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Focal atrial tachycardia ablation: Highly successful with conventional mapping

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Abstract

Background/objective Radiofrequency catheter ablation (RFCA) of focal atrial tachycardia (FAT) traditionally is guided by conventional endocardial mapping of earliest atrial activation; however, more recently electro-anatomical mapping is heralded as a more effective, albeit more expensive, tool to guide ablation. Herein we present the results of conventional mapping-guided RFCA. Apropos, we conducted a literature search of studies reporting > 10 FAT patients submitted to RFCA.

Methods and results Conventional mapping-guided RFCA, performed in 63 FAT patients (aged 42.4 ± 17.3 years; 14 with incessant tachycardia and 12 with tachycardiomyopathy (TCM)), was successful in 61 (96.8%) patients, applied for single foci in 59 (93.7%) and two foci in 4 patients, right ($n = 46$) or left sided ($n = 17$). The earliest atrial activation time at the ablation site was 41.3 ± 16.2 ms. Fluoroscopy time averaged 27.3 ± 18.7 min, and procedure lasted 2.6 ± 1.7 h. Complications occurred in two patients (sinus pauses in one needing a pacemaker and a large inguinal hematoma in one). Over 29.0 ± 22.9 months, four patients (6.5%) had recurrences, of whom three were successfully re-ablated. All patients with TCM showed gradual improvement to normalization over 4–6 months. Literature search showed that RFCA success is equally high when guided with either conventional (88.5%) or electro-anatomical mapping (90%) with similar recurrences (9.6% vs. 9.5%).

Conclusion Conventional mapping-guided RFCA of FAT had high success (96.8%) with low complication (3.2%) and recurrence rates (6.5%). TCM was fully reversible. These results are comparable to those achieved with the more expensive electro-anatomical mapping, which may be reserved for more complex cases or for those failing the conventional approach.

Keywords Radiofrequency catheter ablation · Focal atrial tachycardia · Supraventricular tachycardia · Conventional mapping · Endocardial activation · Electro-anatomical mapping · Tachycardiomyopathy · Heart failure

Abbreviations

AV	Atrioventricular
EAM	Electro-anatomical mapping
ECG	Electrocardiogram
FAT	Focal atrial tachycardia
LV	Left ventricle(ular)
LVEF	Left ventricular ejection fraction
RFCA	Radiofrequency catheter ablation
TCM	Tachycardiomyopathy

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1 Introduction

Focal atrial tachycardia (FAT) accounts for 5–10% of supraventricular tachycardia (SVT) in adults with higher rates in children [1–3]. Although generally benign, 5–30% of patients will present with frequent runs or incessant tachycardia, with a good percentage of these patients eventually developing tachycardiomyopathy (TCM) [4]. FAT often resists antiarrhythmic therapy, while it has an excellent response to radiofrequency (RF) catheter ablation (RFCA), which has become standard therapy for FAT [3, 5, 6]. Conventional endocardial catheter mapping techniques were initially employed to guide ablation with variable success [7–14]. Over the past several years, electro-anatomical mapping (EAM) has been used with high success and heralded as superior to conventional mapping for several arrhythmias, albeit at a much higher cost [15–17]. However, conventional endocardial activation mapping has stood the test of time for a variety of arrhythmias, including classical atrioventricular (AV) nodal tachycardia

and accessory pathways, which constituted the majority of RFCA procedures before the development of techniques for atrial fibrillation ablation [5]. We present herein the results of RFCA with use of conventional mapping in a group of 63 patients with focal atrial tachycardia.

2 Patients and methods

Patients This prospective study included 63 consecutive patients undergoing RFCA of FAT in our institutions over 15 years (Table 1). These were 28 male and 35 female patients, aged 7 to 84 years (mean 42.4 ± 17.3). Procedures were performed in all patients with use of local anesthesia and deep or light sedation. The left heart was accessed with use of a transseptal technique. Electrophysiology testing and RF ablation were performed during the same session in all patients. All patients or patients' parents gave informed written consent for the procedures.

Patients presented with recurrent episodes of palpitations ($n = 43$), palpitations and fatigue ($n = 2$), palpitations and presyncope ($n = 5$), palpitations and syncope ($n = 1$), hemodynamic collapse ($n = 1$), while 9 patients presented with symptoms and signs of heart failure and 2 patients were asymptomatic. Presenting arrhythmias included narrow-complex tachycardia ($n = 58$), wide-complex tachycardia ($n = 4$), and narrow- and wide-complex tachycardias ($n = 1$). Incessant tachycardia was the presenting arrhythmia in 14 patients, one of whom was asymptomatic. Underlying heart disease was present in six patients (one mitral valve prolapse with mild mitral regurgitation, one with prior history of mitral valve replacement, one hypertrophic cardiomyopathy, two coronary artery disease, and one with prior left atrial myxoma resection).

