The advantages of ultra-high-definition (UHD) mapping are presented in the context of different atrial arrhythmias, whether focal or macroreentrant. Not only are these sophisticated systems time-saving, but they also allow accurate identification of the substrate (scar quantification), as well as a more precise characterization of the critical isthmuses or focal sources of the atrial circuits. UHD mapping may become a standard approach for their curative treatment. This new technology allows automatic acquisition and accurate annotation of the electrograms, without the need for manual correction. Owing to better resolution, critical isthmuses and low-voltage regions of interest may now be successfully targeted without the need for entrainment maneuvers. Finally, the system also allows rapid assessment of the completeness of the lesions once delivered. (Circ J 2016; 80: 579–586)

Key Words: Activation mapping; Atrial tachycardia; Ultra-high-definition mapping

Percutaneous radiofrequency (RF) catheter ablation is a validated treatment of most atrial arrhythmias, including atrial flutter (AFL), paroxysmal/persistent atrial fibrillation (AF), and atrial tachycardias (ATs). An international classification for ATs was established in 2001, based on conventional mapping techniques and, at that time, the limited access to computerized electroanatomical mapping (EAM) systems. The latter depend on different mechanisms such as macroreentry or focal (localized microreentry or automaticity). Since then, understanding of the precise mechanisms for these organized arrhythmias (AFL/ATs) has evolved in parallel with technological innovations and improvements. It is known that ATs (spontaneous or in preexisting lesions such as surgery or after AF ablation) can manifest with an AFL electrical activity within the pulmonary veins (PV). Techniques using computerized EAM systems consist of operator-dependent acquisition of bipolar electrograms (EGMs) from a single pair of electrodes (using the distal bipole of the mapping catheter), according to a chosen and predefined intracardiac reference. Recently, multipolar catheters have been developed especially for multi-EGM acquisition (PentaRay Nav®, Biosense Webster; Orion®, Boston Scientific). The newly released EAM systems now allow fast and fully-automatic acquisition with accurate automatic annotation of multiple EGMs during activation mapping. These recent systems allow better definition of the circuits, and accurate identification of the targets that need to be abolished.

After a brief historical review, we will emphasize the various advantages of these ultra-high-definition (UHD) systems for RF ablation of atrial arrhythmias.

**From Conventional (Sequential Activation) to EAM**

Since the first recordings of His bundle activity in humans in 1957 by Latour and Puech, using a single unipolar electrode (Eynard catheter), tachycardias were sequentially mapped using the same technique.

Rapidly, the need for simultaneous multiple sites recordings promoted the development of multipolar catheters. The first multipolar catheters (>4 electrodes) were used for accessory pathway mapping, but also for cavotricuspid isthmus (CTI) RF ablation. These catheters not only allowed fast mapping of the tachycardia, but also immediately after ablation the rapid characterization of the activation sequence, when obtaining a complete block of conduction. After the dedicated catheter for crista terminalis mapping, the most popular are circular mapping catheters that have been developed to map the electrical activity within the pulmonary veins (PV).

Linear multielectrode catheters (14 with an interelectrode distance of 3 mm) were also designed to perform linear RF ablation lesions.

Finally, EAM systems decreased the radiation exposure for both patients and physicians, but were also more precise in terms of catheter visualization and manipulation within a 3D perspective instead of the classical biplane fluoroscopy.

**From Single to Multielectrode Activation Mapping With Electroanatomical Systems: From Regular to High-Definition Mapping**

Many multielectrode mapping (MEM) catheters are now com-
Non-linear closely spaced multi-electrode catheters have the advantage of fast mapping in 2 orthogonal planes. Multiple ATs may arise in a single patient, especially after extensive AF ablation or in pathological atria, and in this situation single-point activation mapping with the ablation catheter can be time-consuming, whereas MEM has proved to be superior in the speed of acquisition, and higher resolution. Another advantage reported by Anter et al was that multielectrode catheters allow more constant capture of the tachycardia because of higher current density.

