Outcome after tailored catheter ablation of atrial tachycardia using ultra-high-density mapping

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Abstract

Introduction: Tailored catheter ablation of atrial tachycardias (ATs) is increasingly recommended as a potentially easy treatment strategy in the era of high-density mapping (HDM). As follow-up data are sparse, we here report outcomes after HDM-guided ablation of ATs in patients with prior catheter ablation or cardiac surgery.

Methods and Results: In 250 consecutive patients (age 66.5 ± 0.7 years, 58% male) with ATs (98% prior catheter ablation, 13% prior cardiac surgery) an HDM-guided catheter ablation was performed with the support of a 64-electrode mini-basket catheter. A total of 354 ATs (1.4 ± 0.1 ATs per patient; mean cycle length 304 ± 4.3 ms; 64% macroreentry, 27% local reentry, and 9% focal) with acute termination of 95% were targeted in the index procedure. A similar AT as in the index procedure recurred in five patients (2%) after a median follow-up time of 535 days (interquartile range (IQR) 25th–75th percentile: 217–841). Tailored ablation of reentry ATs with freedom from any arrhythmia was obtained in 53% after a single procedure and in 73% after 1.4 ± 0.4 ablation procedures (range: 1–4). A total of 228 patients (91%) were free from any arrhythmia recurrence after 210 days (IQR: 152–494) when including optimal usual care.

Conclusions: Tailored catheter ablation of ATs guided by HDM has a high acute success rate. The recurrence rate of the index AT is low. In patients with extensive atrial scaring further ablation procedures need to be considered to achieve freedom from any arrhythmia.

KEYWORDS  
atrial fibrillation, atrial tachycardia, critical isthmus, high-density mapping, pulmonary vein isolation

[Correction added on 14 August 2020, after first online publication: Projekt Deal funding statement has been added.]

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1 | INTRODUCTION

Atrial tachycardias (ATs) occurring after prior catheter ablation or cardiac surgery are of growing clinical importance.1-5 Conservative treatment by cardioversion and antiarrhythmic drugs is ineffective in many cases, making catheter ablation the favored therapeutic option.1 These arrhythmias mostly consist of circuits ineffective in many cases, making catheter ablation the favored conservative treatment by cardioversion and antiarrhythmic drugs is sparse, we here readdressed in limited reentry and focal mechanisms, which now become evident to be more common after AF ablation than previously thought.9,10 Ultra-high-density mapping (HDM) of ATs has been introduced to offer a more detailed and precise insight especially into complex activation patterns as well as underlying substrates, which may not be detectable using classical point-by-point mapping.8,11-14 Due to the density and characteristics of the recorded electrograms and the reliable signal annotation, ultra-HDM has been found to precisely identify areas that are critical for the AT maintenance.15-17 This includes precise detection of the critical isthmus,11 which is usually the narrowest bridge of conducting tissue between scars or anatomic obstacles and may be at a different location than the anatomical isthmus.11 Since these critical isthmuses are known to be often shorter and easier to target than the anatomical isthmuses, tailored ablation of this circumscribed area has been proposed but so far only demonstrated in a limited number of patients.11,15 As outcome data are sparse, we here report follow-up data of patients with ATs, following prior catheter ablation or cardiac surgery, after HDM-guided tailored ablation.

2 | METHODS

In this single-center study all consecutive patients, who were referred to our tertiary center for catheter ablation of ATs following prior catheter ablation or cardiac surgery between November 2015 and September 2019, were retrospectively analyzed. The study was conducted in accordance with the provisions of the Declaration of Helsinki. Data collection and analysis were done under a protocol approved by the Institutional Review Committee. All patients gave written informed consent.

