Three-Dimensional Mapping of Cardiac Arrhythmias – String of Pearls –

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The evolution of 3-dimensional (D) mapping systems has contributed to improved procedures for ablation of complex tachyarrhythmia in terms of providing detailed anatomical information along with the ability to integrate with pre-acquired computed tomography/magnetic resonance imaging/intracardiac echocardiography images, reducing the radiation exposure, and producing activation and substrate maps. 3-D mapping systems are categorized as magnetic based vs. impedance based according to the catheter location technology, and are also classified as contact based vs. non-contact based according to the data collection technology. Contact-based mapping systems are used widely, in which a series of electrograms is taken sequentially in contact with the heart, thus requiring a relatively stable and sustained arrhythmia to create an activation map. Non-contact mapping systems, however, allow a beat-to-beat analysis of the activation even in non-sustained, polymorphic, or hemodynamically intolerant tachycardia. In this article, the clinical utility of 3-D mapping systems is discussed based on the literature and on experience, with particular emphasis on the non-contact mapping system. (*Circ J* 2012; **76**: 572–581)

Key Words: Ablation; Arrhythmia; Mapping

Three-dimensional (D) mapping systems have made a great contribution to the development of various strategies for treating complex tachycardias.^{1–10} The systems visualize the location of a catheter in 3-D space, and thus allow for the construction of a 3-D anatomical geometry onto which the endocardial activation sequence and voltage amplitude is projected in a color-coded fashion. The technologies for the catheter location and data collection have evolved along with the ability to integrate pre-acquired computed tomography/magnetic resonance imaging/intracardiac echocardiography (CT/MRI/ICE) images into the 3-D mapping system. In this article, the clinical utility of 3-D mapping systems will be discussed with particular emphasis on the non-contact mapping system.

3-D Mapping Systems

3-D mapping systems are categorized as contact-based vs. non-contact-based according to the data collecting technology. Frequently used 3-D mapping systems utilize contact-based technology, in which a series of electrograms is taken sequentially in contact with the heart to create the activation map. These mapping systems use a magnetic-based (CARTO; Biosense Webster, Diamond Bar, CA, USA) or impedance-based (EnSite NavX; St Jude Medical, St Paul, MN, USA) catheter location technology.^{1–10} With regard to the magnetic-based technology, a low-level magnetic field is emitted from a locator pad located under the patient's thorax. A miniature magnetic sensor embedded at the tip of a specialized catheter

detects the magnitude of the magnetic field, which is used for determining the 3-D catheter location. When the catheter is manipulated within the heart, the recorded electrograms are combined with the location of the catheter to create activation and/or voltage maps as a 3-D geometric representation.^{1–5}

In the impedance-based system (NavX), a constant high-frequency and low-level current is emitted between 6 patches that are placed on the skin so as to locate the pair in 3 orthogonal axes (x, y, z), in which 1 patch of each pair acts as a sender of the current, and the other as a receiver. When the fixed electrical current goes through the heart, a voltage shows a linear decrease along its axis between each pair of the patches, depending on the distance from the sender to receiver. Any catheter that is connected to the system and located in between the patches acts as a second receiver, and a 3-D position of the catheter is determined in relation to the positional reference according to the impedance on the catheter. When a mapping catheter is manipulated within a chamber of interest, 3-D geographic geometry is created by automatically acquiring sampling points from nominated electrodes, in which the surface is defined as the area connecting the most distant points. After creating the geometry, field scaling is applied to adjust for the non-linearity of the geometry, which results from the inhomogeneity of the impedance field. Up to 132 electrograms can be recorded by any given catheter, and they are projected on the pre-acquired 3-D geometry to create activation or substrate maps.⁶

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Table. Comparison of 3-D Mapping Systems