As shown below, some recent studies have validated the superiority of MEM for AT RF ablation, over the conventional sequential point-by-point acquisition (PBP), but in both cases each EGM must be validated by the operator. In a study of 33 AT occurring after AF ablation where the PentaRay® catheter was used with the NavX system, 365 ± 108 points per map were acquired within 8 ± 3 min, which eventually led to an ablation acute success rate of 96% in 8.3 min. Yet no comparison was made with the PBP technique. We prospectively evaluated it in our laboratory in the same post-AF ablation ATs model, in comparison with the PBP technique (n=16 patients per group). It was found that not only was the mapping time considerably reduced using MEM (26 ± 14 min per AT in the PentaRay® group vs. 33±25 min; P<0.04), but it was also associated with an important increase in map resolution (449±520 vs. 42±18 EGMs in the PBP group). Overall, we think that whenever possible, MEM commercially available, mostly for contact mapping [eg, PentaRay® or Lasso® (Biosense Webster); Inquiry™ or Reflexion HD™ (Saint-Jude Medical), Achieve™ (Medtronic)], and less frequently for non-contact mapping [EnSite Array™, Saint-Jude Medical]. During AF ablation procedures, for example, they may be used during either tachycardia or sinus rhythm for: (1) rapid anatomical mapping and geometry creation of the left atrial (LA) shell; (2) PV mapping and confirmation of persistent isolation; (3) voltage mapping to identify reconnected or atrial fibrotic regions; (4) complex fractionated atrial EGM mapping using dedicated software during ongoing AF; (5) activation mapping when AF terminates and converts into AT, or voltage mapping during sinus rhythm to identify putative channels of activation; and finally, possibly to deliver RF itself. Non-linear closely spaced multielectrode catheters have the advantage of fast mapping in 2 orthogonal planes.

Multiple ATs may arise in a single patient, especially after extensive AF ablation or in pathological atria, and in this situation single-point activation mapping with the ablation catheter can be time-consuming, whereas MEM has proved to be superior in the speed of acquisition, and higher resolution. Another advantage reported by Anter et al was that multielectrode catheters allow more constant capture of the tachycardia because of higher current density.

### Table. Procedural Data During Ultra-High-Definition Mapping for Atrial Arrhythmias Ablation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>46</td>
</tr>
<tr>
<td>Age (years)</td>
<td>64.1±11</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>Typical flutter=9, Persistent AF=13, Post-AF AT=20, Focal AT=4</td>
</tr>
<tr>
<td>Total no. of maps</td>
<td>182</td>
</tr>
<tr>
<td>Mean mapping time per map (min)</td>
<td>16.9±14.5</td>
</tr>
<tr>
<td>Mean no. of electrograms per map</td>
<td>13,724.3±13,152</td>
</tr>
<tr>
<td>Total procedure time (min)</td>
<td>232±78</td>
</tr>
<tr>
<td>Total fluoroscopy time (min)</td>
<td>15.9±8</td>
</tr>
</tbody>
</table>

AF, atrial fibrillation; AT, atrial tachycardia.

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**Figure 1.** Three-dimensional multielectrode activation map (Confidense®, Biosense Webster) of a left atrial tachycardia (with corresponding ECG in (A)), occurring in a 77-year-old female patient with previous mitral valve repair and Maze procedure with epicardial cryoablation. The map shows a roof-dependent macroreentry with a visible gap in the anteroposterior (B) and right lateral (C) projections. Radiofrequency applications terminated the tachycardia when delivered within the scar (grey dots) close to the visual gap.

