4

3D Mapping and Reduction in Radiation Exposure

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Principles of 3D Mapping Systems

Mapping systems rely on two technologies to achieve localization of catheters: electromagnetic mapping and current or impedance-based mapping.

Electromagnetic location technology uses a magnetic field emitter positioned external to the patient and sensor patches on the patient. A metal coil, embedded within the catheter tip, generates a current when exposed to the magnetic field, which size is dependant upon the strength of the magnetic field and the orientation of the coil within the field. The information is then integrated by the system and graphically displayed on the screen. The catheter is located and visualized by the system with a precision of ≤1 mm. An electromagnetic system is independent from physiologic changes that may occur during the procedure. The use of navigation-enabled specific catheters is necessary.

Advantages of the electromagnetic mapping technology are enhanced precision in localization, spatial resolution, and accuracy with the anatomic model. Disadvantages are the need to use dedicated sensor-enabled catheters only, loss of precision if the patient moves, and extra time needed to construct the virtual anatomic shell.

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Current or impedance-based technology uses a signal of low current and high frequency through the catheters or the patches on the patient's body to locate each catheter within the body of the patient. The accuracy of this system is dependant upon impedance changes that may occur physiologically during the procedure (i.e., development of tissue edema or significant fluid shifts). This is an open architecture that allows any catheter to be visualized.

Advantages of the impedance-based technology are its rapidity in constructing a geometry, the flexibility to use any catheter, and stability even with movement of the patient. Disadvantages include less accuracy in spatial localization and loss of precision if the reference catheter moves.

Initially, mapping systems used either electromagnetic location or impedance-based location. Carto™ was based on magnetic technology and EnSite™ was based on impedance. There were therefore significant differences between the two mainly used systems [1].

Nowadays, all major 3D mapping systems integrate both technologies, Rhythmia™ (Boston Scientific) (Fig. 4.1), Carto3™ (Biosense Webster) (Fig. 4.2), and EnSite Precision™ (Abbott) (Fig. 4.3), and all use a combination of impedance and electromagnetic mapping. All systems therefore require a system-dedicated sensor-enabled catheter, but other catheters can also be used in combination that do not necessarily have sensors. The map is built either with a multipolar

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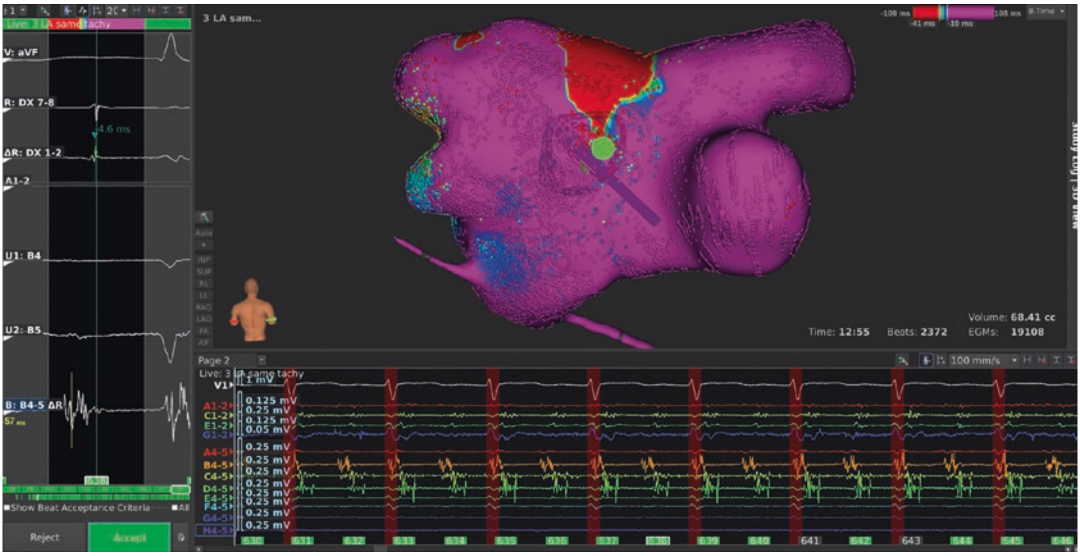

Fig. 4.1 Activation map using Rhythmia™ system (Boston Scientific) along with Orion™ multipolar high-density mapping catheter

