of electrogram voltage; (3) Integration of ‘electroanatomic’ data with non-invasive images of the heart, such as computed tomography or magnetic resonance images. The widespread use of such 3D systems is associated with higher success rates, shorter fluoroscopy and procedure times, and accurate visualization of complex cardiac and extra-cardiac anatomical structures needing to be protected during the procedure.

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1 Introduction

Recent progress in biomedical engineering and imaging technology [1–6] is providing an ever-increasing body of knowledge on the mechanism and onset of cardiac disease, with new options for accurate detection and effective treatment. In the last years, considerable progress has been made in mathematical and computational models/systems, which provide further insights into clinical electrophysiology imaging processing in order to better quantify/simplify from the acquired image data both anatomy and mechanisms of complex cardiac arrhythmias, including but not limited to atrial fibrillation. The development of relatively inexpensive computer systems that have the capacity to process signals rapidly has allowed the development of mapping systems that reliably localize intracardiac catheter positions [7–10]. One such system is the CARTO system (Biosense Webster, Diamond Bar, CA). The system uses a magnet mounted under the catheterization table coupled with a proprietary catheter placed in the intracardiac chamber of interest. The magnet under the table locates the catheter tip in three-dimensional space when an endocardial signal is measured and the system stores the spatial and electrical information. The computer then constructs a virtual three-dimensional electroanatomic map of the chamber. The catheter tip location within the mapped space is displayed on the computer screen allowing catheter manipulation without fluoroscopy. In current versions of CARTO, real-time structural data from intracardiac ultrasound (CartoSound) or changes in impedance (CARTO 3) can be integrated to refine the displayed image. The LocaLisa (Medtronic Inc, St. Paul, MN) system was used in early studies of non-fluoroscopic procedures. The technology was acquired by Endocardial Solutions, which subsequently was acquired by the St. Jude Medical Corporation. The technology was incorporated into the EnSite NavX system (St. Jude Medical, St Paul, MN). Patches are placed on the skin and used to generate an electrical signal sensed by the catheters inside the body. A catheter in a stable position is used as a reference for creating the geometry. The ablation catheter is manipulated within the chamber of interest and when contact with the wall is demonstrated by the measured electrical signal, the catheter position is recorded. Electrical impedance changes are sensed by the system and indicate a change in catheter position, and the system then displays the new catheter position. The system then can simultaneously track 64 separate electrodes on up to 12 different catheters. Their positions are displayed relative to each other within a virtual representation of the cardiac chamber(s) of interest. Although both the CARTO and EnSite systems produce a virtual image of the cardiac chambers and catheter(s), there are differences in them. However, with both systems, there are increased equipment costs associated with both the CARTO and NavX systems. Because the CARTO system is based on changes within a magnetic

field, the ablation catheter has to be magnetically active. This proprietary catheter is more expensive to purchase than commonly used ablation catheters. The NavX system is compatible with most commonly used catheters, but the patches applied to the skin are one-time use only and must be purchased for every case. It is difficult to make a global statement about the absolute cost increase as there may be differences based on volume and specific center preferences. Initially, their use has been in arrhythmias in which the ablation target was difficult to identify, such as ventricular tachycardias in structural heart disease, atypical atrial flutters, or arrhythmias in patients with complex congenital heart defects. In the recent years, electroanatomic mapping systems have also been used to guide catheter-based isolation of the pulmonary veins, an important component of the modern management of atrial fibrillation. Electroanatomic mapping systems integrate three important functionalities, namely (i) non-fluoroscopic localization of electrophysiological catheters in three-dimensional (3D) space; (ii) analysis and 3D display of activation sequences computed from local or calculated electrograms, and 3D display of electrogram voltage ('scar tissue'); and (iii) integration of this 'electroanatomic' information with non-invasive images of the heart (mainly computed tomography or magnetic resonance images). Although better understanding and ablation of complex arrhythmias mostly relies on the 3D integration of catheter localization and electrogram-based information to illustrate re-entrant circuits or areas of focal initiation of arrhythmias, the use of electroanatomic mapping systems in atrial fibrillation is currently based on integration of anatomic images of the left atrium and non-fluoroscopic visualization of the ablation catheter. Currently available registration techniques rely on preprocedural 3D computed tomography or magnetic resonance imaging (MRI) data sets which are aligned with or superimposed to intraprocedural electroanatomical information. Although a reasonable accuracy and usability can be achieved with these techniques, preprocedural anatomic images carry inherent disadvantages: atrial volumes are variable and may change between the imaging session and atrial fibrillation ablation session. Especially in larger atria, the integration error is considerable. Three-dimensional transesophageal ultrasound systems have already been used to guide catheter-based septal defect closures. Although image integration is a fascinating and easily adopted addition to electroanatomical mapping, especially in atrial fibrillation, it has to be appreciated that left atrial anatomy is variable and depends, among other factors, on cardiac rhythm, volume status, respiration, and deformation of the left atrium by electrophysiological catheters during the procedure. Image fusion and non-fluoroscopic catheter visualization can therefore probably not fully replace fluoroscopy or other forms of direct catheter visualization during catheter ablation procedures. About two decades ago, Haissaguerre et al. and Pappone et al. [11–17] firstly reported a potential role of radiofrequency catheter ablation in the treatment of patients with atrial fibrillation, which required an accurate reconstruction of complex anatomic structures. Therefore, continuous technology progresses have been made to realize and perform safer and more effective catheter ablation procedures. The wide area circumferential ablation, as initially proposed by Pappone et al. [12–16], firstly used electro-anatomic systems and this approach was