As shown below, some recent studies have validated the superiority of MEM for AT RF ablation, over the conventional sequential point-by-point acquisition (PBP), but in both cases each EGM must be validated by the operator. In a study of 33 AT occurring after AF ablation where the PentaRay® catheter was used with the NavX system, 365±108 points per map were acquired within 8±3 min, which eventually led to an ablation acute success rate of 96% in 8.3 min. Yet no comparison was made with the PBP technique. We prospectively evaluated it in our laboratory in the same post-AF ablation ATs model, in comparison with the PBP technique (n=16 patients per group). It was found that not only was the mapping time considerably reduced using MEM (26±14 min per AT in the PentaRay® group vs. 33±25 min; P<0.04), but it was also associated with an important increase in map resolution (449±520 vs. 42±18 EGMs in the PBP group). Overall, we think that whenever possible, MEM
Ultra-High-Definition Mapping of Atrial Arrhythmias

Filtering of the system allows accurate detection of very small amplitude signals (described later). A recent study emphasized the superior resolution of this basket for detection of residual PV potentials, in comparison with a standard circular mapping catheter, after incomplete ablation.

Automatic acquisition of the EGMs is based on a predefined set of beat acceptance criteria: cycle length stability, relative timing of 2 different reference EGMs, electrode location stability and respiratory gating. The system allows realization of the chamber geometry, simultaneously with activation mapping, and bipolar/unipolar voltage mapping. One major advantage of the system is that, in most cases, the operator intervention for manual correction and validation of the acquired EGMs is rarely needed (0.17% manual reannotation in the preliminary study).

In our experience with this UHD system for atrial arrhythmias ablation, 182 maps were performed with a mean number of 13,724.3 ± 13,152 EGMs acquired within 16.9 ± 14.5 min/map, and without manual correction (Table).

**Improvement in AT Mechanism Analysis**

**Mechanism of ATs**

As stated earlier, the AT mechanism can be categorized in the clinical electrophysiology laboratory as macroreentrant or focal. An example of focal AT is depicted in Figure 2 concerning a 70-year-old female patient, also treated for mild arterial hypertension, and suffering from incessant episodes of palpitations and shortness of breath. She was referred for AT RF ablation after failure of anti-arrhythmic drug therapy. The right atrial (RA) activation map revealed a focal para-hissian...
Figure 3. Left atrial 3D electroanatomical activation map (anteroposterior projection) during atrial tachycardia occurring after 2 previous radiofrequency catheter ablations for atrial fibrillation in a 64-year-old male patient. No critical isthmus is visible in the first map (A). Decreasing the scar threshold sensitivity from 0.05 mV (A) to 0.10 mV (B), and to 0.20 mV (C) allows visualization of a septal scar area corresponding to a previous atriotomy in this patient. When finally setting the scar threshold (confidence mask) at 0.30 mV (D), a critical isthmus is easily identified, constrained by another anterior area of scar, where 3 radiofrequency pulses successfully interrupt the tachycardia.

Figure 4. Electroanatomical mapping performed in a 61-year-old male patient suffering from a typical clockwise atrial flutter. Activation mapping (left anterior oblique and right anterior oblique projections) revealed a partial rotation around an unexpected lateral scar. Cavo-tricuspid isthmus ablation did not interrupt the tachycardia (A), but unmasked a new atrial tachycardia (with a longer cycle length) with a now complete rotation in a counterclockwise direction around the scar. The scar threshold ("confidence mask") had to be increased from 0.030 mV (A) to 0.015 mV (B) to better visualize the presence of the lateral scar. A final ablation line (B) performed between this lateral scar and the tricuspid annulus allowed sinus rhythm resumption (right anterior oblique view). IVC, inferior vena cava; SVC, superior vena cava.
Ultra-High-Definition Mapping of Atrial Arrhythmias

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AT with a cycle length of 520 ms, successfully ablated only 8.7 mm distant to the His potentials recordings. At the successful site, the unipolar signal showed a QS morphology with a bipolar fragmented signal 30 ms earlier than the atrial deflection on the surface ECG.

Another example of macroreentry circuit is described next.