2.1 | Electrophysiological study

Mapping and catheter ablation was performed as described previously using conscious sedation.14,15,18 In brief, a steerable 6-F decapolar diagnostic catheter (Inquiry™, 2–5–2 mm spacing, St. Jude Medical, St. Paul, MN, USA; or Dynamic DECA, Bard Electrophysiology; Boston Scientific, Marlborough, MA, USA) was placed in the coronary sinus as a reference. The catheters consisted of an expandable, open irrigated 64-pole multielectrode mini-basket catheter (Orion™; Boston Scientific) for the Rhythmia system (Boston Scientific) and an open-irrigated 3.5-mm tip mapping and ablation catheter (Thermocoool®, D- or F-Type-Curve, 2–5–2 mm spacing; Biosense Webster, CA, USA or IntellaNav®, with three mini-electrodes incorporated within the distal tip electrode; Rhythmia; Boston Scientific). The left atrium was accessed and mapped whenever a left atrial origin of the AT was suspected. All catheters were introduced into the left atrium by double transseptal access after a single transseptal puncture using a fixed curve long sheath (SL0, 8-F; St. Jude Medical) for the ablation catheter and a long steerable sheath (Zurpz™, medium curl, 8.5-F; Boston Scientific) for the mini-basket catheter. The periprocedural activated clotting time was aimed to be greater than 300 s. If the AT was not present at the beginning of the procedure, programmed stimulation or burst pacing was performed. The clinical AT was assumed when cycle length and P wave morphology matched the preprocedural 12-lead electrocardiogram (ECG) documentation.

2.2 | Ultra-high-density three-dimensional mapping

The entire chamber of interest was mapped during the AT using the basket catheter.14 Electrogram annotation was performed (semi-)automatically by the mapping system as described previously.15 Maps were considered complete when the entire chamber anatomy was reconstructed with best achievable electrode–tissue contact. If less than 90% of the tachycardia cycle length was displayed in the primarily mapped atrium, additional mapping of the remaining atrium and the coronary sinus was performed.

After completion of the electroanatomical map the wavefront propagation, activation patterns, areas of slow conduction, anatomic and functional barriers, and lines of the block were analyzed. Additional entrainment mapping was performed at the operator’s discretion. For macroreentry ATs a continuous atrial activation sequence was demonstrated with earliest activation neighboring latest activation and the AT’s reentry loop circuiting around a central obstacle covering the entire AT cycle length.11 Localized reentry was defined as continuous activation or reentry mechanism originating within an area less than 2 cm or when dominant small stable rotational activation patterns were identified.10,20 Centrifugal activation from a distinct focal source was considered as true focal AT.11 Voltage maps acquired during the ATs were taken into account for the ablation strategy. A voltage of less than 0.1 mV was considered scar and between more than 0.1 and less than 0.3 mV as a border zone.10,20 Electrograms from areas along the reentry course and at sites that appeared to be critical for tachycardia maintenance in respect to signal duration (ms), signal amplitude (mV), and fractionation (number of deflections) were
analyzed during the procedure manually and using an automated software tool (Lumipoint®) since October 2018.21

2.3 | Catheter ablation

The critical tachycardia site (critical isthmus or earliest activation), at which specific AT termination into sinus rhythm could be achieved, was targeted. Radiofrequency current was applied using a maximum power of 25 W at the posterior atrial wall and of 30 W at the anterior atrium wall.14 For typical atrial flutter, a radiofrequency current of 38 W was used at the cavitricuspid isthmus.22 For macroreentrant tachycardia, the critical isthmus, which was defined as the narrowest pathway between scars and/or anatomical obstacles, was targeted.11 After the restoration of sinus rhythm, the planned ablation lines were completed and their connection to nonconducting structures (areas of dense scar, mitral annulus, pulmonary vein isolation line) was performed if appropriate. In case of mechanical termination prior or subsequent to mapping, reinduction was performed. Validation of ablation lines was performed by differential pacing or repeat mapping. Localized reentries were targeted by the ablation of the earliest activation.23 Endpoints of previously performed ablations such as pulmonary vein isolation or integrity of lines were verified and completed if necessary. After ablation, extensive atrial burst pacing without and with orciprenaline was performed to confirm acute ablation success. The endpoint was the noninducibility of the AT.

Acute procedure-related complications were defined as post-procedure hemorrhage requiring blood transfusion, atrioesophageal fistula, aspiration, cardiac surgery, stroke, pericardial effusion requiring/not requiring pericardiocentesis, postprocedural atrioventricular (AV)-block with/without indication for pacemaker implantation, groin complications requiring/not requiring surgical intervention.