associated with lower rates of atrial fibrillation recurrence than the initially proposed approach by ostial pulmonary vein isolation [17]. In the last ten years, thanks to further technology advancements many multicenter randomized studies worldwide reported higher success rates in maintaining a stable sinus rhythm in patients with refractory paroxysmal recurrent atrial fibrillation [17–31]. Unfortunately, despite technology progresses, currently less consensus exists as to the most appropriate approach strategy in persistent long-standing atrial fibrillation [22, 23], in which there are multiple substrates for re-entry outside pulmonary veins (PVs) or multiple rotors, both of which are difficult to identify and eliminate. As a result, multiple complex lesions are required in a step-wise fashion, which require their accurate anatomic localization with longer procedure times. As a result, further technical advancements are required in persistent atrial fibrillation to overcome these important limitations while refining the best ablation approach in terms of both safety and efficacy. Despite these limitations, if performed in a modern electrophysiology laboratory, catheter ablation of atrial fibrillation may be considered as an effective and safe procedure and this is at least in part due to the use of new tools.

2 An Epochal Change of Cardiac Electrophysiology. Evolution of Electro-anatomic Three-Dimensional Mapping Systems from 2000 to 2015

Currently, the traditional X-ray imaging and catheter diagnostic mapping methods are increasingly being complemented by recent 3D mapping imaging modalities, each with specific strengths and options for improving diagnostic accuracy and effectiveness. High-quality data points offer electrical and anatomical detail in simple and complex cases by traditional and advanced diagnostic catheters. Advanced 3-D mapping modules can integrate multiple data sets and images into one resource for highly detailed, real-time information by image integration tools, as well as several tachyarrhythmias—specific software. With the broadest portfolio of catheters available it is possible deliver optimal treatment, whether it's to ablate or wait by irrigated ablation technology. As a result, currently, chronic antiarrhythmic drug therapy has been replaced in patients with complex arrhythmias by catheter-based interventions. This development is supported by continuous developments in 3D imaging and navigation techniques with newer devices, which enable more complex percutaneous procedures with improved outcomes. In the last 15 years the rapid expansion of indications for catheter ablation from supraventricular tachycardia to very complex tachyarrhythmias, such as atrial fibrillation and ventricular tachycardia led electrophysiologists to face prolonged procedure times with excessive fluoroscopy exposure and the need for stable and reproducible catheter movement, all of which require significant and continuous improvements in the existing traditional 2D mapping technology, and new developments.

3 Current Electroanatomical Mapping Systems

The most commonly used systems are CARTO® System (Biosense Webster, Inc., Diamond Bar, CA, USA) (Figs. 1, 2, 3, 4 and 5) and EnSite NavX™ (St. Jude Medical, Inc., St. Paul, MN, USA) (Figs. 6, 7, 8, 9 and 10, 11). These mapping systems have helped to decrease procedural complexity, procedure time, and improve safety. The CARTO and EnSite NavX system use magnetic or impedance measurements between the individual catheter electrodes and the patches usually placed on the patient's chest and abdomen. Bipolar mapping is the gold standard technique to characterize substrate, and a bipolar voltage amplitude of ≥ 1.5 mV identifies healthy tissue and areas with voltage of 0.5–1.5 mV are considered border zones. Electroanatomical mapping systems accurately depict in different colors (color-coded maps) such areas. During the activation sequence mapping, data points are acquired as the catheter moves across the chamber of interest and the timing of these electrograms are compared with a predetermined reference. As this process continues, a color scheme begins to emerge. Currently, areas of red color usually indicate sites of “early activation” and activation becomes progressive later proceeding through the colors of the rainbow to yellow-green, and finally the blue and purple one that define the sites of late activation relative to the reference electrogram. These colors are displayed as an isochronal time bar adjacent to the 3D map.

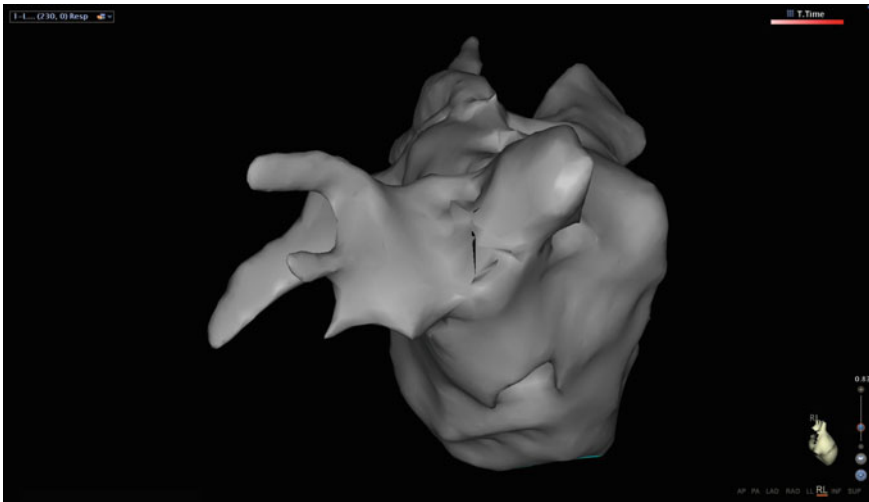


Fig. 1 Pre-ablation endocardial anatomical map of the left atrium in right lateral view obtained by the CARTO system in a patient undergoing atrial fibrillation ablation. The map was created during coronary sinus pacing, as a stable reference point