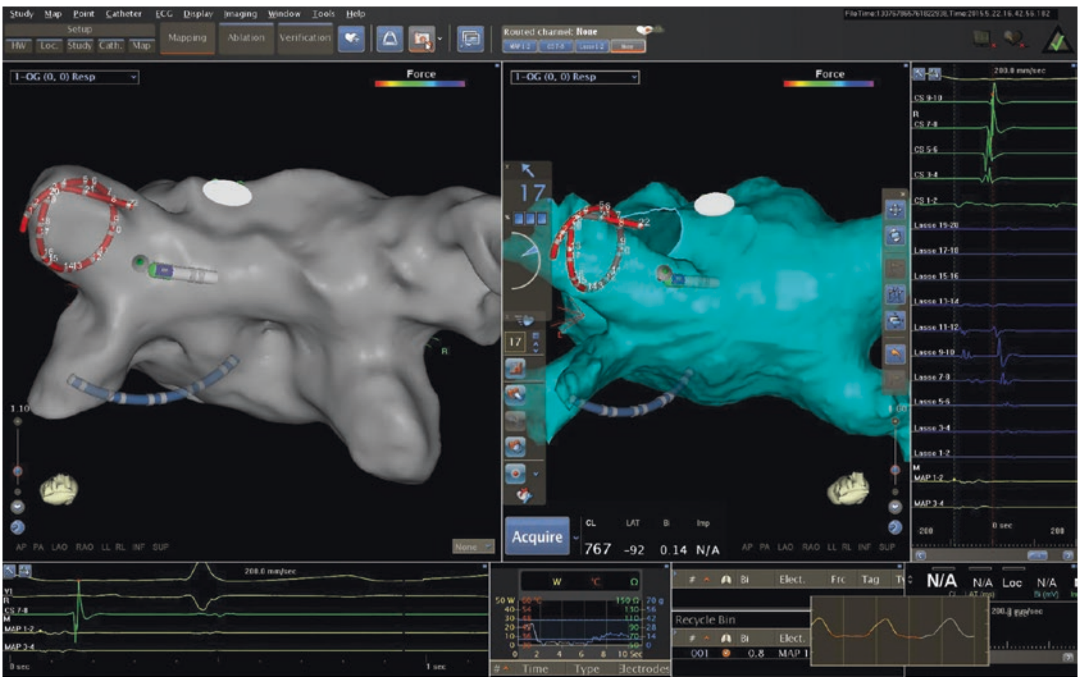

Fig. 4.2 Integration of magnetic resonance imaging (MRI) scan of the left atrium to the anatomic map acquired with Carto3™ (Biosense Webster)

mapping catheter or with the ablation catheter. Anatomic landmarks such as the inferior vena cava, the superior vena cava, and the His bundle are identified and tagged. Depending on the comfort of the operator with the 3D mapping system and his knowledge of the anatomy, the use of fluoroscopy while establishing the landmarks is optional. Once access to the chamber of interest in which arrhythmia will be mapped and/or ablated is secured, a more detailed map of this chamber is