	CARTO3	EnSite NavX (Velocity)	EnSite Array
Catheter navigation technology	Magnetic based	Impedance based	Impedance based
Mapping data collection	Contact based/multi-beat	Contact based/multi-beat	Non-contact based/1 beat
Image integration	MRI, CT and ICE	MRI, CT and rotational angiography	None
Geometry creation			
Catheters to use	Navistar or LassoNav	Any catheter	Any catheter
Max no. electrodes	1 or 10 or 20	132	4
Max no. catheters	1	No limit	2
Contact map construction			
Catheters to use	Navistar	Any catheter	Any catheter
Max no. electrodes	1	132	4
Max no. catheters	1	No limit	2
Catheter visualization			
Catheter	Any catheter (ACL)	Any catheter	Any catheter
Max no. electrodes	80	132	4
Max no. catheters	7	No limit	2
Adjustment for the non-linearity of the geometry	Not necessary	Field scaling	Not necessary
Catheter used for ablation	Navistar only	Any ablation catheter but Navistar	Any ablation catheter but Navistar
Special considerations	Magnetic coil apparatus is required beneath the patient's thorax, and cutaneous patches are required.	Six cutaneous patches emitting low-level electrical current must be placed on the skin.	MEA is required. The geometry and VUE are reliable within 40mm of the center of the MEA.

ACL, advanced catheter location; CT, computed tomography; ICE, intracardiac echocardiography; MEA, multi-electrode array; MRI, magnetic resonance imaging; VUA, virtual unipolar electrogram.

Non-Contact Mapping Systems

The non-contact mapping system (EnSite Array, St Jude Medical) consists of a 9-Fr catheter with a multi-electrode array (MEA) over a 7.5-ml balloon on the top of the catheter.⁷⁻¹⁰ The MEA is adequately placed within a chamber of interest and used to record far-field electrograms from the endocardial surface. This system creates a 3-D geometry by tracing the endocardial surface with a mapping catheter in contact with the surface, from which a low-current alternative electrical signal is emitted from the distal and proximal electrodes of the MEA. It is also used to display the electrodes of a catheter in 3-D geometry space. After creation of the geometry, more than 3,300 virtual unipolar electrograms are created from the far-field global unipolar electrograms using an inverse solution of Laplace's equation with a boundary element method, and they are projected onto the corresponding sites in the geometry. These virtual unipolar electrograms are calculated for every beat in real time, and thus the non-contact mapping system provides both activation and voltage maps on a beat-to-beat basis. The validation of the virtual unipolar electrogram against the real unipolar electrogram taken directly from the corresponding surface of the heart is excellent.

Electrograms recorded in a healthy atrium or ventricle exhibit spectral components between 4 and 16 Hz, whereas those recorded in a slow conduction zone are low frequency and range from 1 to 4 Hz.⁷ The default setting of the band-pass filter of the virtual unipolar electrogram in the non-contact mapping system is set between 2 and 300 Hz in the atrium and from 8 to 300 Hz in the ventricle. The high-pass filter settings are important for visualizing early low-frequency and/or low-amplitude signal components and suppress the repolarization-related far-field signal elements, which is a trade-off relationship. When the high-pass filter is set high in order to remove

the repolarization components from the electrogram, the morphology of the unipolar electrogram is sharpened and comes to resemble the bipolar electrograms, whereas if the high-pass filter is set low, the repolarization-related far-field noise will contaminate the electrogram, making it difficult to exhibit the true local electrogram.

Clinical Utility of the 3-D Mapping System: Advantages and Shortcomings

All 3-D mapping systems enable non-fluoroscopic manipulation of a catheter, leading to a 40–80% reduction in radiation exposure.^{8,9} The reduction greatly benefits patients, physicians and a wide range of laboratory staff members because estimates of between 0.3 and 2.3 excess fatal malignancies per 1,000 patients for each hour of fluoroscopy have been reported.^{8,9}

There are advantages and drawbacks of each 3-D mapping system (Table). In all the systems, dislocation of the positional reference causes a miss-alignment of the geometry map. The transition of tachycardia to another hampers an accurate construction of maps. Therefore, attention should be paid not to move the reference catheter and change a tachycardia. Contact-based technology requires a relatively stable and sustained arrhythmia because it collects sequential data from various points in order to create an activation map on the assumption that the same tachycardia mechanism goes on until the end of the mapping. Sequential contact mapping is time-consuming, especially when a single catheter is used, and thus the contact-based mapping technology is not suitable for elucidating the activation of non-sustained, polymorphic or hemodynamically unstable tachycardias.