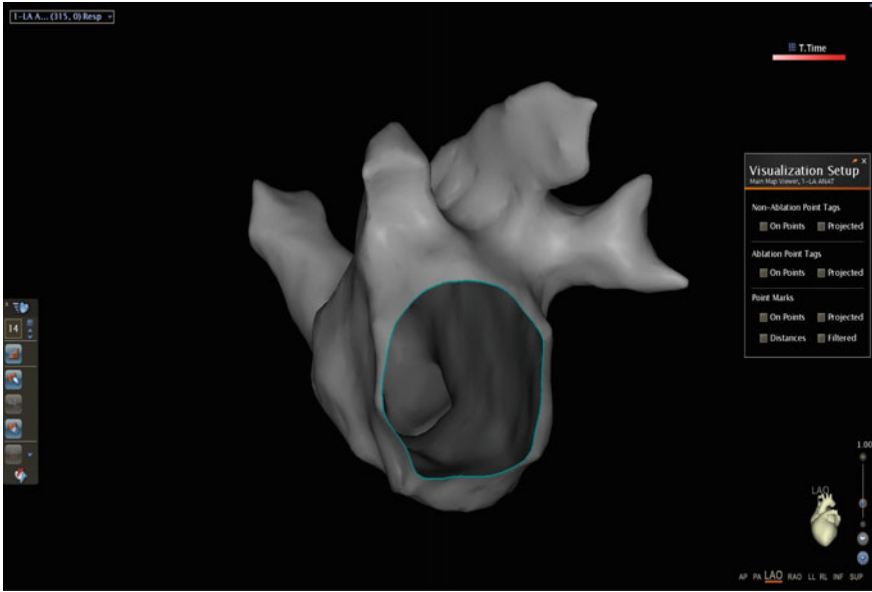


Fig. 2 Pre-ablation endocardial anatomical map of the left atrium in left anterior oblique projection by the CARTO system. Note the mitral valve annulus

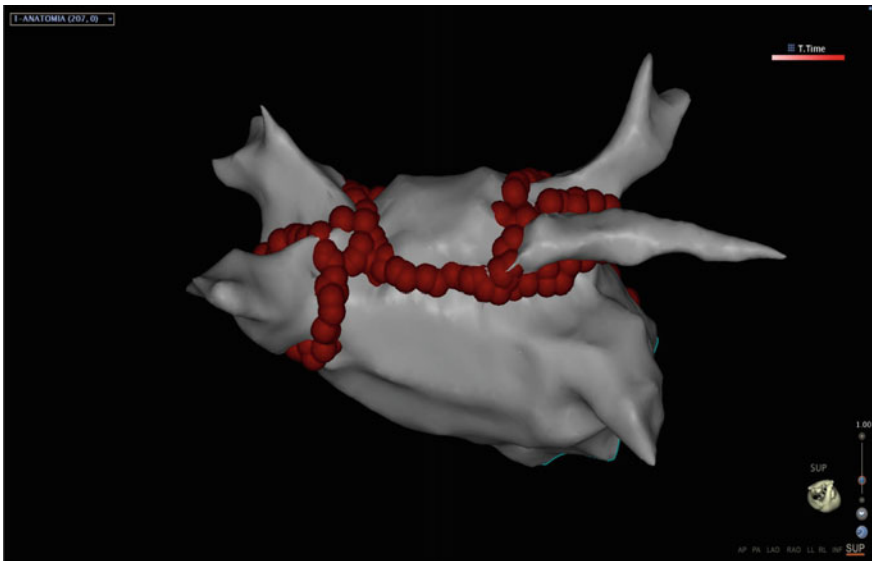


Fig. 3 Pre-ablation endocardial anatomical map in the superior view to validate continuity of the lesion set around the superior pulmonary veins. The map was reconstructed by the CARTO system

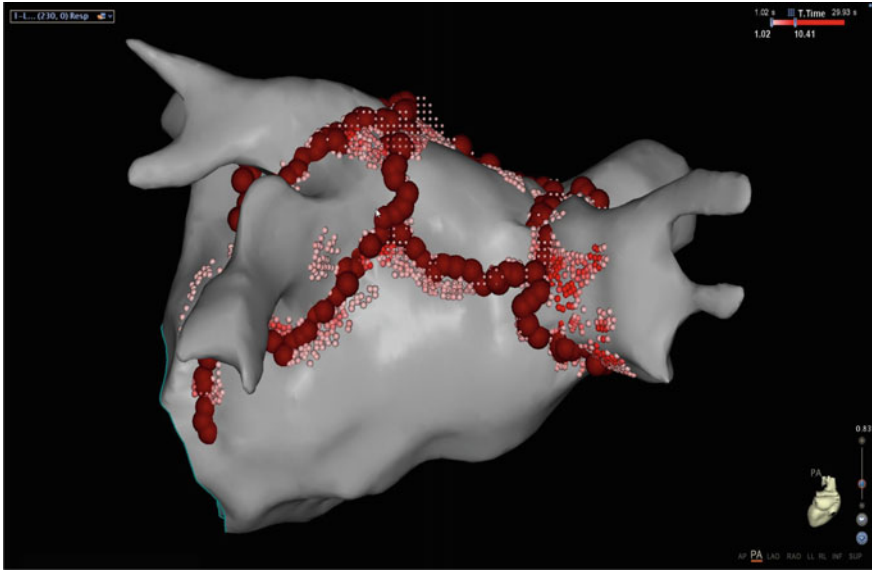


Fig. 4 The figure shows an endocardial anatomical map of the left atrium in the antero-posterior view and the typical lesion set encircling the four pulmonary veins (*red dots*) with superimposed grid points due to every single catheter contact count. The map was reconstructed by the last version of CARTO system

