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ORIGINAL ARTICLE

Comparison between novel and standard high-density 3D electro-anatomical mapping systems for ablation of atrial tachycardia

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Abstract

Ultra-high-density mapping allows very accurate characterization of circuits/mechanisms in atrial tachycardia (AT). Whether these advantages will translate into a better procedural or long-term clinical outcome is unknown. Sixty consecutive AT ablation procedures using ultra-high-density mapping (Rhythmia™, group 1) were retrospectively compared to 60 consecutive procedures using standard high-density mapping (Carto/NavX™, group 2) (total 209 AT, 79% left AT). A higher number of maps were performed in group 1 (4.8 ± 2.5 vs 3.2 ± 1.7, $p = 0.0001$) with similar acquisition duration (12 ± 5 vs 13 ± 6 min per map, $p = \text{ns}$), although with a greater number of activation points ($10{,}543 \pm 5854$ vs 689 ± 1827 per map, $p < 0.0001$). AT location remained undetermined in 5 AT in group 1 vs 10 ($p = 0.1$). Mechanism remained undetermined in 5 AT from group 1 vs 11 ($p = 0.06$). Acute complete success was achieved in 77%, in both groups. At 1-year follow-up, AT recurred in 37% in group 1 vs 50% in group 2 ($p = 0.046$). There are less long-term recurrences after AT ablation using ultra-high-density mapping system compared to standard high-density 3D mapping, possibly because of a better comprehensive approach of AT mechanisms.

Keywords Atrial tachycardia · Mapping · 3D electro-anatomical system · Ablation

Introduction

Mechanisms and anatomical locations of atrial tachycardia (AT) have been widely investigated over previous decades [1, 2]. Understanding of these mechanisms and anatomical characteristics has dramatically increased with the advent of three-dimensional navigation mapping systems [3, 4]. Such navigation mapping systems reconstruct three-dimensional left or right atrial anatomy, while adding some informations about activation—propagation of the depolarization wavefront—of the atrial myocardium during AT. Increasingly complex mechanisms have been elucidated, leading to more complex ablation strategies, especially for AT occurring after previous ablation of atrial fibrillation (AFib) [2], after cardiac surgery [5] or in patients with surgically palliated congenital heart disease [6–9].

Standard usual 3D electro-anatomical mapping systems are sometimes of limited help for very complex AT mechanisms, and ablation strategies based on these systems may offer varying success rates (from 73 to 100%) and relatively high recurrence rates (up to 53%) [1, 3, 5, 6, 8–13]. More sophisticated 3D systems with high-density mapping are currently used, although with still imperfect results [14].

A novel high-density 3D mapping system (Rhythmia™, Boston Scientific Inc.) seems to offer more detailed insight into activation/mechanisms because of the density of recorded electrograms, the reliability of electrogram annotation, low noise and enhanced characteristics of recording [15]. Recent reports demonstrated the possibility of very accurate characterization of AT circuits using the Rhythmia™ system [16] which may even allow correction of erroneous evaluations of AT mechanisms made by other systems

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[17]. However, whether these advantages will translate into a better procedural or long-term clinical outcome is unknown.

The aim of this study was to compare procedural parameters as well as acute and long-term outcomes of AT ablation using standard (Carto™, NavX™) versus Rhythmia™ 3D high-density mapping systems. We hypothetized that ultra-high-density mapping may lead to more efficient ablation and better outcome.

Methods

We conducted a retrospective study comparing consecutive patients presenting for AT ablation with the Rhyhmia™ system to those using the standard 3D mapping systems (Carto™ and NavX™) over the same period of time. This study was performed in both University Hospitals of Toulouse and Caen from 2015 to 2016. Use of 3D mapping system was randomly allocated, every operator/center using both systems without any preference or reason of choice at this time.

Only patients referred for scheduled AT ablation were included. Ablation procedures for scheduled typical atrial flutter or AFib were not considered, as well as AT occurring during AFib ablation.