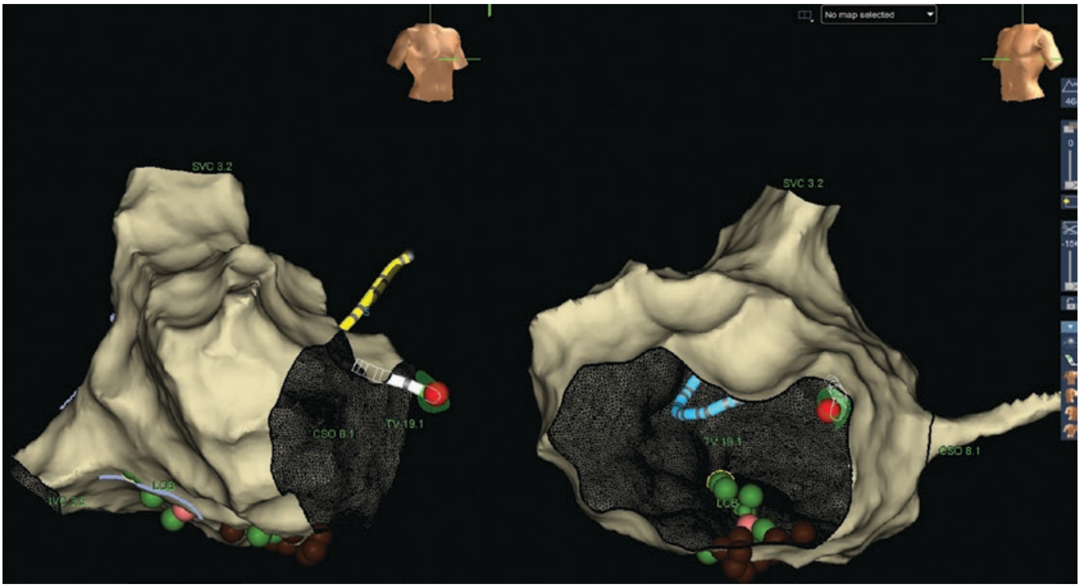

Fig. 4.3 Mapping of the right atrium and ablation of cavo-tricuspid isthmus in a patient with typical atrial flutter using a zero fluoroscopy approach with EnSite Precision™ (Abott)

constructed. Points are taken and integrated by the system inside the heart chamber being mapped and are graphically shown on the screen to form a virtual shell of the cavity. Clues such as electrogram timing and amplitude, electrogram morphology, and impedance are used to define the borders of the chamber and the different anatomical structures. When available, contact force information helps to define tissue contact. The anatomy constructed is then used to guide navigation within the virtual shell. The use of 3D mapping has proven to reduce the use of fluoroscopy [2, 3] and even eliminate the need for fluoroscopy in some cases by some operators especially dedicated to reduce radiation exposure [4–8]. Such procedures have been performed safely with good outcomes [9–11]. For standard noncomplex procedures (supraventricular tachycardia, atrial tachycardia), the complication rates using a nonfluoroscopy approach were 0.85% [11] and 0.8% [9]. The complication rate during atrial fibrillation ablation using a near-zero fluoroscopy approach was 2% in a cohort of 1000 patients, which is comparable to or even lower than the complication rate observed using a conventional approach [10, 12].

Long-term success of ablation of different tachyarrhythmias was 90.8% in a cohort with zero-fluoroscopy procedures [9].

Anatomic Reconstruction

Anatomic reconstruction is most useful for procedures in which the ablation is guided by anatomy such as pulmonary vein isolation for atrial fibrillation, slow pathway ablation for AVNRT (atrioventricular nodal reciprocating tachycardia), or cavotricuspid isthmus ablation for typical atrial flutter (Fig. 4.4).

Activation Mapping

In patients with active ongoing arrhythmia, activation mapping helps to identify the mechanism of arrhythmia (reentry versus focal) and the site of origin of a focus or the critical isthmus in case of a reentrant mechanism. The activation map can be constructed during or after the acquisition of the anatomy by integrating the timing of electrogram at each point compared to a fix reference point. Color is attributed to each point according to its timing compared to the fix reference, colors blue and purple meaning far, late or "cold" related to the reference, getting closer or "heating up" to shades of yellow, and orange and then red to the earliest activation points (white in some systems). Activation mapping is performed