2.4 | Follow-up

Patients were routinely followed-up at 6 months after the index procedure. If patients missed this appointment, the referring physician was contacted and all available patient data and ECG recordings were acquired and analyzed. If patients experienced symptoms of arrhythmia such as tachycardia or palpitations, additional ECGs or 24-h ambulatory ECG recordings were recorded. All patients were followed-up for a minimum follow-up period of 6 months after the last procedure. In the case of a recurring, sustained or symptomatic arrhythmia patients were considered for a further procedure. Types of arrhythmia recurrences were determined as AT, AF, or typical cavitricuspid dependent right atrial flutter. Besides the arrhythmia mechanism, the origin of the clinical tachycardia and cycle length of the AT was analyzed. If the cycle length in the following procedures was in a range of ±20 ms of the index procedure’s AT cycle length and had the same origin as determined in the three-dimensional (3D) maps, the ATs were considered similar. Usual care of an arrhythmia recurrence consisted of optimal antiarrhythmic medication and pharmaceutical or electrical cardioversion and was defined as successful when the arrhythmia converted into sinus rhythm.

2.5 | Statistical analysis

Continuous variables are presented as mean ± SEM or the median (interquartile range [IQR]: 25th–75th percentile), according to the normality of the distribution. They were compared by Student’s t-test, Mann–Whitney, or Wilcoxon signed-rank tests, as appropriate. Categorical variables are presented as counts and percentages and were compared by the χ² test. A Kaplan–Meier analysis was used to determine the percentage of patients free from arrhythmia recurrences a minimum of 90 days after the procedure. Single procedure and overall procedure success were defined as arrhythmia freedom after the index and the last ablation procedure. All analyses were performed using Graphpad Prism 6.0 (Graphpad Inc., La Jolla, CA, USA). A p value of less than .05 as considered significant.

3 | RESULTS

3.1 | Patient characteristics

Two hundred and fifty patients (66.5 ± 0.7 years, 58% male) with a mean arrhythmia history of 7.4 ± 0.4 years underwent AT ablation. A prior ablation was performed in 98% of patients (mean number of previous procedures: 2.2 ± 0.1), 13% had prior cardiac valve surgery, and 6% a surgically palliated congenital heart disease. A mean left ventricular ejection fraction of 55 ± 0.5% and a mean body mass index of 26.5 ± 0.3 were reported. Detailed patient characteristics are presented in Table 1.

3.2 | Procedural characteristics

A total of 354 ATs with a mean cycle length of 304 ± 4.3 ms were mapped during the index procedure. Detailed procedural characteristics are presented in Table 2. Patients presented to the procedure with an initial rhythm of AT (58%), sinus rhythm (34%), AF (6%), or pacemaker stimulation (2%). The mean mapping time was 16.4 ± 0.6 min in the left and 4.6 ± 0.4 min in the right atrium. The described mechanisms were macroreentry (64%), localized reentry (27%) or focal (9%; see Table S1). The ATs were mainly targeted in the left atrium (70%), but also in the right atrium (22%) or biaatrially (7%; Figure 1). Ablation was performed at the mitral-isthmus (MIG) area in 33 ATs (9%). In 94.8% of cases, the AT could be acutely terminated into sinus rhythm. Among all 342 procedures in 250 patients the following complications occurred: pneumonia following intraprocedural aspiration (n = 1; 0.3%), cerebral embolic events with (n = 2; 0.6%) or without (n = 1; 0.3%) complete clinical recovery, pericardial effusion requiring (n = 2; 0.6%) or not requiring pericardiocentesis (n = 1; 0.3%).
postprocedural persistent AV block I° (n = 1; 0.3%) and groin complications not requiring vascular intervention (hematoma n = 10; 2.9%), femoral arteriovenous fistula n = 5 (1.5%). No atrioesophageal fistula was reported after ablation.

### 3.3 Follow-up and further ablation procedures

During a median follow-up period of 535 days (IQR: 217–841), freedom from the AT of the index procedure was reported in 245 of 250 patients (98%). In four of these five patients, an additional procedure was performed revealing the MIG area as a similar target as in the index procedure in two patients. All five patients were arrhythmia free after one (n = 3) or two (n = 1) further procedures or optimal usual care (n = 1) during a median follow-up of 205 days (IQR: 163–208) after the last procedure.