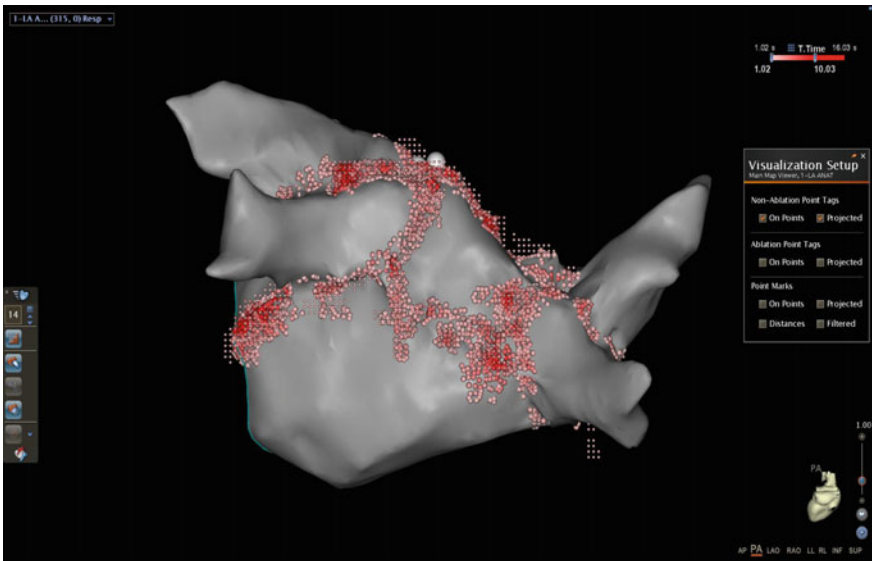


Fig. 5 Same map in the same patient without red ablation points. The endocardial map was reconstructed by CARTO system

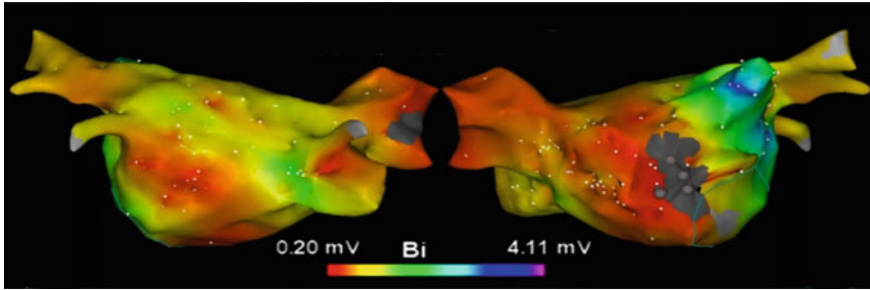


Fig. 6 Electroanatomic color-coded voltage map of the left atrium in postero-anterior (*left panel*) and antero-posterior view (*right panel*) by CARTO system. Red color represents low-voltage areas due to radiofrequency applications while green and blue colors depict higher voltage areas. Post-ablation areas within and around the ablation lines, involving to some extent the left atrial posterior wall, show low-amplitude electrograms. This purely anatomic approach yields a profound atrial electroanatomic remodeling, as expressed by the voltage abatement inside the encircled areas

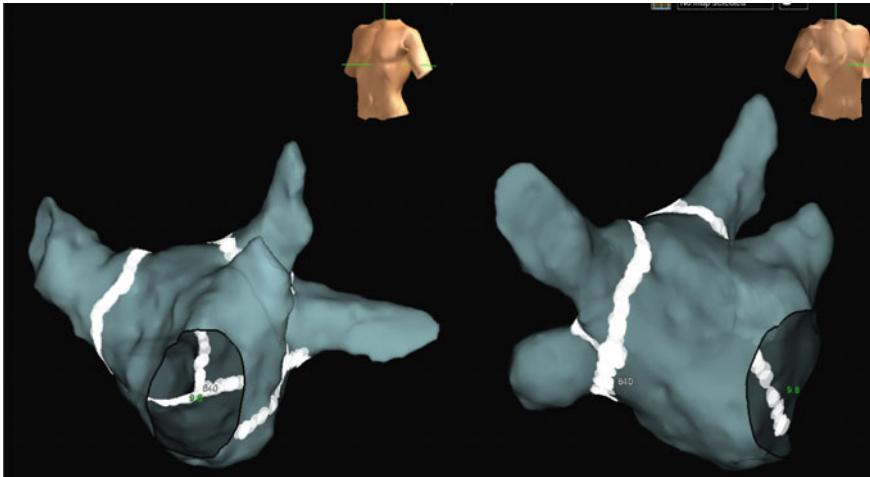


Fig. 7 Anatomical maps of the left atrium geometry in LAO (*left*) and RAO (*right*) view obtained by the NavX EnSite mapping system. The white line markers correspond to the lesions indicating the path of RF ablation for the modified pulmonary vein isolation

4 Electroanatomic Mapping Systems. Newer Advanced Versions

Recent technical advances resulted in the development of new versions of both systems. Carto Express version allows quicker mapping and reconstruction of heart cavities and great vessels geometry as compared to previous versions of Carto XP. EnSite Velocity system incorporates more precise catheter visualization,