In order to create an accurate map using the non-contact mapping system, there are some technical points to note. In

Figure 1. Representative cases of atrial tachycardia (AT) examined within the RA. Case 1, focal AT (FAT) originating from the crista terminalis (CT). Case 2, macroreentrant AT (MRAT) rotating around the incisional scar (SCAR). Case 3, FAT originating from the coronary sinus (CS) ostium. Case 4, FAT originating from the right atrial appendage (RAA). Case 5, FAT originating from the tricuspid annulus (isochronal map). Case 6, AT originating from the His bundle region. IVC, inferior vena cava; SVC, superior vena cava; TV, tricuspid valve. (Reproduced with permission from Narita et al, *Circ J* 2010; **74**: 59–65.)

remote areas >4.0 cm from the center of the MEA, the reliability of the virtual unipolar electrogram is attenuated. The high-pass filter setting should be adequately lowered to visualize the slow conduction in the particular region or explore the region with contact mapping. It is challenging to accurately visualize activation within a tubular structure using non-contact mapping, and this is called a “line-of-sight issue”. Therefore, the virtual electrograms around tubular anatomical structures such as the pulmonary vein (PV), and superior and inferior vena cavae (SVC/IVC) are less reliable, and thus these structures should be cut out from the proximal portion to avoid this phenomenon. Owing to these technical limitations, there are some limitations in the clinical utility of non-contact mapping system-guided ablation. It does not appear to be suitable for any tachycardia originating from a huge cardiac chamber and a macroreentrant tachycardia involving an area with very-low-amplitude electrograms. This system requires heavy heparinization, with a recommended activated coagulation time of >200 s in the right side of the heart and >300 s in the left side of the heart, therefore, those for whom heavy anticoagulant use is not suitable, are not indicated to use this system.

Atrial Tachycardia (AT)

AT is classified as focal vs. macroreentrant from the standpoint of the activation pattern analyzed by the 3-D mapping systems. Focal AT has a discrete focal activation from which subsequent activation spreads out radially toward the entire atrium, but in some patients, activation from an AT focus is

conducted over a preferential pathway to a break-out point, from which subsequent activation proceeds toward the entire atrium in a centrifugal pattern.^{10–17} Typically, the activation map of the chamber shows the activation during only a portion of the AT cycle length, usually <50%, whereas in a macroreentrant AT the total conduction time within the chamber of origin accounts for at least 90% of the tachycardia cycle length with a specific “head-meets-tail” activation pattern.² The focal AT results from diverse mechanisms including abnormal automaticity, triggered activity and microreentry.^{12,13} Focal ATs have some anatomically common sites including the crista terminalis, coronary sinus (CS) ostium, and tricuspid annulus in the right atrium (RA), and PVs, atrial septum and mitral annulus in the left atrium (LA). At the AT focus, pre-systolic potentials or fragmented electrograms are recorded preceding the P wave by at least 30 ms along with a q-QS or QS morphology in the unipolar electrogram recording.¹¹

Most macroreentrant ATs are related to scar and/or anatomical obstacles except for ATP-sensitive AT originating from the His bundle region.^{14–17} The location of scar is easily identified by voltage mapping as an area with a low voltage (peak-to-peak bipolar electrogram <0.5 mV) or no voltage at all. The scar-related macroreentrant AT results from previous open heart surgery or previous radiofrequency (RF) catheter ablation,¹⁴ but no obvious cause is found in some cases.^{15,16} Contact-based 3-D mapping systems work well to locate narrow conduction channels, which are good targets for ablation. In the non-contact mapping system, the virtual activation map of the AT superimposed on a pre-acquired voltage map during

Figure 2. Representative cases of atrial tachycardia (AT) examined within the left atrium (LA). Case 1, focal AT (FAT) originating from the LA appendage (LAA). Case 2, FAT originating from left superior pulmonary vein (LSPV). Case 3, FAT originating from the LA septum. Case 4, macroreentrant AT rotating around the anterior LA (isochronal map). Case 5, FAT originating from the posterior LA. LIPV, left inferior pulmonary vein; MV, mitral valve; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein. (Reproduced with permission from Narita et al, *Circ J* 2010; **74**: 59–65.)