For patients investigated with the Rhythmia™ system ($n=60$), mapping was performed using the Intella Map Orion™ catheter [15] which is an 8-spline expandable basket-like catheter including 64 mini-electrodes (0.4 mm^2, 2.5 mm inter-electrode distance).

For the procedures involving the Carto 3™ system ($n=38$), mapping was also performed with multipolar electrode catheters (Lasso-Nav™ with 10 to 20 electrodes or PentaRay-Nav™ with 20 electrodes). Automatical annotation system (Confidense™) was used in 18 procedures; otherwise, points were manually acquired. Manual points acquisition was also performed with similar multipolar catheters (Lasso Biosense™ or Spiral St Jude™ with 10 to 20 electrodes) in patients investigated with the NavX™ Velocity system ($n=22$).

For the 60 Rhythmia™-based procedures, radio-frequency (RF) ablation was performed with standard irrigated 4-mm-tip catheters (Cordis Thermocool™ $n=51$, Boston Blazer OI™ $n=9$), while contact force irrigated 4-mm-tip catheters (Biosense Thermocool Smarttouch™ or St-Jude TactiCath™) were used for every Carto™ and for most NavX™ -based procedures (Cordis Thermocool™ $n=5$ and St-Jude Coolflex™ $n=2$ in the remaining ones).

AT mechanism was investigated by carefully analyzing activation in every case without entrainment mapping. Mechanisms of AT were defined as focal (concentric activation of the whole atrium from one localized area without returning wavefront to this area), localized reentry (recording of a full reentry circuit not related to macro-reentry) and macro-reentry (recording of a full reentry circuit including the LA roof and/or the mitral isthmus). True determination of the mechanism/location of each AT was defined by the interruption of the AT during RF application at a critical site determined by the system (either resumption of sinus rhythm or abrupt change in AT rate and/or atrial activation); otherwise, mapping was continued until better delineationof the AT mechanism.

Complete success of the ablation procedure was defined by the elimination of all successive mapped AT with resumption of sinus rhythm, while partial success was defined by the elimination of the clinical AT only (with failure to ablate other AT). Failure of the procedure was defined by the inability to ablate the clinical AT. Bidirectional conduction block across linear lesion sets was checked and eventually completed. For avoiding induction of AT of uncertain significance, attempts to reinduce AT or use of isoproterenol were not routinely performed after resumption of sinus rhythm by ablation.

Clinical outcome was assessed in all patients by retrospectively retrieving consultation or hospitalisation files, or by contacting the patients/physicians to determine freedom from recurrence. Informations about recurrence of AT or AFib were assessed by ECG documentation or 24-h ambulatory recordings as needed in case of palpitations. Informed consent was obtained from all patients and the study has been performed in accordance with ethical standards and declared to the CNIL (Commission Nationale de l'Informatique et des Libertés) according to the French law.

Statistical analysis

Categorical variables were described as numbers and percentages and compared using Chi-square test or Fisher's exact test as appropriate. Continuous variables were expressed as mean ± standard deviation and compared using unpaired *t* test.

Logistic regression was performed for determining the parameters associated with the recurrence of AT. Parameters significantly related to recurrence in univariate analysis were considered as eligible explanatory variables in a full multivariate logistic model.

The Kaplan–Meier method was used to generate actuarial arrhythmia-free survival curves for each group. Events were censored at the time of first recurrence and follow-up duration was 1 year for any patient (no patient was lost to follow-up). Differences between groups were assessed with the Breslow–Gehan–Wilcoxon test.

Because only a few patients had more than one procedure, for clearer presentation of the results, each procedure was considered as a different patient. Analysis and calculations were performed using StatView ™ program (Abacus

Concepts, Inc. Berkeley, CA 1992–1996, version 5.0). A p value ≤ 0.05 was considered statistically significant for each analysis.