Freedom from any arrhythmia was reported in 64% and 56% at 1 and 2 years after the index procedure, respectively (Figure 2). In total, freedom from any arrhythmia was observed in 133 of 250 (53%) patients after the index procedure. Recurrent arrhythmias were ATs in 65% (n = 76), AF in 33% (n = 38), or typical atrial flutter in 2% (n = 3; Figure 3) of patients. Of the 117 patients with recurrence of any arrhythmia, 71 underwent a further ablation procedure after a median time of 276 days (IQR: 169–480) after the index procedure. In these additional procedures, ultra-HDM-guided ablation was performed in 83% (n = 59), other 3D mapping approaches were used in 10% (n = 7) and no 3D electroanatomical mapping in 7% (n = 5); three patients undergoing AV node ablation, one patient with typical flutter undergoing cavitricuspid isthmus ablation, and in one patient no AT was inducible. Of the 71 patients that underwent repeat ablation, 54 patients underwent in total two ablations, 13 patients had three ablations, and 4 patients underwent four ablations. After a mean of 1.4 ± 0.04 ablation procedures, 182 patients (73%) were free from any arrhythmia recurrence during a median follow-up time of 211 days (IQR: 163–578) after the last procedure (Figures 2B and 3). The 6-month freedom from any arrhythmia was 84% (40 recurrences) after the last ablation.

An arrhythmia recurrence was noted in 53.1% of patients treated with the Thermocool catheter (94/177 patients), in 32.8% of patients treated with the IntellaNav catheter (22/67 patients) and in 25% of patients treated with both the Thermocool and IntellaNav catheter (1/4 patients; p = .0122).

Forty-six patients with recurrence of arrhythmia after the index procedure were treated with optimal usual care without a further ablation. Nineteen (41%) of these patients had a spontaneous conversion to sinus rhythm, another nineteen patients (41%) underwent cardioversion and optimization of antiarrhythmic medication, and eight patients (17%) were treated with optimization of antiarrhythmic medication only. Thirty of these forty-six patients (65%) were in sinus rhythm and free from any recurring arrhythmia after a median follow-up of 303 days (IQR: 147–507).

In total, 228 patients (91.2%) were in sinus rhythm and free from recurrences of any arrhythmia after one to three further procedures and optimal usual care during a median follow-up of 210 days (IQR: 152–494).
Patients with arrhythmia recurrence after the index ablation ($n = 117$) had a longer procedure duration ($181 \pm 5.9$ vs. $164 \pm 5.4$ min, $p = .03$), longer fluoroscopy time ($23.5 \pm 1.2$ vs. $19.3 \pm 0.9$ min, $p = .005$), higher area dose product ($839 \pm 73$ vs. $639 \pm 42$ cGy·m², $p = .015$) and a greater amount of ablation application points ($1897 \pm 136$ vs. $1541 \pm 105$, $p = .04$) compared with patients without an arrhythmia recurrence ($n = 133$). Patients with arrhythmia recurrences were not different compared to those without recurrence when analyzing the type of previous ablations (pulmonary vein isolation: 102 vs. 112; AT: 69 vs. 75; defragmentation: 48 vs. 50, $p = .98$), the mean number of previous ablations ($2.2 \pm 0.1$ vs. $2.2 \pm 0.1$, $p = .92$), the number of ATs occurred during the index procedure ($1.5 \pm 0.08$ vs. $1.4 \pm 0.06$, $p = .54$) or the mechanism of all ATs (macroreentry: 112 vs. 115; localized reentry: 43 vs. 51; focal mechanism 15 vs. 18, $p = .80$).

4 | DISCUSSION

Mapping and ablation strategies in patients with ATs following prior catheter ablation or cardiac surgery are increasingly evolving. The major findings of the present study, reporting outcomes following HDM-guided tailored catheter ablation, are as follows: (1) The acute success rate is high, even in patients with several previous ablation procedures. (2) Freedom from the index AT can be achieved in most patients with a single ablation procedure. (3) To achieve freedom from any arrhythmia in midterm follow-up further procedures can be necessary for a relevant number of patients due to various critical isthmus sites over time.