Figure 3. Examples of multi-electrode array (MEA) placement for ventricular tachycardia/premature ventricular contraction (VT/PVC) originating from (A) the right ventricular outflow tract, (B) aortic sinus cusp, (C) anterior or lateral left ventricle, and (D) septal, posterior or inferior left ventricle. The MEA was placed via the antegrade trans-septal approach in (B,C), and via the retrograde transaortic approach in (D). ABL, ablation catheter; LAO, left anterior oblique; MV, mitral valve; RAO, right anterior oblique. (Reproduced with permission from Miyamoto et al, *Circ J* 2010; **74**: 1322–1331.)

Figure 4. Non-sustained ventricular tachycardia (VT) originating from the lateral wall of the right ventricle (RV). (A) Twelve-lead electrocardiogram during a premature ventricular contraction (PVC) with left bundle branch block and left axis deviation. (B) Contact voltage map of the RV obtained during sinus rhythm in the right anterior oblique (RAO) and left anterior oblique (LAO) projections. There is no low-voltage zone detected in the RV. (C) VT virtual activation map showing that the VT is originating from the lateral wall of the RV. Red arrows, activation direction. The earliest activation site was identified at the lateral wall of the RV, and the electrogram at the site preceded the QRS by 40 ms. The virtual unipolar electrogram at the VT origin has a QS deflection. Radiofrequency ablation was performed at the VT focus, which resulted in the abolition of the VT. Brown, red circles, sites of successful ablation. TV, tricuspid valve; RVOT, right ventricular outflow tract. (Reproduced with permission from Miyamoto et al, *Circ J* 2010; **74**: 1322–1331.)

sinus rhythm is useful for identifying the critical narrow conducting isthmus, especially in those with non-sustained AT or hemodynamically unstable AT.

We examined how non-contact mapping-guided ablation works to eliminate AT in 51 patients with 74 ATs, 14 patients of whom underwent previous open heart surgery, and 5 of whom had structural heart disease.¹⁸ Figures 1,2 show representative cases of ATs originating from the RA (Figure 1) and LA (Figure 2). RF ablation was performed at the AT focus for focal AT with an endpoint of AT termination and subsequent non-inducibility (n=48), and it was performed at a critical conducting pathway for reentrant AT with creation of a block line in the critical reentry circuit (n=26). All but 1 AT were successfully eliminated by RF ablation without any complications and the long-term success rate was 98%. The data showed that non-contact mapping-guided RF ablation was safe and effective for AT, irrespective of its mechanism or sustainability and regardless of any underlying heart disease.

Ventricular Tachycardia (VT)

VT is classified as idiopathic or as associated with structural heart disease. In the latter, various ablation strategies using a contact-based 3-D mapping system have been established and are widely accepted.^{19–26} The non-contact mapping system works well in the ablation of hemodynamically unstable VT, polymorphic VT and non-sustained VT.^{24,25} VT is also classified as focal or macroreentrant according to the map presentation, as with AT. The main mechanism of VT associated with structural heart disease is macroreentry (91%), with a second major mechanism of focal VT (9%).²⁶ In contrast, idiopathic VTs result either from focal or macroreentrant mechanisms with a similar prevalence, especially in Japan.²⁷