Scar Quantification and Background Noise
Critical areas of arrhythmogenesis occur mostly in diseased tissue where voltage is attenuated often below the background noise. Anter et al studied patients with structurally normal atria and compared the PentaRay® EGMs with those of a conventional 3.5-mm electrode tip catheter and found similar normal voltage amplitude of 2.6–2.9 mV. They also mapped 18 scar-related circuits (including 13 performed sequentially with both catheters) with high-resolution maps and found that in patients with scar-related atrial arrhythmias the total area of bipolar voltage <0.5 mV measured using 1-mm electrode catheters was 30% smaller than that measured using 3.5-mm catheters, whereas the bipolar voltage amplitude in the low-voltage area was significantly higher with 1-mm electrode catheters. This allowed 54.4% of all low-voltage data points recorded with small interelectrode distance to have distinct EGMs, allowing annotation of local activation time (compared with only 21.4% with 3.5-mm electrode tip catheters) and yielding improved delineation of the low-voltage zones.

The Rhythmia® system allows fast assessment of the atrial scar (shown as grey areas) using a bipolar voltage map. The level of bipolar noise is reported to be close to 0.01 mV with the system. This background noise was measured in our laboratory at different locations of the LA and RA from 17 patients undergoing scar-related AT RF ablation. Background noise was also assessed on standard decapolar catheter (2-mm ring electrodes and 2.5-mm interelectrode spacing) and on surface ECGs. Mean background noise of basket EGMs was much lower than that of the decapolar catheter (0.019±0.023 mV). This level of noise is lower than in other available electro-physiological recording systems.

Yet in selected cases of very diseased and scarred atria, low-voltage signals may still not be seen with a standard cut-off sensitivity. The confidence mask is a complex multifactorial specific algorithm designed to improve scar identification within low-voltage areas. It uses the combination of an amplitude-based definition and the consistency of the timing of local EGMs with those of the surrounding areas. The operator may have to increase the sensitivity (scar thresholding) to very low values (as low as 0.015 mV in our experience) to make the distinction between low-voltage but viable and conducting areas, and dense scar tissue. Similarly, a decrease in sensitivity promotes scar exposure (Figure 3). The very low noise on the bipolar EGMs recorded with the basket catheter allows setting of a low scar threshold. Our preliminary data suggest that the cut-off values for defining atrial dense scar may be lower than those previously reported with other existing catheters.

In another case, a 73-year-old male patient with limited post-myocardial infarction was referred for symptomatic AFL. Endocardial mapping was compatible with a typical clockwise flutter with associated partial rotation around a lateral scar. Ablation of the CTI did not interrupt the tachycardia and resulted into a significant increase in cycle length from 265 ms to 290 ms. This is related to CTI block completion with occurrence of a new AT with a now complete (and unmasked) counterclockwise rotation around the lateral RA scar. A final ablation line performed between the scar and the tricuspid annulus allowed resumption of sinus rhythm (Figure 4). The UHD map allowed not only identification of an unexpected lateral scar, but also suggested the outline of a secondary loop that was entrained during the pericristipud rotation and emerged after CTI ablation.

Figure 5. 3D electroanatomical left atrial activation map of a roof-dependent macroreentry showing a critical isthmus (in dark red color) located on the roof, between 2 areas of scar (shown in grey), in the anterosuperior (A) and posterosuperior (B) projections. The electrodes and the acquired points have been hidden for better visualization of the map. Atrial tachycardia was successfully terminated by performing an ablation line to transect the critical isthmus (width 6.9 mm) on the roof.