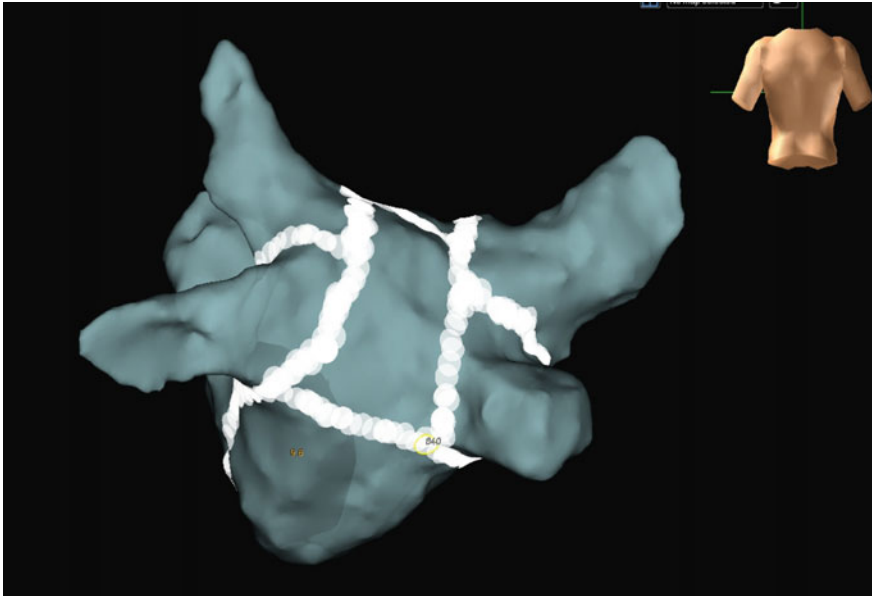


Fig. 8 Postero-anterior view of the left atria geometry created by the EnSite mapping system. The complete set of lesions created during RF ablation are evidenced by the white lesions markers around the pulmonary veins and posterior wall line

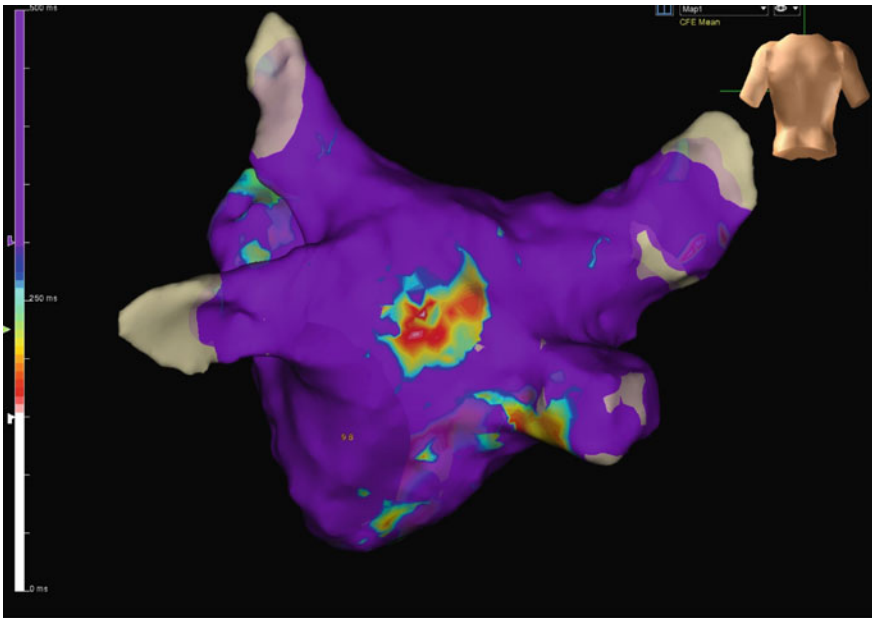


Fig. 9 Postero-anterior view of a color-coded activation map of the left atrium created by the EnSite mapping system in a patient with incessant atrial tachycardia. The color scale is expressed in msec, corresponding to the earliest area of activation (*red color*) located on the posterior left atrium

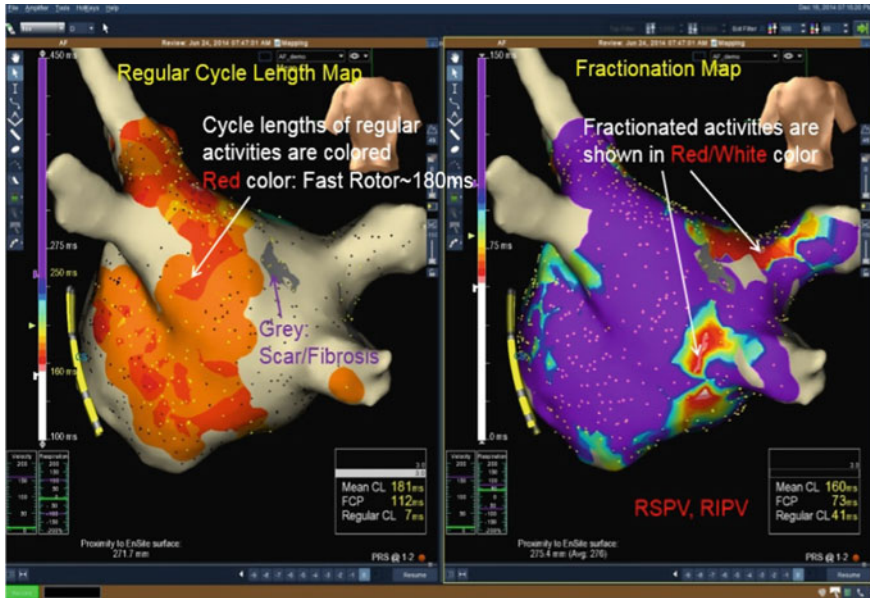


Fig. 10 Postero-anterior views of electroanatomical color-coded maps of the left atrium created by the Ensite mapping system in a patient with atrial fibrillation. The map on the left shows the regions that have the most regular cycle length with the fast “rotor” activity (*red/orange color* scale corresponding to 180 ms) representing the ablation targets. Note that the regular rotor activity is characterized by short cycle length or fractionated potentials (*right panel*)