We studied 55 patients with 79 VTs/premature ventricular contractions (PVCs) who underwent non-contact mapping-guided VT ablation, of whom 7 had organic heart disease. Sixty-six VTs/PVCs originated from the right ventricle (RV) including the RV outflow tract in 57, lateral wall in 4, His bundle region in 3 and tricuspid annulus in 2, while 10 VTs/PVCs originated from the left ventricle (LV) including the LV

Figure 5. Ventricular tachycardia (VT) originating from the left ventricle (LV) endocardium. **(A)** Twelve-lead electrocardiogram during an induced non-sustained VT. The VT had a right bundle branch block pattern with a superior axis and ventricular rate of 198 beats/min. **(B)** Multi-electrode array (MEA) positioning in the right anterior oblique (RAO) and left anterior oblique (LAO) projections. The MEA was placed into the LV via the retrograde transaortic approach to locate the MEA tip near the posteroinferior wall of the LV. Two deflectable electrode catheters were introduced into the LV by transaortic (map 1) and trans-septal (map 2) approaches to create the LV geometry and construct a contact voltage map. **(C)** Contact voltage map during sinus rhythm (SR) in the RAO and posteroanterior (PA) projections. A low-voltage zone (LVZ) defined as an area with a voltage amplitude of <1.2 mV is present on the posteroseptal wall of the LV. Purple, voltage >1.2 mV. A VT virtual activation map superimposed on the contact voltage map indicates macroreentrant activation, and shows the entire reentrant circuit of the VT, in which the activation slowly passes through the LVZ. Red arrow, direction of the VT activation. The contact bipolar electrograms during SR exhibit fragmented electrograms along the slow conducting pathway within the LVZ. B-LV, B-RV, biventricular pacing leads located in the LV and RV; RA, right atrium; RV, right ventricle. (Reproduced with permission from Miyamoto et al, *Circ J* 2010; **74**: 1322–1331.)

endocardium in 7 and aortic sinus cusp in 3. The number of VTs was 38, with sustained VT in 6 and non-sustained VT in 32. The MEA was strategically placed as close as possible to the focus for focal VTs/PVCs and at the exit site for macroreentrant VTs estimated on 12-lead electrocardiogram (ECG; **Figure 3**). RF catheter ablation eliminated all but 3 focal PVCs, and all macroreentrant VTs at a critical conduction pathway. Representative cases of non-sustained VT and hemodynamically intolerant VT are shown in **Figures 4,5**. We failed to eliminate 3 PVCs with an epicardial origin, which were indicated by the presence of tiny r waves in the initiation of the virtual unipolar electrogram at the earliest activation site. All patients with acute success were free of any symptoms during a follow-up period of 21 ± 11 months. We think that non-contact mapping-guided ablation is safe and effective for VT/PVCs, irrespective of their origin, mechanism, sustainability, hemodynamic condition, or underlying heart disease.

Atrial Fibrillation (AF)

There are some excellent reviews that deal with the current strategies of AF ablation utilizing contact-based 3-D mapping technology.^{28,29} Therefore, I will mainly discuss the findings for non-contact-based 3-D mapping systems in this article. There is a huge variation in the LA and PV anatomies, and thus preoperative CT/MRI/ICE imaging is important to determine accurate anatomical characteristics. The size of the LA and PVs is known to be larger in patients with AF than in controls. Kato et al reported that variation in the PV anatomy was found in 38% of AF patients on MRI, including a short common left PV trunk, long common PV trunk, right middle PV branch(s), and an anomalous “roof” vein distinct from the right superior PV.³⁰

The PVs play an important role in initiating and maintaining AF in AF patients, and PV isolation is the cornerstone of all procedures of AF ablation,^{31,32} in which AF is eliminated