Results

Population characteristics

Sixty consecutive procedures (56 patients) using the Rhythmia™ system (group 1) were compared to 60 consecutive procedures (55 patients) using the Carto/NavX™ systems (group 2). Examples of activation map during AT with the Rhythmia™ and Carto™ systems are shown in Figs. 1 and 2.

Characteristics of the patient population are depicted in Table 1. There was no significant difference between groups, except for a moderately lower LVEF in group 2 patients (46 ± 16 vs 52 ± 13, $p = 0.04$). Almost all patients had been unsuccessfully treated by anti-arrhythmic drugs, with beta-blockers in two-thirds and amiodarone in half.

An history of previous AFib ablation was noted in the majority of patients, slightly more in group 1 compared to group 2 patients (75 vs 58%, $p = 0.05$). Previous AFib ablation included pulmonary vein isolation in all, with or without additional linear and/or substrate ablation. Forty-four patients (37%) already underwent previous AT ablation and thirty patients (25%) had undergone previous cardiac surgery with either right or left atrial incisions, without difference between groups. Repaired congenital heart disease were present in 10 cases (8%) without significant difference between groups, mainly represented by surgical closure of atrial septal defects.

Ablation procedures

Procedural durations were slightly longer in group 1 (216 ± 66 vs 195 ± 61 min, $p = 0.07$), while fluoroscopy duration did not significantly differ (29 ± 16 vs 25 ± 12 min, $p = 0.15$).

A higher total number of maps were performed in group 1 patients (4.8 ± 2.5 vs 3.2 ± 1.7, $p = 0.0001$), represented by a higher number of activation maps (3.6 ± 2.3 vs 2.7 ± 1.5, $p = 0.017$) and a higher number of maps for assessing linear lesions (1.2 ± 1.6 vs 0.5 ± 1.1, $p = 0.007$).

Total duration of map acquisition was longer in group 1 (49 ± 21 vs 41 ± 17 min) although not significantly ($p = 0.1$), but mean map acquisition duration did not differ (12 ± 5 vs 13 ± 6 min per map, $p =$ ns). A much greater number of activation points were recorded in group 1: total $23{,}255 \pm 9828$ vs 1542 ± 2138, and $10{,}543 \pm 5854$ vs 689 ± 1827 per map