and allows Fig. 3. One kernel at x_s (*dotted kernel*) or two kernels at x_i and x_j (*left and right*) lead to the same summed estimate at x_s . This shows a figure consisting of different types of lines. Elements of the figure described in the caption should be set in italics, in parentheses, as shown in this sample caption.

Quicker mapping as compared to previous version of EnSite. The CARTO system utilizes magnetic location technology to provide accurate visualization of the magnet sensor-equipped catheter tip. The original electroanatomic 3D Carto® system is essentially based on three active weak magnetic fields (5×10^{-6} to 5×10^{-5} T), generated by a 3-coil location pad placed underneath the patient’s thorax. Magnetic field strengths are measured with mini-sensors embedded in the catheter tip on a continuous basis providing data about the real time and exact position and orientation of the sensor in space. One sensor attached to the patient’s skin within the working space of interest serves as a location reference. Patient movement or dislocation of the location pad may lead to uncorrectable map shifts. Recent versions of Carto System (Carto3®) integrate a hybrid of magnetic and current-based catheter localization technology enabling visualization of multiple catheters simultaneously without fluoroscopy use. For this, six electrode patches positioned at the patient’s back and chest continuously screen the current emitted at a unique frequency from different catheter electrodes. Localization of the

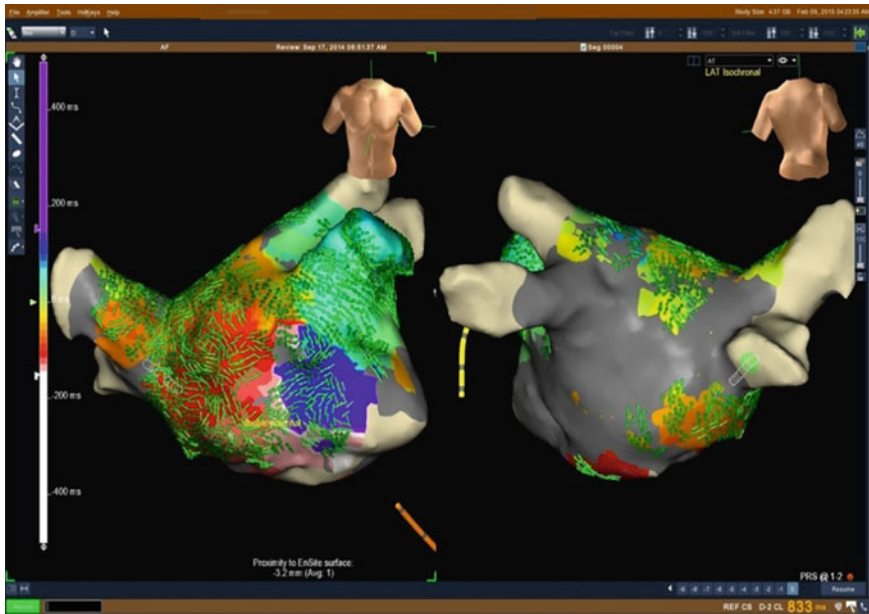


Fig. 11 The map shows color-coded left atrial activation time in a patient with atrial fibrillation obtained by the EnSite mapping system. The activation time is calculated from a reference marker (in this example the coronary sinus catheter distal to second electrode signal), allowing identifying the propagation path of the arrhythmia. Note post-ablation dense scar low voltage areas in grey (*right panel*) in the posterior wall and residual very fast rotor activity in the anterior septum (*left panel*)

non-magnetic electrodes can be calibrated by the detection of the magnetic sensor within the coordinate system in order to overcome distortions from non-uniform intrathoracic resistances. Other newer development of the Carto3® system is the fast anatomical mapping (FAM) which allows real time accurate reconstruction of detailed shells by a multipolar mapping catheter simply moving the catheter all around in the chamber of interest, thus providing a better reconstruction than the point-by-point maps in the earlier Carto® versions. Another development targeting the accuracy of surface reconstructions is accomplished by a unique type of respiratory gating in which varying thoracic impedances are measured throughout the respiratory cycle. The new developments in the current Carto3® version have already been shown beneficial in terms of fluoroscopy requirements, when compared to the older CartoXP® version. The other electroanatomical mapping systems currently used is the EnsiteNavX® system, which is essentially based on the LocaLisa® technology using six skin electrode patches to create high frequency electric fields (approximately 8 kHz in the current version) in three orthogonal planes. The 3D-localization of conventional electrophysiology catheters is calculated based on an impedance gradient in relation to a reference electrode. The body's non-linear impedance may be partially corrected by a process called field

scaling. To improve compensation for cardiac and respiratory motion artifacts, a stable reference catheter in the proximal coronary sinus is placed to avoid uncorrectable map shifts. The advantage of the EnSiteNavX® system over the Carto® system is that it allows for visualization of multiple catheters from different manufacturers and that all electrodes of any catheter can be used simultaneously for a relatively quick reconstruction of cardiac chambers providing not only anatomical information but also electrophysiological mapping data. In the last 15 years the Authors have performed more than 15,000 invasive catheter ablation procedures using both CARTO and Ensite systems (Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11), particularly in patients with atrial fibrillation with a median age of 60 years (IQR, 55-64). Our experience indicates that multi-electrode mapping represents a significant advancement in mapping technology, allowing physicians to acquire multiple mapping points simultaneously with a high level of detail and accuracy. Combined with the new Pentarray Navigation Catheter, it is possible to reduce the number of required catheter maneuvers to quickly diagnose any arrhythmia. (Unpublished observations). This would further support the safety, effectiveness and efficiency of cardiac ablation procedures.