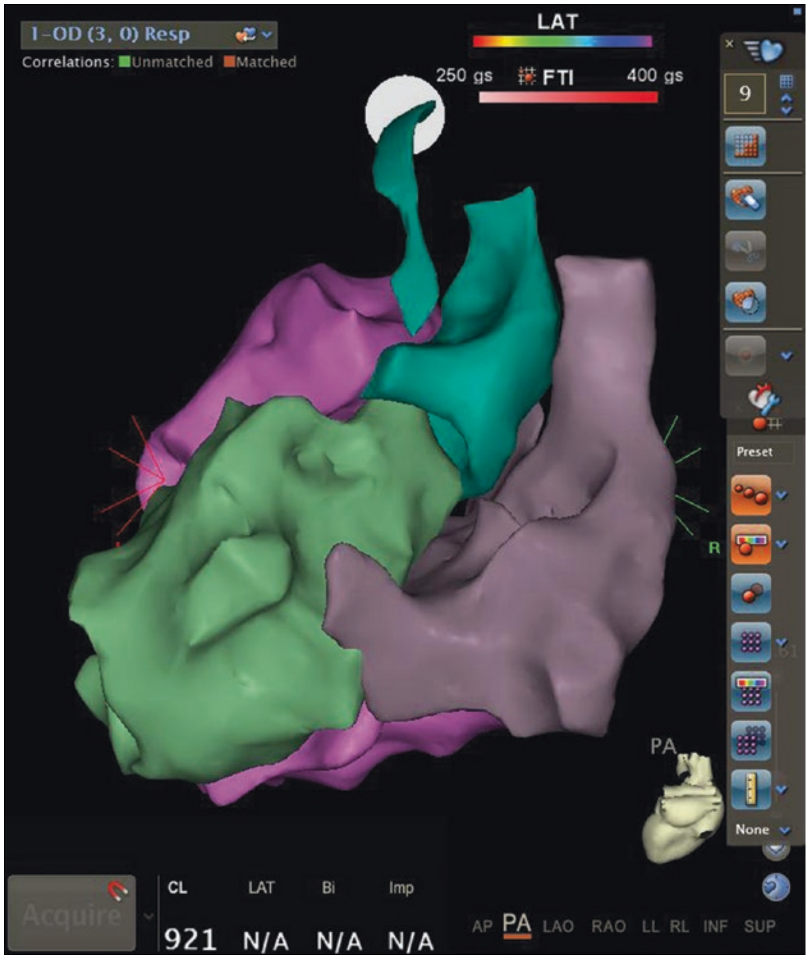

Fig. 4.4 Anatomic reconstruction of the right atrium, right ventricle, aorta, and left ventricle using Carto 3™ without using fluoroscopy

for atrial tachycardia, atrial flutter, premature atrial contractions, stable ventricular tachycardia, and premature ventricular contraction ablation (Fig. 4.5). It can also be used for accessory pathway-mediated reentrant arrhythmias.

Voltage Mapping

To construct a voltage map, signal amplitude is collected at each point. In the ventricle, scar border zone is defined by endocardial amplitude signal 0.5–1.5 mV [13]. Color coding according to the voltage of the signal visually defines endomyocardial scar. This type of map is used in patients with scar-related ventricular tachycardia and atrial arrhythmias and in some isolated cases to guide endomyocardial biopsy [14] or to help with diagnostic such as arrhythmogenic right ventricular tachycardia [15]. In both voltage and activation maps, the density of points collected is important to have adequate resolution and to locate with precision focus or isthmus of the tachycardia.

Ripple Mapping

Ripple mapping is voltage and activation mapping integrated and displayed as moving bars instead of colors [16–18]. The bars are perpendicular to the surface and dynamically protrude out according to the activation time of the local potential. Their length is proportional to the voltage amplitude. The final graphical display is a propagation map.