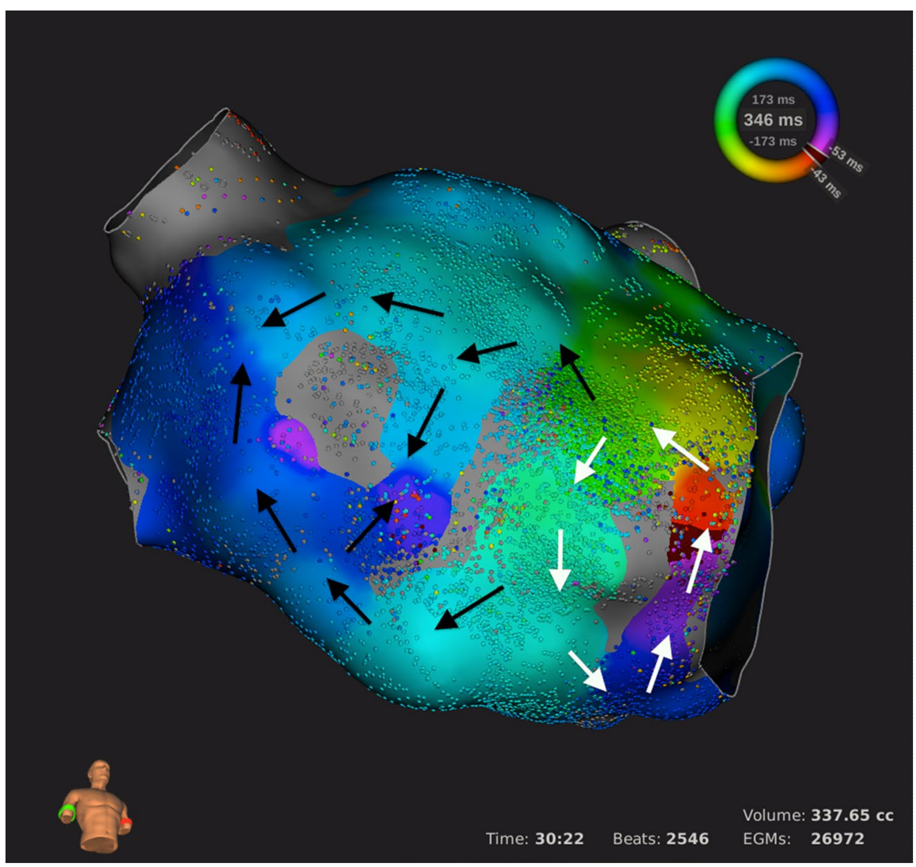

Fig. 1 Right anterior view of an activation map of a left AT investigated with the Rhythmia™ 3D electro-anatomical system, showing a localized re-entry at the low septal aspect of the left atrium (white arrows) with collision of bystander wavefronts outside the circuit (black arrows)

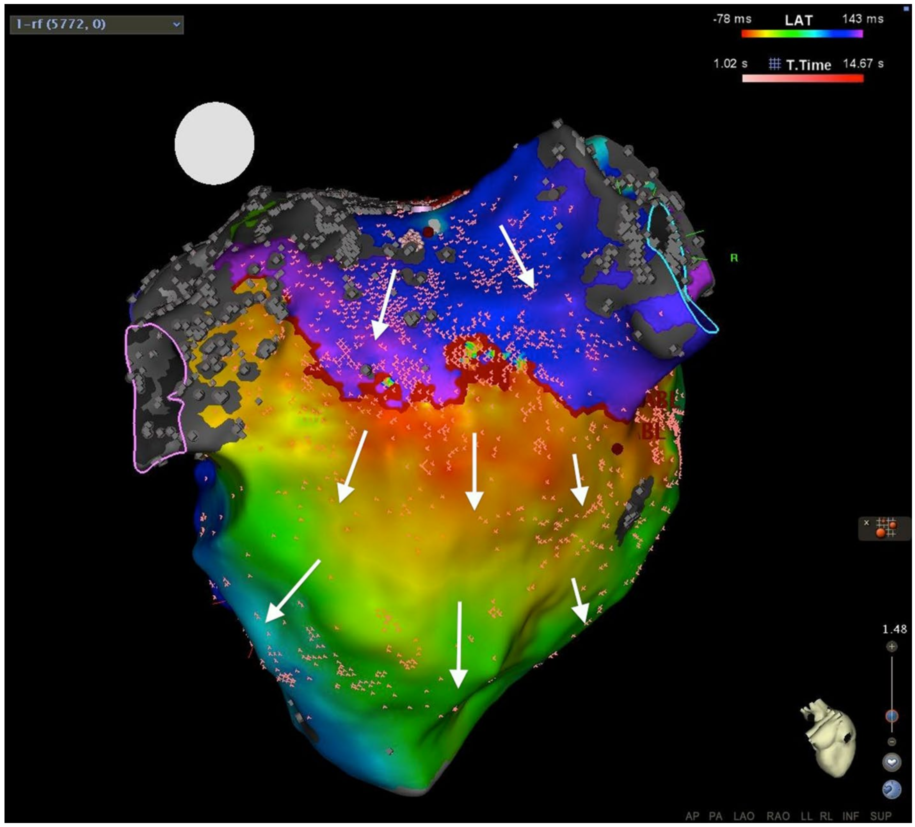

Fig. 2 Posterior view of an activation map of a left AT investigated with the Carto™ 3D electro-anatomical system, showing a large macro-reentry through the roof of the left atrium and with a large descending wavefront over the posterior wall

($p < 0.0001$ for each comparison). As a rule, for each patient, after the first map, progressively less activation points were recorded in the following successive maps. Changes in the number of recorded points according to the map order in each group are shown in Fig. 3.