Electrophysiology study The diagnostic electrophysiology (EP) study was performed in the fasting state after all antiarrhythmic agents had been discontinued for at least five drug elimination half-lives, except for patients with incessant atrial tachycardia, who were kept on antiarrhythmic agents for rate control. Routinely, three 5F or 6F quadripolar electrode catheters were introduced from the left femoral vein and with fluoroscopy guidance were positioned at the high right atrium, across the tricuspid valve for His bundle recording, and at the right ventricular apex. A 6F steerable quadripolar catheter was placed in the coronary sinus from the femoral vein. Standard recording methods, programmed stimulation techniques, protocols, and definitions were employed [18–21]. All patients underwent a combined diagnostic and therapeutic procedure.

Table 1 Clinical, procedural characteristics, and outcome in 63 patients with focal atrial tachycardia undergoing ablation

Men/women	28/35
Age (years)	42.4 ± 17.2
Symptoms*	61
SHD (%)	6 (9.5%)
Tachycardia cycle length (ms)	376 ± 87
TCM (%)	12 (19%)
Type of tachycardia	
Automatic (%)	48 (76.2%)
Incessant (%)	14 (22.2%)
Non-automatic (%)	15 (23.8%)
WCT (%)	5 (7.9%)
Site	
RA (%)	46 (73%)
LA (%)	17 (27%)
One focus (%)	59 (93.7%)
Two foci (%)	4 (6.3%)
Other tachycardias (%)	15 (23.8%)
Atrial flutter	9
AF	2
AVNRT	4
Successful ablation (%)	61 (96.8%)
EAT (ms)	41.3 ± 16.2
RF applications	11.3 ± 8.1
Fluoroscopy time (min)	27.3 ± 18.7†
Procedure duration (h)	2.6 ± 1.7†
Complications (%)	2 (3.2%)‡
Follow-up (months)	29.0 ± 22.9
Recurrence (%)	4 (6.6%)
Repeat ablation	3

AF atrial fibrillation, *AVNRT* atrioventricular nodal reentrant tachycardia, *EAT* earliest atrial activation (at successful ablation site), *LA* left atrium, *RA* right atrium, *SHD* structural heart disease, *TCL* tachycardia cycle length, *TCM* tachycardiomyopathy, *WCT* wide-complex tachycardia

*Palpitations (60), presyncope (8)/syncope (2), fatiguability (10), dyspnea (12); one patient with acute heart failure and cardiogenic shock

† Significantly reduced after the first 10 procedures to 23.6 ± 15.5 min ($p = 0.015$) for fluoroscopy time and 2.2 ± 1.4 h for total duration of the procedure ($p = 0.005$)

‡ One pacemaker implantation for sinus pauses; one large groin hematoma

The recognition of the FAT on ECG was based on rapid rate of atrial rhythm and/or abnormal P wave morphology and axis; AV block, either spontaneously or with carotid sinus pressure, or after intravenous administration of adenosine, with persistence of the primary atrial rhythm; and variation in the PP interval during tachycardia with gradual shortening upon initiation and lengthening upon termination ("warm-up" and "cool-down" phenomena). Electrophysiological

characteristics included inability to interrupt or pre-excite the tachycardia with rapid atrial pacing at rates capturing the atria; "reset" phenomenon producing less than a fully compensatory pause when atrial extrastimuli were introduced into the tachycardia; inability to terminate the tachycardia by programmed electrical stimulation from the right ventricle (except for cases of micro-re-entry); and inability to activate the atria with single ventricular extrastimuli delivered during the tachycardia at the time of refractoriness of the His bundle. Adenosine was selectively used to explore the induction of AV block and discern atrial tachycardia from other forms of supraventricular tachycardia and not systematically to identify the mechanism of atrial tachycardia. An initial approach to the localization of the FAT focus was made with the analysis of the P wave morphology on the ECG [22]; however, definite identification of focus location was based on intracardiac recordings of the earliest atrial activation site.

2.1 Mapping technique

Conventional catheter mapping searching for the earliest atrial activation was utilized in all patients using bipolar electrogram recordings. A dual mapping catheter (roving or "leap-frog" or encircling) technique for mapping of the atrial activation sequence was employed in the first 10 patients with right atrial tachycardia. Two roving map/ablation catheters were moved in succession to search for the site of earliest atrial activation, earlier than the onset of the P wave on the surface ECG; where the onset of the P wave could not be easily discerned, earliest atrial activation was compared to the earlier endocardial activation on the standard catheters (His bundle, high right atrial, and coronary sinus). In patients with concomitant atrial flutter, a multipolar (eicosapolar) circular (halo) catheter was also employed. For left atrial foci, one map/ablation catheter was used.

Ablation procedure After completion of the electrophysiology study, a 7F steerable quadripolar deflectable-tip catheter with a 4-mm distal electrode and 2-5-2-mm interelectrode spacing (Biosense-Webster, Irvine, CA, USA) was employed for precise mapping and subsequent ablation with delivery of RF current. The transseptal approach for obtaining access to the left heart was used for ablation of left atrial foci. Patients undergoing ablation of a left-sided arrhythmia focus received anticoagulation with heparin.