Figure 6. Representative pulmonary vein (PV) map created during coronary sinus (CS) pacing in a patient with a left common PV (LCPV). (A) PV map showing a conduction gap (GAP) at the posterior part of the antrum of the LCPV. Electrogram, that recorded at the conduction gap. The morphology was simple with an amplitude of 1.14 mV. (B) Position of the ablation catheter (ABL) located on the conduction gap and that of the circular mapping catheter (CMC), which was located at a distal portion of the LCPV. (C) Fluoroscopic view from the left anterior oblique (LAO) projection showing the ABL and CMC. (D) Point ablation at the conduction gap, which eliminated all the PV potentials (PVPs). (A,B) posteroanterior view; (C) LAO view. CPVA, circumferential pulmonary vein antrum ablation; EAS, earliest site; MAP, mapping catheter; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein. (Reproduced with permission from Miyamoto et al, *Circ J* 2011; **75**: 2363–2371.)

in 80–90% of those with paroxysmal AF and in 60–70% of those with persistent AF, depending on the ongoing AF duration.^{28,29} Non-PV foci are also found in 20% of AF patients,³³ which is related to recurrence after PV isolation. Episodes from non-PV foci are unpredictable and transient, and can easily change into AF. Non-contact mapping is useful in predicting these episodes because it visualizes the activation on a beat-to-beat basis. We examined 75 patients with paroxysmal AF using the non-contact mapping system. All 75 patients had ectopies initiating AF or AT; 48 of these patients had PV foci alone (59 foci) and 17 had non-PV foci (19 foci).³³ It was noted that 71% of the patients with non-PV foci had PV foci as well. The non-PV foci were frequently located at the LA roof and SVC, with less frequent locations in the LA, RA, CS ostium and so on. Interestingly, ongoing AF was terminated by PV antrum isolation alone in 92% of the patients with PV foci alone, whereas it was terminated in 29% of the patients with non-PV foci, suggesting that non-PV foci contribute to the maintenance of the AF.

A PV antrum isolation is superior to a segmental ostial isolation with regard to long-term efficacy and prevention of PV

stenosis.³⁴ Identifying the site of a conduction gap on the PV antrum line, however, is sometimes challenging. We developed a PV map technique for a quick identification of the conduction gap after 1 round of PV antrum isolation (PVAI) with the use of a 20-pole circular mapping catheter and NavX.³⁵ PV map constructed from 71±37 sampling points indicated 1.4±0.7 gaps per PV antrum with a procedure time of 101±46 s, where the electrogram amplitude was 0.8±0.7 mV. A point ablation at the gap completely isolated 24 out of 26 PV antra (92%), with 1.9±1.3 applications. A representative PV map is shown in Figure 6.

The PVAI may be insufficient in patients with the AF substrate in the LA body, CS and RA, especially in those with long-lasting persistent AF. In these patients, LA substrate ablation is performed, which targets complex fractionated atrial electrogram (CFAE) and sites with the dominant frequency and ganglionated plexi (GP).^{36,37} LA lines creation at the LA roof, mitral isthmus and septal area are also known to be useful to modify the LA substrate.³² The non-contact mapping system is useful to quickly confirm the completeness of the line of block. Recently, Oakes et al reported that the extent of

Figure 7. Virtual activation map of peri-mitral atrial tachycardia (AT); left atrial (LA) roof reentrant AT; peri-left atrial appendage (LAA) AT; pulmonary vein (PV) AT; LA inferior AT; and an isochronal map of an LA anterior localized AT. LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; MV, mitral valve; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein. (Reproduced with permission from Nagamoto et al, *Circ J* 2011; **75**: 1080–1089.)