5 Electroanatomic Mapping Systems. Image Integration

Image integration is a new tool which can be used to further increase the understanding of the patient's complex atrial anatomy, such as the pulmonary vein-atrial junction and the ridge between the left pulmonary veins and the left atrial appendage. CT or MRI data, which are acquired prior to the procedure, are integrated in the EAMS. After image processing (segmentation), 3D images are either merged or fused with the 3D reconstructions with fusion usually requiring a more extensive registration process. Utilization of intracardiac echocardiography (ICE) is less frequently used for guidance of transseptal puncture, and early detection of complications such as pericardial effusion, thrombus formation, or tissue overheating (microbubble formation). The most widely used ICE technology runs integrated in the Carto® system (CartoSound®, Biosense Webster). It uses a phased-array ultrasound tipped catheter consisting of a 64-element transducer (Sound29Star® Catheter, Biosense Webster). The high-resolution, multiple-frequency transducer (5–10 MHz) is incorporated into a 10F steerable catheter and provides 90° sector images with depth control [31]. The CartoSound® module is capable of creating 3D models by combining multiple 2D ultrasound cross sections generated by the transducer. The latter can be merged with segmented CT/MRI left atrial models. The technology allows improvement in success and complication rates as well as shortening of LA catheter dwell and fluoroscopy times when compared with the fluoroscopy-only approach [31]. Use of intracardiac ultrasound requires an additional 11F sheath for transducer introduction, potentially raising the risk of femoral access complications as well as adds a non-negligible cost to the procedure all of which strongly limit its widespread use.

6 Electroanatomic Mapping Systems. Remote Navigation/Ablation

Remote-controlled navigation technology provides for precise navigation with the hope that this translates to improved lesion contiguity. Recently, remote-controlled robotic catheter ablation has emerged as a new ablation approach to achieve these goals [20, 21]. Two remote-controlled systems, which have the added benefit of reducing the physician's radiation exposure, have been developed to facilitate catheter navigation and ablation by increasing catheter stability. The first one available for clinical use is a magnetic navigation system (Niobe II system, Stereotaxis, St. Louis, Missouri) and the second one is a robotic navigation system (Sensei system, Hansen Medical, Mountain View, California). Although both systems have shown the feasibility and safety of remote-controlled ablation, further technological innovations are required to expand applicability and research is needed to establish non-inferiority to manual approaches. Therefore, technical innovations are clearly warranted which could: *a*) minimize the physician's fluoroscopy exposure; *b*) reduce physical demands on the operator by allowing for a more relaxed ablation procedure from within the control room; *c*) improve catheter stability and reproducibility of the procedure; and *d*) increase patients' safety by avoiding serious complications. The Stereotaxis navigation system includes two large external magnets positioned on either side of the fluoroscopy table to generate a uniform magnetic field (0.08 T) of approximately 15-cm diameter within the patient's chest [20, 21]. The ablation catheters are extremely floppy along their distal end with small magnets embedded at the tip of the catheter. The catheter tip aligns with the orientation of the generated magnetic field. Using a software interface, the operator can manipulate the magnetic field and, by extension, the tip of the ablation catheter, providing the first level of freedom of movement with this new system. The other level of freedom of movement is the ability remotely to advance or retract the catheter tip by a computer-controlled catheter advancer system (CardioDrive), which consists of a disposable plastic unit positioned at the femoral catheter insertion site. The catheter shaft is affixed to a CardioDrive unit where it enters the sheath, and can transduce the remote operator instructions to advance or retract the catheter appropriately. This combination of remote catheter advancement-retraction and magnetic field manipulation allows the operator a great deal of flexibility for navigation, mapping and ablation. The magnetic navigation system is integrated with one of the electroanatomic mapping systems (CARTO RMT, Biosense Webster, Diamond Bar, CA), which also allows integration of 3-dimensional computed tomography or MRI models. Once integrated, the magnetic field can be directly controlled with the computer mouse. The mapping system can precisely localize the catheter tip in space to a submillimeter resolution. By precisely tracking the catheter location, the combination of mapping and navigation systems allows automated chamber mapping. The operator can remotely manipulate the magnetic catheter within the left atrium to a predefined anatomic location, such as PV ostia or mitral valve annulus. Based on these parameters, the system

automatically manipulates the catheter throughout the chamber to facilitate generation of an electroanatomic map. New software allows the system to manipulate the catheter tip automatically to create linear ablation lesions within the chamber as per the operator's wishes. The efficiency and accuracy of these automatic software solutions, however, remain to be demonstrated. The other significant advance is the ability to incorporate pre-acquired 3-dimensional MRIs or computed tomography scans into the system to allow mapping on a realistic model of the heart. With the current generation software, clinical data are available on its efficacy for atrial fibrillation ablation. In more than 500 patients with atrial fibrillation, the Authors have demonstrated that electroanatomic maps are accurate and have recently reported that the standard set of lesions with remote PV isolation can be reproducibly achieved using an irrigated ablation catheter [24, 25].