A conventional electrosurgical unit (Biosense-Webster or Atakr-Medtronic) was used to generate RF current at a frequency of 500 kHz. The RF current was delivered between the distal electrode and a cutaneous indifferent dispersive pad positioned on the posterior thorax or left thigh. Once the target site was identified, RF energy was delivered via the ablation catheter, guided by monitoring the temperature at the catheter tip, which was limited to maximum 65 °C. After successful ablation, one additional "bonus" application was given. Half an hour after ablation, programmed stimulation was repeated with and without the infusion of isoproterenol. After the procedure, patients were monitored for 24–48 h prior to discharge. During this period serial electrocardiograms were obtained to evaluate for recurring arrhythmia, and an echocardiogram was performed to evaluate for cardiac complications. Intravenous heparin for those who underwent ablation in the left heart was continued for 12 h after the ablation procedure.

Patient follow-up After discharge from the hospital, patients were followed up at our arrhythmia clinic or by their referring cardiologists every 3–6 months for the first year and annually thereafter. All patients after the RF ablation procedure received one aspirin (100 mg or 325 mg) tablet daily for 1–3 months. Those with concomitant atrial flutter were continued on oral anticoagulants for at least 1 month.

2.2 Statistics

Data are presented as mean ± SD. Quantitative data were analyzed using a two-tailed Student's *t* test and qualitative data were compared with use of the chi-square statistic with Yates' correction or Fisher's exact test, or the *z* statistic where appropriate. A mean difference was considered statistically significant at a p value of < 0.05.

3 Results

Ablation results and procedure variables Ablation was successful initially in 61 (96.8%) patients with a mean of 11.3 ± 8.1 RF applications (median: 9) (Table 1). Two patient examples are illustrated in Figs. 1 and 2. Ablation was applied for single foci in 59 (93.7%) patients and for two foci in 4 patients. The tachycardia focus (Fig. 3) was in the right atrium in 46 (73%) patients and in the left atrium in 17 (27%) patients; the latter was accessed via a transseptal approach. Ablation failed in 2 patients with right atrial tachycardia. The mean earliest atrial activation time recorded at the successful site of ablation was 41.3 ± 16.2 ms. A potpourri of early activation times in different FATs is depicted in Fig. 4. The mean number of RF current applications of 11.3 ± 8.1 (median 9) also includes the total number of RF pulses applied in 6 of 15 patients with other tachycardias (Table 1) having concurrent ablation that were not logged separately. Exposure to radiation (fluoroscopy time) averaged 27.3 ± 18.7 min (median: 20), and the procedure duration 2.6 ± 1.7 h (median: 2.0). Both fluoroscopy time and procedure duration were reduced significantly after the first 10 procedures (to 23.7 ± 15.4 min, $p = 0.015$; and 2.2 ± 1.4 h, $p = 0.005$, respectively).