AT characteristics

A total of 209 ATs were mapped: 112 in group 1 and 97 in group 2, from one to six per procedure (mean 1.7 ± 0.9) (1.9 ± 1.1 in group 1 and 1.6 ± 0.8 in group 2, p = ns).

One hundred and sixty-six ATs originated from the left atrium (LA) (79%) and 43 from the right atrium (RA) (21%). The majority of right AT mechanisms were typical atrial flutter ($n = 24$, 56%) and the majority of left AT were peri-mitral reentry ($n = 33$, 20%), roof-dependant AT ($n = 31$, 19%) and pulmonary vein AT ($n = 19$, 11%) (see Table 2).

There were more left AT (87%) in group 1 vs group 2 (71%) ($p = 0.006$), but there was no significant difference according to the various locations of AT ($p = 0.3$), although more typical atrial flutter were present in group 2 and more mitral/roof-dependent AT were present in group 1) (Table 2). Precise location of AT circuit/focus remained undetermined in 15 cases (8%) (5 in group 1 and 10 in group 2, $p = 0.1$).

AT mechanisms were macro-reentry in 100 (48%), localized reentry in 69 (33%), focal in 24 (11%) and remained undetermined in 16 (8%). There were significantly less focal ($n = 8$) and more macro reentry mechanisms ($n = 66$) diagnosed in patients investigated with the Rhythmia™ system compared to Carto/NavX™ group ($n = 16$ and 34, respectively), while localized reentry were equally found in both groups ($n = 33$ and 36, respectively) ($p = 0.004$ for global comparison). Precise mechanism remained undetermined in 5 AT from group 1 vs 11 from group 2 ($p = 0.06$).

Procedural success and complications

RF duration did not differ between groups (27 ± 17 vs 27 ± 22 min, p = ns). Complete success was achieved in 92 procedures (77% in both groups), partial success was noted in 19 procedures (16%) (18 vs 13% in group 1 and group 2) while failure to ablate the clinical AT was observed in 9 procedures (7%) (5 vs 10%) (p = ns).

Major complications occurred in one patient from group 1 (tamponnade) vs none in group 2 (p = ns). Minor complications (non surgical vascular complications or asymptomatic pericardial effusions) happened in 12 and 15 patients respectively (p = ns).

Table 1 Clinical characteristics of the population

	Whole $n=120$	Rhythmia ™ $n=60$	Carto/Navx™ $n=60$	$p=$
Age (years)	64 ± 11	63 ± 11	64 ± 11	ns
Male gender	92 (77%)	46 (77%)	46 (77%)	ns
Hypertension	68 (57%)	34 (57%)	34 (57%)	ns
Diabetes	20 (17%)	7 (12%)	13 (22%)	ns
Left atrium area (cm^2)	27 ± 8	26 ± 9	28 ± 7	ns
LVEF (%)	49 ± 15	52 ± 13	46 ± 16	**0.04**
Heart failure	64 (53%)	30 (50%)	34 (57%)	ns
Structural heart disease	96 (80%)	47 (78%)	49 (82%)	ns
NYHA class				
I	32 (27%)	20 (33%)	12 (20%)	
II	60 (50%)	27 (45%)	33 (55%)	ns
III	21 (17%)	9 (15%)	12 (20%)	
IV	7 (6%)	4 (7%)	3 (5%)	
Anti-arrhythmic drug	115 (96%)	57 (95%)	58 (97%)	ns
beta-Blocker	79 (66%)	38 (63%)	41 (68%)	ns
Ca channel blocker	7 (6%)	4 (7%)	3 (5%)	ns
Amiodarone	64 (53%)	32 (53%)	32 (53%)	ns
Class 1 drug	7 (6%)	4 (7%)	3 (5%)	ns
Sotalol	6 (5%)	4 (7%)	2 (3%)	ns
Paroxysmal AFib	24 (20%)	13 (22%)	11 (18%)	ns
Persistent AFib	89 (74%)	45 (75%)	44 (73%)	ns
Previous typical AF	46 (38%)	23 (38%)	23 (38%)	ns
Previous AFib ablation	80 (67%)	45 (75%)	35 (58%)	**0.05**
Linear ablation	65 (82%)	36 (82%)	29 (83%)	ns
PV isolation	78 (98%)	43 (97%)	35 (100%)	ns
Defragmentation	61 (81%)	38 (86%)	23 (74%)	ns