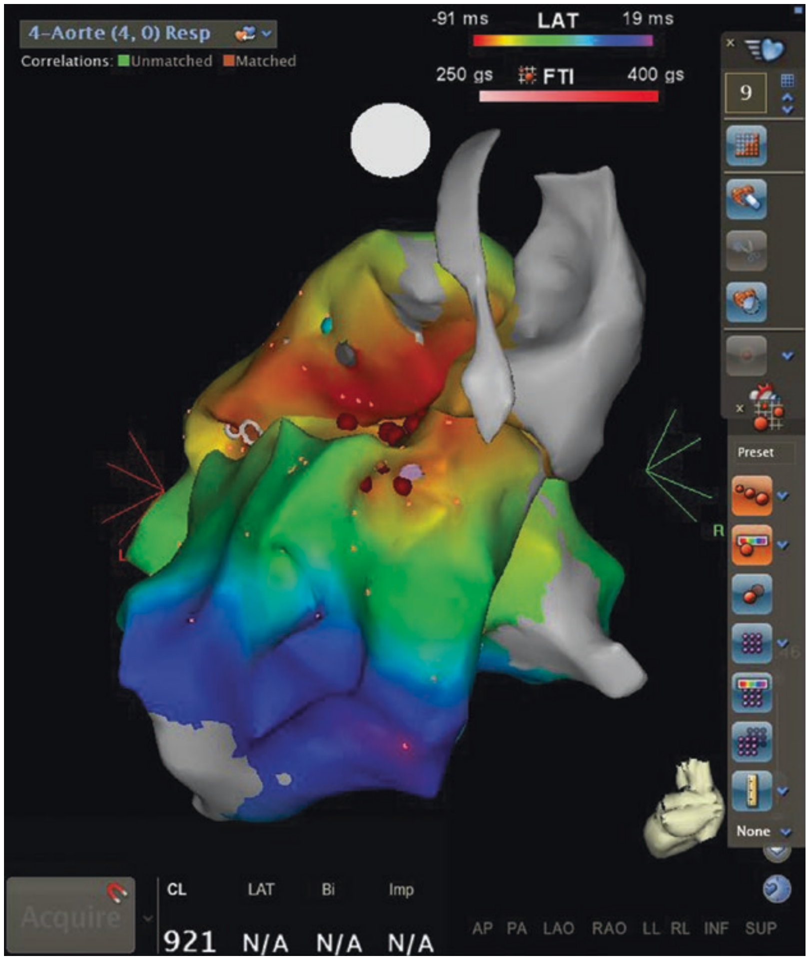

Fig. 4.5 Activation mapping of a PVC arising from the interventricular septum, with activation earliest in the left ventricle and successful elimination after ablation in the right and left ventricle on each side of the septum. The map was created with Carto3™ using no fluoroscopy

All these maps can be performed with minimal or no fluoroscopy since navigation and point collection are performed within the virtual anatomy with excellent reliability. It is even more valuable to reduce radiation in cases of multiple arrhythmias where several maps need to be constructed.

Image Integration

Carto3™ (Biosense Webster) and EnSite Precision™ (Abbott) systems can integrate computed tomography (CT), magnetic resonance imaging (MRI), or rotational angiography images and merge them with the anatomy constructed by the 3D mapping system. It has the advantage to identify unusual anatomies, such as additional pulmonary veins, or anatomical variants such as a common venous pulmonary trunk. It also helps in defining borders such as pulmonary vein antrum. However, care needs to be taken to acquire imaging close to the time of the procedure and during similar rhythm as volume may vary with time and with underlying rhythm. Image integration contributes to reduce or eliminate fluoroscopy during the ablation procedure; however to reduce radiation exposure to the patient and not only to the staff, imaging modalities not using ionizing radiation, such as MRI, should be preferred.

Intracardiac Ultrasound

Intracardiac ultrasound can be used in order to reduce fluoroscopy [19]. Please refer to other chapters for details. However intracardiac ultrasound can also be integrated with the Carto™ system using the CartoSound™ module [20]. Images obtained by the intracardiac ultrasound are used to draw the borders or the walls of the mapped cavity. It is especially useful to draw inner structures such as papillary muscles in the left ventricle or the ridge between the left pulmonary veins and the left atrial appendage in the left atrium and to assess catheter location and catheter stability on such structures. Moreover, points obtained by the mapping catheter are integrated in the ultrasound anatomic images and the location of the catheter is visualized on the ultrasound environment.

Additional Features

Different additional features are available to help ablation procedures. Pacemapping is facilitated by matching a template of the spontaneous or induced arrhythmia and the paced morphology at different points. The Paso™ (Carto, Biosense Webster) or Automap™ (Abbott) modules compare the pacemapped QRS morphology to that of the ventricular tachycardia or premature ventricular beat and calculates a matching score. Both QRS are superimposed so visual assessment of each lead concordance is facilitated. The use of such automated matching improves pacemapping precision compared to visual assessment only [21].

Automated fractionation mapping and complex and fractionated atrial electrogram (CFAE) mapping are also provided by 3D mapping system [22]. The usefulness of such mapping and ablation in patients with atrial fibrillation is still a controversial area [23].

During ablation, all mapping systems tag ablation points. Tags can be manually appointed or can be automatically appointed according to preset criteria such as contact force, energy, and time. Ablation tags are useful to assess lesion contiguity and to recall exact point location.

Differences Between Available Systems

Although the different available 3D mapping and navigation systems share similar basic technology, the different platforms all have distinctive characteristics. The Rhythmia™ system with its dedicated Orion™ multipolar (64 poles) catheter can create ultrahigh-density maps with superior resolution (Fig. 4.1). Carto3™ and EnSite Precision™ each has proprietary modules and functions; for example the CartoSound™ module integrating intracardiac ultrasound with 3D mapping as discussed above is distinctive to Carto™. Both Carto3™ and EnSite Precision™ have contact force-sensing catheter display, available for the ablation catheter.