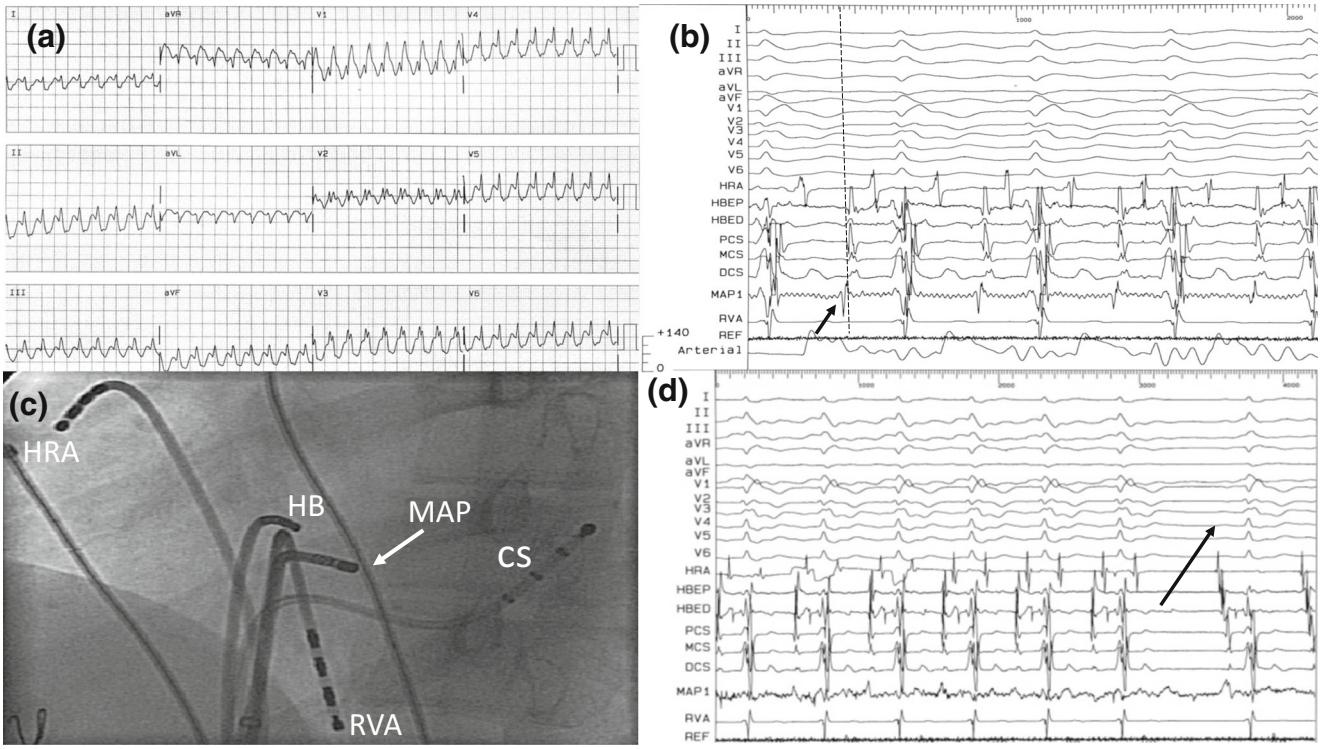

Fig. 1 A 43-year-old lady presented with recurrent episodes of strong palpitations due to a tachycardia with variable rate ranging between ~167 and 210 bpm (**a**). Intracardiac recordings showed an atrial tachycardia (cycle length 280 ms) with variable atrioventricular conduction with the earliest atrial activation (30 ms) (arrow, **b**) compared to the His bundle and coronary sinus electrograms localized at the right mid-septal area (**c**, left anterior oblique fluoroscopy view, MAP catheter), where radiofrequency energy application resulted in termination of the tachycardia (arrow, **d**). CS coronary sinus, HB His bundle, HRA high right atrium, RVA right ventricular apex

Over 29.0 ± 22.9 months of follow-up, arrhythmia recurrences were noted in four patients (6.5%), of whom three were successfully submitted to repeat RF ablation. The location of FAT in these four patients was right-sided in three (one at the appendage and two at the crista terminalis) and left-sided (septum) in one.

The mean cycle length of the presenting atrial tachycardia was 376 ± 87 ms (range, 220 to 560 ms). Comparative data between patients with and without tachycardiomyopathy (TCM) are presented in Table 2. Male preponderance, slower tachycardia rates, and longer procedures are noted in patients with TCM.

Other tachycardias A total of 15 (23.8%) patients had other coexisting tachycardias, including atrial flutter (9), atrioventricular (AV) nodal reentrant tachycardia (4), and atrial fibrillation (2). Except for the two patients with atrial fibrillation, the other 13 patients had concurrent ablation of these other tachycardias.

Complications Among all RF ablation procedures, two complications were observed. One patient with FAT in the vicinity of the sinoatrial node developed long sinus pauses and required a permanent pacemaker. A large groin hematoma developed in another patient.

3.1 Regression of tachycardiomyopathy during follow-up

Of the 14 patients presenting with incessant FAT, 12 had signs of left ventricular (LV) dysfunction with depressed LV ejection fraction (LVEF), with 10 of them presenting with symptoms and signs of heart failure (TCM). All patients with LV dysfunction showed a gradual improvement after RF ablation, with restoration of the LV systolic function to normal at 4- to 6-month follow-up echocardiography study in all but one patient; one older patient (aged 55) with an initial LVEF of 23% improved significantly at 6 months to LVEF of 45% but remained stable thereafter. Patients remained in sinus rhythm at follow-up.

3.2 Literature search

Review of published studies to date reporting results of RFCA in > 10 patients with FAT (Table 3) indicated high procedural success of RFCA with either conventional (88.5%) or electroanatomical mapping (90%) with similar tachycardia recurrence rates (9.6% vs. 9.5%). Patients with FAT had a mean age of 45, the mean cycle length was 375 ms (160 bpm), and TCM was observed in ~ 12% of patients with almost all occurring in those with incessant tachycardia.