Bold indicates significant p values

Long-term follow-up

At 1 year follow-up, 22 patients in group 1 presented with recurrent AT (37%) vs 31 in group 2 (51%) ($p=0.046$). AT-free survival curve is displayed in Fig. 4. From all clinical, procedural and electrophysiological parameters, only a previous atrial surgery, previous linear ablation and lack of linear complete ablation block, failure of the procedure and % of ablated AT were significantly related to the long-term recurrences of AT (see Table 3). In multivariate analysis, only incomplete block during previous linear ablation remained correlated with outcome although with borderline significance (OR 4.69, 95% CI 0.67–32.9, $p=0.1$).

Five patients presented with AFib at 1 year (three in group 1 and two in group 2, $p=$ ns). These patients did not experience recurrent AT, while patients with a relapse of AT did not present with AFib.

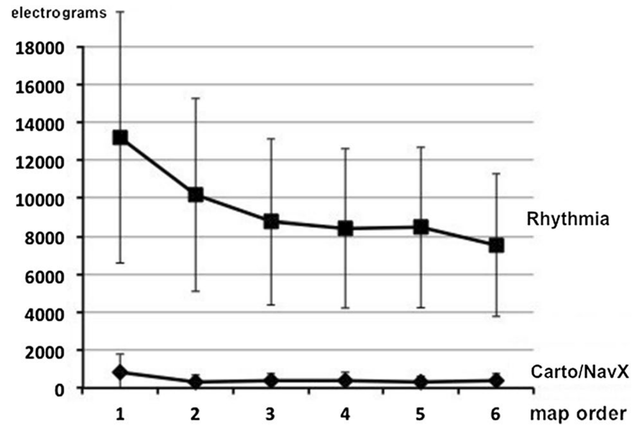

Fig. 3 Changes in the number of recorded electrograms according to the map order in each group. Even after repeated maps, the number of activation points remains very high in the Rhythmia™ group

Discussion

Due to the various anatomical substrates or mechanisms involved, ablation of AT has lower success rates than for typical atrial flutter [1]. The progressive inclusion of increasingly complex AT have led to more complex procedures, especially for AT recurring after AFib ablation, cardiac surgery or in operated congenital heart disease, hampering the success rate of ablation [2, 5–9].

Although randomized comparison of 3D mapping systems against conventional electro-physiological fluroscopic procedures failed to demonstrate any superiority in acute outcome [4, 18], these techniques are currently used worldwide and allow more detailed activation and better understanding of underlying complex mechanisms [3, 4, 6, 14, 18]. However, standard 3D mapping systems (Carto™ or Ensite NavX™) are sometimes of limited help for very complex AT, and ablation based on these systems may offer non-optimal success rates [5, 8, 19], even using high-density mapping [14], while recent studies demonstrated the acute and long-term benefits of ultra-high-density mapping compared to conventional point-by-point 3D mapping in AT [20].

The Rhythmia™ system offers enhanced features for recording and annotation of electrograms [15]. Very accurate diagnosis of AT circuit or mechanism has been demonstrated using this system [16], which may be even able to correct erroneous interpretations resulting from use of other systems [17]. However whether these advantages translate into a better procedural or long-term clinical outcome remained to be proved.