the delayed enhancement in the LA shown on cardiac MRI, which was well correlated with the low-voltage zone on the CARTO map, predicted outcome after AF ablation.³⁸ We examined how the low-voltage zone was related to the local conduction velocity and electrogram morphology in those with an early stage of AF.³⁹ We found that the low-voltage zones were mainly distributed along the septal, anterior and posterior LA, and those with a low-voltage zone had a longer total activation time than those without (107 ± 25 ms vs. 85 ± 13 ms, $P < 0.05$). We also found that the conduction velocity was slower in the areas with a low-voltage zone as compared to those without (1.4 ± 0.6 mV vs. 0.8 ± 0.5 mV, $P < 0.01$) and that they had a higher prevalence of double or fragmented electrograms. Those with low-voltage zones had a lower prevalence of AF termination by PVAI alone compared with those without a low-voltage zone, suggesting that the low-voltage zone functioned as an AF substrate to maintain it. We further addressed the significance of the low-voltage zone in 20 AF patients in relation to CFAEs.⁴⁰ In that study, a voltage map was constructed during SR, and a CFAE map was created during ongoing AF, and a comparison between the extent of the CFAE area and low-voltage zone was made to examine their relationship. CFAEs were defined as having a mean AF-CL < 120 ms over a 5-s period. Interestingly, the electrogram amplitude during sinus rhythm was higher at the CFAE sites than at the non-CFAE sites (2.4 ± 1.7 mV vs. 1.9 ± 1.9 mV, $P < 0.0001$), whereas fractionated or double electrograms were found in a similar range between the two areas (2% vs. 3%, $P < 0.21$). When analyzed further in terms of the AF termination by PVAI alone, the voltage of the electrograms at the

CFAE sites was lower (2.1 ± 1.7 mV vs. 2.6 ± 1.8 mV, $P < 0.0001$), and the morphology was more complex in the patients without AF termination as compared with those with AF termination. The data suggested that the CFAE sites in patients with AF termination by PVAI alone represent healthy atrial tissue with rapid electrical activity in response to an AF driver located in the PVs. In patients without AF termination, however, they represent more damaged tissue responsible for maintaining the AF.

The long-term results of AF ablation are largely satisfactory, but there are some serious complications, including atrioesophageal fistula, PV stenosis and secondary AT.^{41,42} Secondary AT is categorized as occurring during the ablation procedure, and late secondary AT as that occurring after the procedure. We characterized early secondary AT that occurred during AF ablation during ongoing AF, using the non-contact mapping system in 33 patients with 46 ATs, consisting of either a sustained form ($n=39$) or non-sustained form ($n=7$) (Figure 7).⁴³ Nineteen ATs were due to a focal mechanism with the major foci in the PVs ($n=8$) and LA roof ($n=3$), and 27 ATs resulted from a macroreentrant mechanism with a reentrant circuit around the mitral annulus ($n=10$), around the tricuspid annulus ($n=10$) or that involving the LA roof ($n=3$). After ablation targeting the critical area, 41 ATs in 28 patients (85%) were eventually rendered non-inducible, and 30 of the 33 patients (91%) were free from any recurrence on a follow-up period of 21 ± 8 months. It was noted that macroreentrant AT can be further divided into 2 categories: gap-related AT and non-gap-related AT. Gap-related macroreentrant AT is a man-made tachycardia in which activation passes through a

conduction gap in a prior incomplete ablation line, and includes PV reentrant AT, peri-mitral AT, LA roof reentrant AT and peri-LA appendage AT. The remaining category of macroreentrant AT, or non-gap-related AT, seems to be a secondary consequence of AF termination and includes common atrial flutter, peri-mitral AT, LA roof reentrant AT, septal AT and LA anterior wall-localized AT. Early secondary AT should be ablated when it presents as a pre-ablation AT or an early secondary AT resulting from a focal or gap-related macroreentrant mechanism. Non-gap-related AT except for common atrial flutter can be left untreated and can be monitored.

Future Directions

Recently, a hybrid of the magnetic- and impedance-based catheter location technologies has been introduced (CARTO 3; Biosense Webster), which allows display of multiple electrodes with an accurate anatomical location on a 3-D representation. Also, a hybrid of the magnetic-based catheter location technology and angiography system has recently been introduced (MediGuide; St Jude), which locates the catheter position using magnetic technology, and displays its electrode icons in real time on a previously acquired fluoroscopy image.

In the future, next-generation mapping will utilize more advanced hybrids of electroanatomical mapping, in addition to more sophisticated integration of CT/MRI/ICE, which will facilitate fast and accurate identification of tachycardia substrate.

Disclosures

Conflict of Interest: T.T. has served as a speaker and consultant for Nihon Kohden and St. Jude Medical.

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