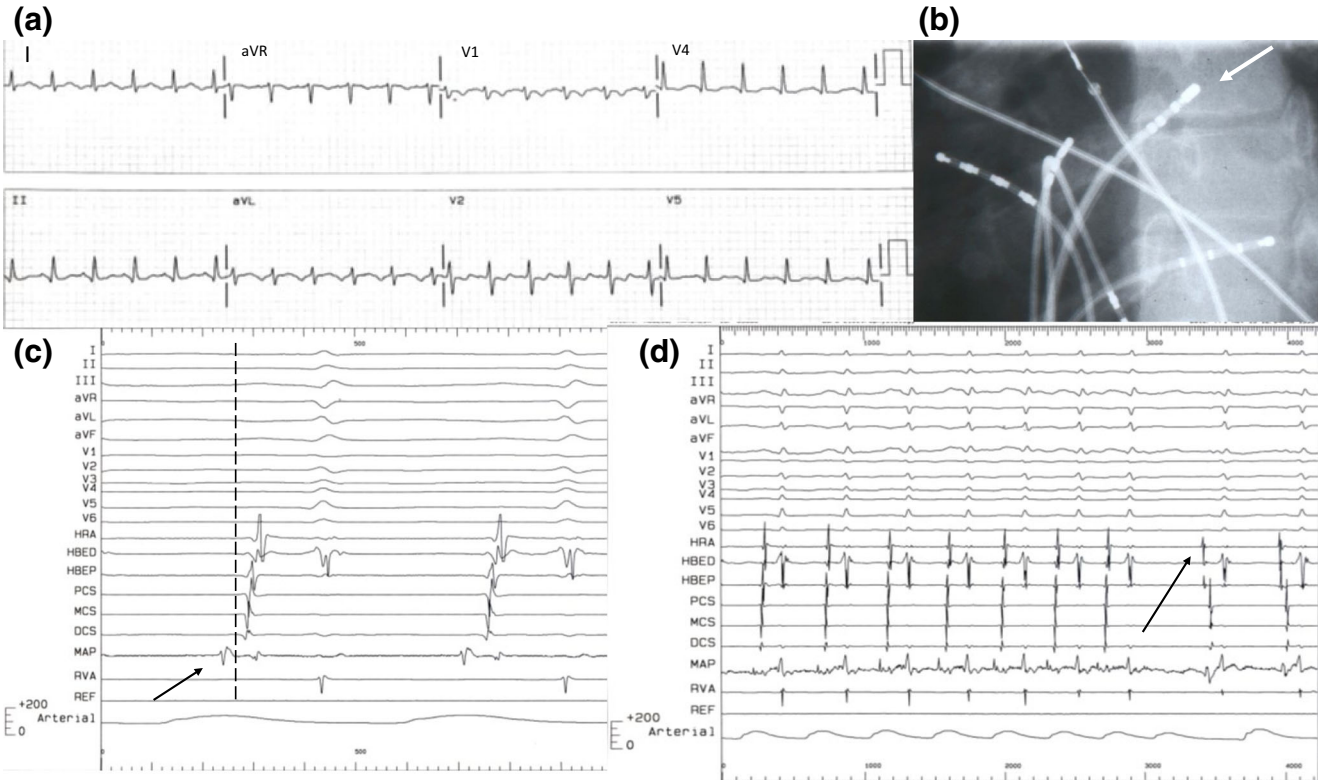

Fig. 2 A 36-year-old lady presented with incessant tachycardia and left ventricular dysfunction attributable to a focal atrial tachycardia (rate ~ 130 bpm) (**a**) with negative P waves in leads I and aVL, and earliest atrial activation at the coronary sinus electrograms indicating a left atrial focus. The left atrium was approached via transseptal puncture and the inserted mapping catheter recorded a very early atrial activation (55 ms) at the orifice of the left superior pulmonary vein (arrows, **b**, **c**), where application of radiofrequency energy abolished the tachycardia focus (arrow, **d**)

4 Discussion

The present study showed that conventional mapping remains highly effective in guiding successful RFCA in patients with focal atrial tachycardia (FAT). The procedural success was 96.8% with minimal number of complications (2) and low (6.7%) recurrence rate. These results compare well with the recently reported results from the German Ablation Registry among 431 patients with FAT undergoing ablation between the years 2007 and 2010 (constituting 3.4% of the whole group of patients with various arrhythmias submitted to ablation during the same period), wherein the acute success rate was 84% [23]. At 1 year, arrhythmia freedom without antiarrhythmic drugs was only 58%. The results of this real-world registry experience indicate that FAT ablation can be a challenging procedure, even when using electro-anatomical mapping (EAM) which was used in 46% in this series. Other smaller series comparing the two techniques report a higher success rate with EAM (80–90%) vs. conventional mapping (60–72%) [16, 24], albeit still quite lower than the success rate (96.8%) obtained in our series with sole use of conventional mapping.

Our review of all published studies to date (to the best of our knowledge) reporting results of RFCA in > 10 patients with FAT (Table 3) indicates that FAT concerns a younger age group (mean age 45) compared to other atrial tachyarrhythmias, is usually a slower tachycardia than other types of SVT (mean cycle length 375 ms or tachycardia rate of 160 bpm), and produces TCM in ~ 12% of patients with almost all occurring in those with incessant tachycardia. The procedural success of RFCA is equally high when guided with either conventional (88.5%) or electro-anatomical mapping (90%) with similar tachycardia recurrence rates (9.6% vs. 9.5%).

The present study, to the best of our knowledge, reports the second highest number of FAT patients in the literature submitted to RFCA guided by conventional mapping and the sixth highest number of FAT patients submitted to RFCA guided by either mapping technique (Table 3). A previous study reporting the results of conventional mapping-guided RFCA in 105 FAT patients had a success rate of only 77% with a 10% recurrence rate [11]. The other four studies reporting higher patient numbers of RFCA guided by either technique had success rates ranging from 84 to 94% with 6–42% recurrence rates [23, 25–27].