Table 2 Locations of AT

Right AT	$n=43$ 15 (group I) vs 28 (group II)	Left AT	$n=166$ 97 (group I) vs 69 (group II)
Typical atrial flutter	$n=24$ 7 vs 17	Mitral isthmus dep AT	$n=33$ 23 vs 10
Crista terminalis	$n=9$ 5 vs 4	Roof dependant AT	$n=31$ 19 vs 12
Right appendage	$n=4$ 1 vs 3	Pulmonary veins	$n=19$ 13 vs 6
Other right AT	$n=3$ 1 vs 2	Septum	$n=17$ 9 vs 8
Undetermined right AT	$n=3$ 1 vs 2	Anterior LA	$n=11$ 5 vs 6
		Left appendage	$n=11$ 7 vs 4
		Posterior LA	$n=10$ 5 vs 5
		LA floor	$n=10$ 5 vs 5
		Coronary sinus	$n=5$ 3 vs 2
		Other left AT	$n=7$ 4 vs 3
		Undetermined left AT	$n=12$ 4 vs 8

Patients with previous ablation of typical atrial flutter presented with left AT ($n=40$, 87%) but also right AT ($n=5$, 11%) and recurrent common atrial flutter ($n=6$, 13%). For left AT, we observed macro reentry using the mitral isthmus in 11 and the roof in 12, and other localized reentry of focal left AT from various locations in 26

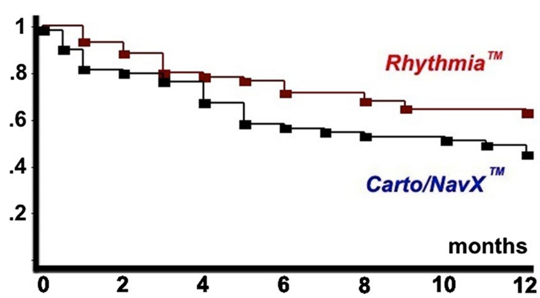

Fig. 4 AT-free survival curves showing less AT recurrence with the Rhythmia™ mapping system over time ($p=0.05$)

Table 3 Univariate analysis of predictors of AT recurrence

Parameter	OR	95% CI	*p* value
Previous atrial surgery	3.45	1.44–8.26	0.005
Previous linear ablation	3.07	0.92–10.2	0.07
Lack of previous linear block	4.74	0.99–22.5	0.05
Procedural failure	3.60	1.46–8.85	0.005
% of ablated AT	0.98	0.96–0.99	0.01

In this study, we found that ablation based on ultra-high-density mapping as allowed by the Rhythmia™ system offers more detailed insight into activation/mechanisms and improved long-term success rates compared with conventional high density 3D mapping systems. To the best of our knowledge, no previous study had been dedicated to compare long-term efficiency of different 3D systems.

We also found that procedural durations were slightly longer with the Rhythmia™ system, but without an increased duration of fluoroscopy, RF delivery or complication rate. This was related to the higher number of maps recorded with the Rhythmia™ system, as mean durations of map acquisition were not significantly longer, despite a higher number of recorded electrograms. The higher number of maps in the Rhythmia™ group despite a similar number of AT is explained by the convincing quality of the system, leading to more frequent map acquisition to more precisely elucidate AT features in case of uncertainty, or to better confirm the completeness of linear lesions.