7 Clinical Benefit of Electroanatomic Mapping Systems

In patients with complex tachyarrhythmias such as atrial fibrillation and/or atrial tachycardia electroanatomical mapping systems are useful for substrate identification and successful ablation. The accurate identification and modification of complex arrhythmogenic substrates is considered as primary ablation strategy in contemporary ablation procedures. Comparative studies have shown that by means of the 3D electroanatomic mapping systems both, radiation exposure and procedure duration can be significantly shortened versus conventional fluoroscopy-guided atrial fibrillation ablation procedures. Small single-center studies comparing the two systems in atrial fibrillation ablation directly demonstrated similar clinical results, but advantages of Carto® over EnsiteNavX® in terms of fluoroscopy use and procedure durations. There are many limitations of integration of virtual models: (1) different volume status during CT/MRI and during the procedure may result in mismatches of image integration; (2) additional radiation exposure due to CT scans, potential kidney damage or allergic reactions induced by contrast agents; (3) additional logistic and economic burden.

8 Discussion

It has become clear that the introduction and advances of the electroanatomical mapping system technology have facilitate many ablation strategies including but not limited to PV isolation serving as a prerequisite for more complex substrate modification followed by successful treatment of several and different tachyarrhythmias including incessant refractory primary or post-interventional atrial tachycardias. The two most widely used contact-based electroanatomic mapping systems worldwide in the context of atrial fibrillation ablation are the Carto® and EnsiteNavX® systems, which have evolved as the standard electroanatomic

mapping systems today leading to EAMS-based strategies [14–21]. In the last few years, although the electroanatomical mapping technology has been enhanced by integrating data from other imaging modalities, such as computed tomography and cardiac magnetic resonance, the contact-based electroanatomic mapping systems remains the standard of care in most patients, while non-contact and/or multipolar catheters enable high-density mapping of arrhythmias in as few as a single beat. More recently, the remote technology applied to electroanatomic mapping systems has made the ablation procedures shorter in duration, easier, less dependent on fluoroscopy, safer, and last but not least more effective but have reasonable additive costs for hardware installations [25]. Image integration and precise autoregistration of 3D models may result in (1) less fluoroscopy use due to improved awareness of the individual anatomy, and (2) in prevention of complications like pulmonary vein stenosis or esophageal thermal damage [32–39]. Although these potential advantages have not yet been proven in clinical trials, further clinical benefits of image integration remain controversial. Indeed, there are significant limitations of integration of virtual models, which require to be considered and discussed. First, contemporary 3D models represent static representations of a moving organ and not all motion artifacts from the beating heart or respiration can currently be entirely compensated. Second, the different volume status during CT/MRI and during the procedure may result in mismatches of image integration. Further disadvantages relate to the additional radiation exposure due to CT scans, to potential kidney damage or allergic reactions induced by contrast agents, or to an additional logistic and economic burden. In our experience activation mapping using multielectrode catheters should be considered as a standard tool in a modern electrophysiology laboratory particularly in treating complex arrhythmic substrates in patients with cardiomyopathies, who are increasingly referred for catheter ablation. In such patient population enhanced efficacy should be associated with lower risks of the procedure remaining one of the most important goals of future advances in ablation tools.

9 Conclusion and Future Work

The introduction and advancements of electroanatomic mapping systems have facilitated many complex catheter ablation procedures, such as atrial fibrillation ablation or incessant atrial tachycardia. The newer versions of Carto® and EnsiteNavX® systems are very effective and safe and currently are considered worldwide as the standard electroanatomic mapping systems making mapping and ablation procedures shorter, easier, less dependent on fluoroscopy, safer, and more effective with reasonable costs. Due to improved awareness of the individual anatomy, prevention of major complications of complex procedures, such as atrial fibrillation ablation, may be expected, as demonstrated in large multicenter studies. In conclusion, electroanatomical mapping systems have three major clinically relevant advantages. They visualize catheter positions in 3D space during the

procedure without ionizing radiation. They allow the detailed analysis of arrhythmia mechanisms and to guide ablation procedures in patients with complex arrhythmia substrates such as atrial fibrillation. Finally, they allow movement of electrophysiological catheters in a ‘virtual anatomy’ showing the catheter position visualized onto preprocedural and, in the near future, in accurate intraprocedural anatomic images (‘image fusion’). Although the first advantage has been demonstrated in controlled trials, the latter two did so far not undergo rigorous clinical testing. Real-time feedback on tissue-catheter contact and multi-electrode high-resolution mapping with automatic point annotation further increase current mapping tools. Our primary future goal should be to improve effectiveness of mapping with the help of electroanatomic mapping systems through advancement of technologies available, along with implementing state-of-the-art technology in as many electrophysiology labs worldwide with rational cost. In the future, substrate modification in atrial fibrillation ablation should move toward individualized patient-tailored ablation procedures. Magnetic resonance imaging could play a major role for noninvasively describing the localization and extent of fibrotic areas. Specific new strategies that could be used include precise localization and ablation of rotors that maintain the arrhythmia using multielectrode mapping during atrial fibrillation and box isolation of fibrotic areas guided by electroanatomic voltage mapping during sinus rhythm. Predicting the future is hard, but that doesn’t stop us from trying. Advances are getting bigger and bigger and happening more and more quickly.

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