An initial crude approach to localizing the focus of FAT relies on the ECG analysis of the morphology and axis of the P wave and several algorithms have been proposed for this

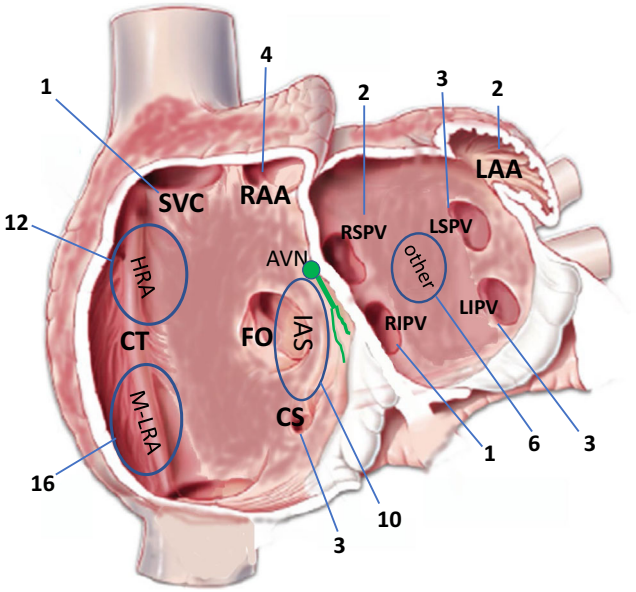

Fig. 3 The schema depicts the distribution of the location of focal atrial tachycardia foci as identified during conventional mapping and ensuing successful radiofrequency catheter ablation in 63 patients. AVN atrioventricular node, CS coronary sinus, CT crista terminalis, FO fossa ovalis, HRA high right atrium, IAS interatrial septum, LAA left atrial appendage, LIPV left inferior pulmonary vein, LSPV left superior pulmonary vein, M-LRA mid-low right atrium, RAA right atrial appendage, RIPV right inferior pulmonary vein, RSPV right superior pulmonary vein, SVC superior vena cava

purpose [22, 28–30]. However, more precise or definite identification of the FAT origin is based on conventional endocardial mapping of the earliest atrial activation site using bipolar local electrogram recordings or on EAM that guide successful RFCA (Figs. 1, 2, and 4). Some investigators have proposed the combination of paced P wave morphology (pace mapping) and intracardiac activation sequence (activation mapping) for the identification of FAT origin, particularly in patients with difficult-to-induce and non-sustained FAT [31, 32]. Other investigators have suggested that the use of unipolar recordings with a local QS pattern with a rapid initial intrinsic deflection may identify the ablation site [10] and may have some advantages over bipolar recordings as they may allow for assessment of the prematurity of local electrograms from a focal source without the use of the P wave onset as a timing reference [33].

A most important initial step in approaching the interventional management of atrial tachycardia is the exclusion of macro-re-entry. For this purpose, EAM appears superior [34, 35] and when not available, entrainment techniques need to be applied to test for tachycardia resetting [36, 37], while some investigators have proposed an algorithm with the routine use of IV adenosine which will affect FAT when automatic (slowing or suppression) or due to triggered activity (termination), while having no effect in reentrant tachycardias [38, 39]. Further defining the specific operative mechanism (automatic, micro-re-entry, or triggered activity) of FAT may not be that crucial to the outcome of RFCA, since the focus is circumscribed and the tachycardia amenable to focal ablation.

EAM can certainly facilitate the anatomical location of FAT origin and is more important in complex cases, such as in the presence of significant atrial disease (congenital, atriotomy scars, or prior extensive ablation scars) [40–42]. However, EAM, in addition to its high cost, has its own inherent limitations, such as when mapping and navigation of the endocardial surface are inadequate, EAM may lead to serious misinterpretation of the arrhythmogenic focus location [43]. Furthermore, right-sided breakthroughs of left atrial foci may also be misleading. A major advantage of EAM relates to the reduction of exposure to radiation, although this may not always be feasible [16].

Anatomic location The anatomic localization of FAT foci in the present study is depicted in Fig. 3. The majority of foci clustered along the crista terminalis (~44%) with the interatrial septum being the next most common location (~16%). An early (1998) study of FATs indicated that approximately two thirds of them occurring in the absence of structural heart disease arise along the crista terminalis [44]. In other series, similar distribution of foci localization has been observed in adult patients with the crista terminalis or the septum as the most frequent locations [23, 24], while the origin of FAT in children may differ, often located at the atrial appendages [45]. Among four pediatric cases in our series, the location was on the right side in three (one in the appendage) and on the left side in one.