Advantages of 3D Mapping-Only Ablation (Zero Fluoroscopy Approach)

The use of 3D mapping systems allow to work in a minimal or even no radiation environment. Other advantages include: the need for less localisation catheters since anatomical landmarks can be marked within the anatomic reconstruction, easier and more precise recall of areas of interest whether it is during activation mapping or voltage mapping, visual integration of all collected information. It also saves time if more than one arrythmia needs to be targeted and reduce the risk of having to reschedule a procedure because of unexpected complexity.

Limitations of Current Technology

With most 3D systems only the tip of the catheter is depicted within the map. For almost all instances, it is sufficient, but if the catheter loops inside the vascular system, there is little clue (unexpected extra length of the catheter already inside the vessel, abnormal transmission of force or torque to the catheter) to detect it with the 3D mapping system; future design will help to allow better visualization of a longer distal part of the catheters.

The left atrium is accessed via transseptal using a long sheath and transseptal needle. Future design allowing to visualize the introducer on the mapping system would simplify left atrial access and minimize the need for radiation.

Remote Navigation

Remote magnetic navigation Stereotaxis™ is integrated with 3D mapping (Carto™). Remote robotic navigation Hansen™ is also used in conjunction with 3D mapping. The mapping principles are the same; only catheter steering is done remotely. Radiation to the operator can be significantly reduced since he/she can work remotely outside the field of radiation, and the use of 3D mapping reduces radiation exposure to the patient.

Conclusion

3D mapping is now part of many EP procedures. All systems share fundamental technology, magnetic and impedance; however each system has unique characteristics that differentiate one from another. The optimized use of 3D mapping significantly reduced radiation exposure during EP procedures [24]. As the EP community is getting more and more conscious of deleterious effect of radiation exposure, 3D mapping for navigation, anatomic reconstruction, voltage, and anatomic mapping is increasingly performed by several operators and centers across the world.

References

1. Khaykin Y, Oosthuizen R, Zarnett L, Wulffhart ZA, Whaley B, Hill C, et al. CARTO-guided vs. NavX-guided pulmonary vein antrum isolation and pulmonary vein antrum isolation performed without 3-D mapping: effect of the 3-D mapping system on procedure duration and fluoroscopy time. J Interv Card Electrophysiol. 2011;30(3):233–40.
2. Christoph M, Wunderlich C, Moebius S, Forkmann M, Sitzy J, Salmas J, et al. Fluoroscopy integrated 3D mapping significantly reduces radiation exposure during ablation for a wide spectrum of cardiac arrhythmias. Europace. 2015;17(6):928–37.
3. Estner HL, Deisenhofer I, Luik A, Ndrepepa G, von Bary C, Zrenner B, et al. Electrical isolation of pulmonary veins in patients with atrial fibrillation: reduction of fluoroscopy exposure and procedure duration by the use of a non-fluoroscopic navigation system (NavX). Europace. 2006;8(8):583–7.
4. Yang L, Sun G, Chen X, Chen G, Yang S, Guo P, et al. Meta-analysis of zero or near-zero fluoroscopy use during ablation of cardiac arrhythmias. Am J Cardiol. 2016;118(10):1511–8.
5. Calkins H, Hindricks G, Cappato R, Kim YH, Saad EB, Aguinaga L, et al. 2017 HRS/EHRA/ECAS/APHRS/SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation. Heart Rhythm. 2017;14(10):e275–444.
6. Prolic Kalinsek T, Jan M, Rupar K, Razen L, Antolic B, Zizek D. Zero-fluoroscopy catheter ablation of concealed left accessory pathway in a pregnant woman. Europace. 2017;19(8):1384.
7. Karbarz D, Stec PJ, Deutsch K, Sledz J, Stec S. Zero-fluoroscopy catheter ablation of symptomatic pre-excitation from non-coronary cusp during pregnancy. Kardiol Pol. 2017;75(12):1351.
8. Huang X, Chen Y, Huang Z, He L, Liu S, Deng X, et al. Catheter radiofrequency ablation for arrhythmias under the guidance of the Carto 3 three-dimensional mapping system in an operating room without digital subtraction angiography. Medicine (Baltimore). 2018;97(25):e11044.
9. Giaccardi M, Mascia G, Paoletti Perini A, Giomi A, Cartei S, Milli M. Long-term outcomes after "Zero X-ray" arrhythmia ablation. J Interv Card Electrophysiol. 2019;54:43–8.
10. Sommer P, Bertagnolli L, Kircher S, Arya A, Bollmann A, Richter S, et al. Safety profile of near-zero fluoroscopy atrial fibrillation ablation with non-fluoroscopic catheter visualization: experience from 1000 consecutive procedures. Europace. 2018;20:1952–8.
11. Alvarez M, Bertomeu-Gonzalez V, Arcocha MF, Morina P, Tercedor L, Ferrero de Loma A, et al. Nonfluoroscopic catheter ablation. Results from a prospective multicenter registry. Rev Esp Cardiol (Engl Ed). 2017;70(9):699–705.
12. Cappato R, Calkins H, Chen SA, Davies W, Iesaka Y, Kalman J, et al. Updated worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. Circ Arrhythm Electrophysiol. 2010;3(1):32–8.
13. Hsia HH, Lin D, Sauer WH, Callans DJ, Marchlinski FE. Anatomic characterization of endocardial substrate for hemodynamically stable reentrant ventricular tachycardia: identification of endocardial conducting channels. Heart Rhythm. 2006;3(5):503–12.
14. D'Amario D, Leone AM, Narducci ML, Smaldone C, Lecis D, Inzani F, et al. Human cardiac progenitor cells with regenerative potential can be isolated and characterized from 3D-electro-anatomic guided endomyocardial biopsies. Int J Cardiol. 2017;241:330–43.
15. Corrado D, Basso C, Leoni L, Tokajuk B, Bauce B, Frigo G, et al. Three-dimensional electroanatomic voltage mapping increases accuracy of diagnosing arrhythmogenic right ventricular cardiomyopathy/dysplasia. Circulation. 2005;111(23):3042–50.
16. Linton NW, Koa-Wing M, Francis DP, Kojodjojo P, Lim PB, Salukhe TV, et al. Cardiac ripple mapping: a novel three-dimensional visualization method for use with electroanatomic mapping of cardiac arrhythmias. Heart Rhythm. 2009;6(12):1754–62.
17. Luther V, Cortez-Dias N, Carpinteiro L, de Sousa J, Balasubramaniam R, Agarwal S, et al. Ripple mapping: Initial multicenter experience of an intui-