ATs are becoming increasingly relevant, as a larger number of patients are undergoing cardiac surgery and catheter ablation has become the gold standard for multiple rhythm disorders. Still, catheter ablation of these ATs can be challenging as they can have a complex course. They can occur between prior ablation scars and fibrotic areas with multiple entrances, exits, dead ends, and most...
important areas of slow conduction, which results not only in various kinds of reentry circuits, but might also be key for future arrhythmias. The use of ultra-HDM facilitates a detailed analysis of complex atrial arrhythmias. To optimally characterize the mechanism and origin of the clinical AT, entrainment mapping was only marginally used in our study to reduce the risk of modification, termination, or degeneration to AF. Detailed HDM has been proposed as a useful basis for a more tailored and a potentially easier ablation strategy targeting the critical isthmus. The acute high success rates in this study support this concept.

In the present study, the relatively high recurrence of any atrial arrhythmia after the index procedure can be attributed to the complex substrates oftentimes including large low voltage areas with multiple areas of slow conduction, which are the underlying substrate for potential critical isthmus sites. The relevance of the type of ablation catheter regarding the recurrence of any arrhythmia needs to be interpreted with caution. As the IntellaNav catheter was only introduced after the first 155 patients, interventionists’ experience and also the smaller number of patients need to be taken into account. The relatively high number of previous ablations in our patient collective and thus presumably extensive ablation can increase the risk of the stiff left atrial syndrome and the probability of future myocardial sites, which are prone to reentry. Up to 40% of patients suffer from an AT following circumferential pulmonary vein isolation plus additional ablation of left atrial lines, while those undergoing a mere antral circumferential pulmonary vein isolation present with an AT at follow-up in only 0%–11%. A tailored ablation of the critical isthmus, which can be shorter than the anatomical isthmus, can reduce the amount of scarred atrial tissue and may thus prevent the probability of stiff left atrial syndrome and the occurrence of new ATs.

Several single-center and one multicenter study report acute success rates between 77% and 97% targeting ATs following prior catheter ablation or cardiac surgery. After a mean follow-up of 1 year, Maury et al. who compared conventional point-by-point 3D mapping with HDM, reported freedom from AT recurrence in 50% in the conventional and 63% in the HDM group. A recent study using HDM in 147 patients describes freedom from scar-related ATs in 54% of patients after a mean follow-up of 4.2 months. Our study reports midterm outcomes (18 ± 12 months) using HDM-guided tailored catheter ablation in a large series of patients with ATs following prior catheter ablation or cardiac surgery, which supports findings from previously described smaller patient series.

5 | LIMITATIONS

This single-center observational study included patients, which were referred for catheter ablation to our tertiary arrhythmia center, so that patient selection was biased and results may not be transferable to other patient populations. Voltage maps were acquired during AT mapping and we did not perform additional voltage mapping in sinus rhythm to not prolong procedures. Determination of the similarity of the recurred atrial arrhythmia with the index AT can be challenging, especially when the patient does not present with a running AT to the second intervention. However, additionally to 12-lead ECG analysis, in which the P wave can be obliterated by the QRS complex or the T wave, also intraprocedural information such as the cycle length and the area of origin was taken into account to reduce uncertainty. Although the area of termination is often a line, for example, connecting two scars, the location of the tailored catheter ablation is schematically depicted as a point for easier visualization (Figure 1). A learning curve and accumulating evidence regarding AT mechanisms within the last 4 years might have impacted procedural outcomes over time. Outcome might also be improved by a new analysis algorithm (e.g., Lumipoint), which has been used since October 2018. This software tool helps to identify areas of interest, for example, by visualizing how much tissue is activated at a certain time point, which has been found to additionally facilitate the critical isthmus detection. The long-term follow-up was limited as only 85 of
250 patients (34%) had a follow-up time of over 12 months after the last ablation. A recent single-center study describes that the use of this ultra-HDM system in AT patients may be accompanied by a high incidence of silent cerebral embolisms. Whether this might be relevant in the here presented patient population is not known as no brain MRIs were performed in asymptomatic patients.

6 | CONCLUSIONS

HDM-guided tailored catheter ablation in patients with ATs following prior catheter ablation or cardiac surgery leads to a high acute success rate including AT termination and noninducibility in most patients. Freedom from the index AT is common. To achieve freedom from the recurrence of any arrhythmia further ablation procedures are necessary for a relevant number of patients. Whether additional ablation at areas of slow conduction during the index procedure might minimize the number of necessary ablation procedures to achieve freedom from any arrhythmia needs to be investigated in future studies.

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section.

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