Focal right atrial appendage (RAA) tachycardia has been reported in ~8% of adult patients with FAT with approximately half of them presenting with incessant tachycardia, of whom half had developed TCM [46]; left atrial appendage (LAA) has been reported as an even less common site of origin (2–3%) for FAT [47, 48]. Four (6.3%) patients in our series had FAT located in the RAA and two in the LAA; two patients with right-sided foci had incessant FAT-producing TCM. Other investigators have observed high incidence (33%) of TCM in appendage FATs, while they reported encountering particular difficulty in ablating such FATs, requiring to resort to a hybrid approach [49]. Although RAA FATs cannot be easily discerned by P wave morphology on the ECG, LAA FATs have characteristic and discernible P morphology with negative P waves in lead I and aVL, and upright or biphasic (±) P waves in V1 and isoelectric in V2–V6; furthermore, the earliest endocardial activation is recorded on the distal coronary sinus electrogram [48, 50].

Several studies have pointed out that foci in the parahisian area, particularly those surrounding the anterior atrial septum, may actually be approached more effectively and purportedly safely via the aortic cusps, usually the non-coronary cusp, even if the recorded atrial activation is not the earliest [26,

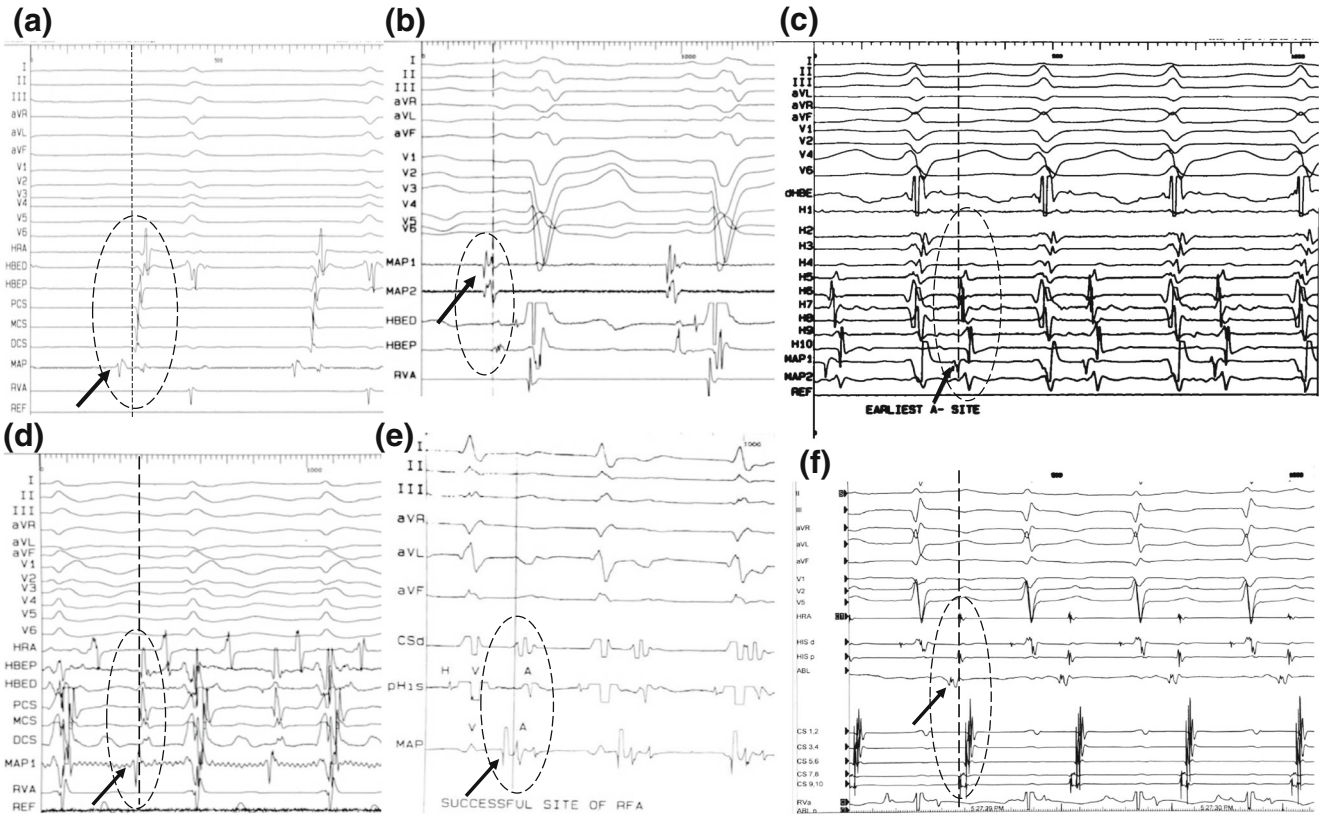

Fig. 4 Representative examples of conventional mapping with earliest atrial activation electrograms recorded at successful ablation sites are depicted in **a**–**f** in which one can visually appreciate (in the circled areas) the earliest atrial electrograms (arrows) recorded with the map catheter relative to the onset of the P wave and/or the endocardial electrograms at standard catheter locations (high right atrium, His bundle, coronary sinus). Notably, in **b**, two mapping catheters (Map 1 and Map 2) were used and moved in succession to different locations (roving catheter technique) for more precise mapping; in **c**, an eicosapolar catheter has been employed (patient with concomitant atrial flutter) which facilitated the mapping process; in **e**, except for an early atrial activation, a complex, triple-component atrial electrogram is seen at the successful ablation site in a patient with left atrial tachycardia, in the absence of underlying structural heart disease