tive approach to overcoming the limitations of 3D activation mapping. J Cardiovasc Electrophysiol. 2017;28(11):1285–94.
18. Luther V, Linton NW, Koa-Wing M, Lim PB, Jamil-Copley S, Qureshi N, et al. A prospective study of ripple mapping in atrial tachycardias: a novel approach to interpreting activation in low-voltage areas. Circ Arrhythm Electrophysiol. 2016;9(1):e003582.
19. Enriquez A, Saenz LC, Rosso R, Silvestry FE, Callans D, Marchlinski FE, et al. Use of intracardiac echocardiography in interventional cardiology: working with the anatomy rather than fighting it. Circulation. 2018;137(21):2278–94.
20. Khaykin Y, Skanes A, Wulffhart ZA, Gula L, Whaley B, Oosthuizen R, et al. Intracardiac ECHO integration with three dimensional mapping: role in AF ablation. J Atr Fibrillation. 2008;1(2):32.
21. Moak JP, Sumihara K, Swink J, Hanumanthaiah S, Berul CI. Ablation of the vanishing PVC, facilitated by quantitative morphology-matching software. Pacing Clin Electrophysiol. 2017;40(11):1227–33.
22. Wu J, Estner H, Luik A, Ucer E, Reents T, Pflaumer A, et al. Automatic 3D mapping of complex fractionated atrial electrograms (CFAE) in patients with paroxysmal and persistent atrial fibrillation. J Cardiovasc Electrophysiol. 2008;19(9):897–903.
23. Jadidi AS, Arentz T. A decade of CFAE mapping: still seeking more specific tools to identify sources and substrate of persistent atrial fibrillation. Arrhythm Electrophysiol Rev. 2015;4(2):108.
24. Lehrmann H, Jadidi AS, Minners J, Keyl C, Hochholzer W, Carrapatoso F, et al. Important reduction of the radiation dose for pulmonary vein isolation using a multimodal approach. Europace. 2018;20(2):279–87.