535455

131.02 cc

Time: 16.45

Beats: 3945

EGMs: 535455

Volume: 131.02 cc

A

B

Critical isthmus

scar

left pulmonary vein

6.9 mm

0.118 mV

A

B

Figure 5. 3D electroanatomical left atrial activation map of a roof-dependent macroreentry showing a critical isthmus (in dark red color) located on the roof, between 2 areas of scar (shown in grey), in the anterosuperior (A) and posterosuperior (B) projections. The electrodes and the acquired points have been hidden for better visualization of the map. Atrial tachycardia was successfully terminated by performing an ablation line to transect the critical isthmus (width 6.9 mm) on the roof.
Isthmus Identification and Low-Voltage Signals
Classically, a macroreentrant circuit is composed by a central obstacle, either anatomical or functional, around which (or within which) an impulse will circulate. It incorporates a zone of slow conduction that will be targeted by ablation pulses at its narrowest part (the critical isthmus [CI]). Thus precise isthmus identification and characterization is critical during the mapping. The CI may be difficult to visualize in severely scarred areas but also sites of narrowing and/or slowing of the wavefront. As it is known that the CI is most often in an area of particularly low voltage, this is the major limitation to it being able to be recorded. In our initial experience with Rhythmia®, the bipolar EGM amplitude within the CI was measured at 0.1±0.1 mV in 17 patients referred for scar-related AT RF ablation (Figure 5). In a large number of cases, the isthmus bipolar EGM amplitude was <0.05 mV and even in a few cases was <0.03 mV, but above the adapted scar threshold.

In our opinion, the major advantage of this system is the ability to display low-voltage isthmuses in severely scarred atria without the need for entrainment. The system also allows easy identification of the CI by analyzing the conduction
velocity of the impulse on activation propagation maps.

An example of a macroreentrant circuit is described in Figure 5, in a 65-year-old female patient who was referred because of symptomatic recurrent AT, after previous RF ablation for AF. After the automatic acquisition and validation of 53,545 EGMs in 16 min 45 s, the activation map revealed a LA circuit propagating through a CI (width 6.9 mm) located at the roof, between 2 areas of scar. Two RF pulses applied within this CI interrupted the tachycardia. Block on the ablation line was confirmed and no other AT could be induced afterwards.

Gap Identification and Completeness of the Ablation Line

The completeness of any ablation line is critical to avoid any recurrence of the arrhythmia.13 Using UHD mapping allows rapid identification of a gap in patients presenting with a recurrent arrhythmia.26 Figure 6 shows a map performed in a 61-year-old patient without structural heart disease who came back with a recurrent typical AFL after previous successful ablation 4 months earlier. A new UHD activation map was performed and easily identified a zone of reconduction (gap) in the anterior (ventricular) part of the C1. The gap was targeted, resulting in AFL interruption and C1 block completion after a single pulse RF application. The fast localization of the zones of gap of conduction may limit the amount of RF delivery to achieve a complete line of block.

It is well established that clinical recurrences are related to significant late conduction recovery that may occur despite initially proven acute block completion. The system is also able to rapidly identify a line of block of conduction either during sinus or paced rhythm, or during tachycardia. The other example demonstrates a complete line of block over the LA roof, when performing an activation map for a figure-of-eight LA macroreentry in a 51-year-old male patient, occurring 3 years after AF ablation (Figure 7). This patient had mitral valve repair in 1997, and PV isolation, perimetal and septal flutter ablation during the index procedure.

Future Directions

The first studies with the Rhythmia system included RA tachycardias or PV mapping. There are ongoing studies concerning the role and potential superiority of this system for complex scar-related ATs, in comparison with the other available systems. Another area of research may be the possibility to map AF. Our preliminary data reveal the possibility of mapping in a sequential manner disorganized arrhythmias, such as AF, in order to display the areas of rather "organized" activity within the atria (so-called "drivers", "focal impulses", or "rotors", which have been reported with systems using simultaneous mapping of the entire atrium).

Conclusions

UHD mapping has become a powerful tool for atrial arrhythmia management. Not only it is faster and more accurate for complex circuits, but it also allows more precise identification of the atrial substrate (scar) and the site of origin or the anatomical and functional barriers of the tachycardia under study. Finally, UHD mapping quickly enables assessment of the efficacy of the therapy, once delivered (completeness of the lesion). We think that owing to its high degree of precision, speed of execution, and lack of intervention such as entrainment mapping, UHD mapping of atrial arrhythmias is here to stay.

Disclosures

S.-S.B. and D.G.L. serve as consultants for Boston Scientific.

References