Acute success rates were found similar for any system, leading to around 75% complete and 93% partial acute success in this highly selected population. Looking more in details, however, procedural failure was noted more frequently with conventional 3D mapping systems (10 vs 5%), as were the undetermined AT mechanisms or precise locations which were twice more frequently observed using conventional 3D mapping systems, although the difference was of borderline significance possibly due to the low number of cases. This may possibly be related to the greater ability of the Rhythmia™ system to precisely delineate mechanisms and locations of an AT isthmus/focus. In the same way, there were significantly less diagnosis of focal and more diagnosis of macro-reentry mechanisms in patients investigated with the Rhythmia™ system compared to Carto/NavX™. This should not be interpreted by an hypothetical different population, but more likely by a more accurate in-depth determination of the actual AT mechanism [17]. In fact more undetermined mechanisms were observed using standard 3D mapping systems. While entrainment mapping may characterize focal or reentrant mechanisms as well, this technique was marginally used here because of the risk of AT modification or interruption. Instead, we found that high-definition mapping alone may depict AT mechanisms with enough precision, especially using the Rhythmia™ system.

In addition, we observed that ablation of AT using the high-density Rhythmia™ 3D mapping system was achieving a higher long-term success rate compared to standard 3D mapping systems. Of note that this was observed despite the lack of contact force ablation catheters in the Rhythmia™ group, while such catheters are considered to achieve better long-term results [21] and were used in most patients investigated with standard 3D mapping systems. Moreover, there were more left AT in group 1 which are usually considered more challenging to localize and ablate, and group 1 patients represented our very first experience with the Rhyhmia™ system, while more solid knowledge and habit were present using the Carto™ or NavX™. Thus, these differences will surely increase while gaining expertise in Rhythmia™. Better understanding of the AT mechanisms and/or critical reentry isthmuses using the Rhythmia™ system probably led to more precisely targeted RF applications, and thus to a better long-term outcome, although this remains speculative. Finally, although we did not look at this point, complete block of linear lesions may be better assessed by the Rhythmia™ vs Carto/NavX™ systems, and this deserves further study.

Limitations

LVEF was lower in group 2 and previous AFib ablations were more frequent in group 1, but groups appear quite similar for other clinical relevant parameters. Although they may be suspected to favor one or the other groups, these differences were indeed minor or of borderline significance and probably did not have relevant implications.

Although procedures were consecutive in each group and performed over the same time period, the findings of this retrospective study should need now confirmation in a prospective randomized trial. Detection of recurrences was not based on ambulatory recordings. However, this was similar for both groups, and relapses of AT are usually symptomatic and/or persistent; thus, regular clinical follow-up probably did not miss a relevant number of recurrent arrhythmias.

The high recurrence rates observed here reflect the selected population, since most of cases were redo procedures, or underwent previous surgery or AFib ablation. All these conditions are known to be related to more difficult procedures. Thus, our results should not be applicable to unselected AT ablation procedures. Moreover, attempts to reinduce AT or use of isoproterenol were not routinely performed after resumption of sinus rhythm by ablation, and this also may explain the high recurrence rate.

Use of contact force ablation catheters will probably still increase the long-term success rate in the Rhythmia™ group and render the differences more relevant.

This study was dedicated to AT, and whether ultra-high-density mapping systems are useful for AFib or ventricular tachycardia ablation is not established. Although some publications tend to show that 3D mapping systems are equivalent for pulmonary vein isolation [22], a very recent study demonstrated the superiority of ultra-high-density mapping in AFib recurrences through detection of concealed low-voltage signals after pulmonary vein isolation [23].

No blanking period was used in this study, allowing to consider early recurrences as long-term failures (22 patients before 3 months). Adding a blanking period was not feasible in this retrospective study, since cardioversion was not performed in every case with early relapse. Although blanking periods are used for most studies about AFib ablation, this does not seem to be the case for ablation of AT.

Finally, since new versions of 3D systems with high-density mapping are now available, our results may not be applicable to these new generation systems. However, quality of signal acquisition has not changed; thus, our results are probably still valid.

Conclusion

Ultra-high-density mapping as provided by the Rhythmia™ system allows lower long-term recurrences after AT ablation compared to standard high-density 3D mapping, possibly because of a better comprehensive approach of AT mechanisms due to the higher precision of mapping.

Compliance with ethical standards

Conflict of interest None except for SC who is employed by Boston Scientific.

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