27, 51–53], especially after failure of initial endocardial ablation attempts. However, caution is advised even when ablating in this presumably safe region, as disasters may occur, such as rupture of the aortic valve [54]. We did have foci located at the septal area (Fig. 1), spread along the entire (anterior, mid, and low) septum; however, they were all approached and ablated successfully from the right side. Other series have reported successful ablation of septal FAT from right endocardial locations [55], or from either side after having mapped both sides of the septum [56]. In three (4.8%) patients, the focus was located at the coronary sinus os; other series have shown similar frequency (6.7%) of such location [30]. Four (6.5%)

Table 2 Comparative data between patients with and without TCM

	Patients with TCM ($n = 12$)	Patients with no TCM ($n = 51$)	p value
M/F	10/2	18/33	0.007
Age (years)	38.8 ± 20.8	43.3 ± 16.3	NS
Automatic FAT	11	37	NS
TCL (ms)	421.4 ± 65.6	357.5 ± 88.5	0.022
RA/LA site	7/5	39/12	NS
Successful ablation	91.7%	98%	NS
Fluoroscopy time (min)	37.6 ± 23.3	24.9 ± 16.8	0.033
Procedure duration (h)	3.3 ± 1.6	2.4 ± 1.7	0.10
RF applications	9.4 ± 10.7	11.8 ± 7.3	NS

FAT focal atrial tachycardia, *LA* left atrial, *RA* right atrial, *RF* radiofrequency, *TCL* tachycardia cycle length, *TCM* tachycardiomyopathy

Table 3 Results of catheter ablation in published series of (> 10) patients with focal atrial tachycardia

Author/year	Patients	Age (years) (mean)	AAT	LA	TCM	TCL (ms)	Map	EAT (ms) (mean)	RFA success	Complications	Recurrence
Walsh/1992 [7]	12	12	12	7	12	377	C	42 (median)	92%	1	9%
Goldberger/1993 [12]	15	38	11	0	7	372	C	30	80%	0	26.7%
Kay/1993 [9]	15	50	11	1	2	NA	C	21	100%	1	20%
Lesh/1994 [60]	12	41	12	5	5	379	C	45	91.7%	0	10%
Chen/1994 [8]	34	57	7	9	4	356	C	32	94.1%	0	6.3%
Tang/1995 [22]	31	39	31	14	4	NA	C	43	91.7%	NA	NA
Wang 1995 [61]	13	33	10	3	1	400	C	38	69%	1	11.1%
Poty/1996 [10]	36	40	16	3	5	NA	C	45	86%	0	6.5%
Pappone/1996 [31]	45	29	45	9	17	335	C	NA	93.3%	3	7.1%
Natale/1998 [43]	24	59	24	13*	NA	NA	E	–	100%	NA	4.2%
Kalman/1998 [44]	27	41	27	4	2	370	C	47	96%	0	16%
Anguera/2001 [11]	105	48	23	14	12	385	C	47	76.2%	2	10%
Frey/2001 [56]	16	53	1	6	0	440	C	50	100%	1	12.5%
Weiss/2001 [59]	15	51	NA	1	0	379	E	35	100%	6	13.3%
Hoffmann/2002 [15]	42	51	42	12	2	371	E	–	84.2%	0	12.5%
Kammeraad/ 2003 [24]	37	46	0	10	0	380	C 16 / E 22	–	79% (C 72%/E 80%)	1	7%
Higa/2004 [62]	13	45	13	0	2	394	E	51	92.3%	0	7.6%
Kistler/2005 [30]	13	41	6	0	NA	360	C	36	84.6%	0	9.1%
Gurevitz /2005 [40]	16†	48	NA	NA	NA	NA	E	–	82%	1	15%
Dong/2005 [17]	33	54	29	33	1	309	E	–	94%	3	6%
Freixa/2008 [46]	15	32	15	0	4	364	C 12 / E 3	28	100%	0	0%
Hu/2009 [25]	207 SF	53	27	16	3	373	C 180 / E 27	NA	95.2%	NA	6.1%
	44 MF	54	7	10	3	335	C 37 / E 7	NA	84.1%	1	19.2%
Toyohara/2011 [45]	35	7	35	16	10	410	E	–	100%	0	11.4%
Wang/2011 [51]	22	53	3	3	1	341	E	35	100%	0	0%
Yang/2012 [47]	14	25	14	14	2	433	E	47	92.9%	0	0%
Biviano/2012 [63]	19	48	6	19	1	347	E 71%	–	84.2%	0	7%
Guo/2014 [49]	42	27	NA	19	14	370	E	37	71.4%	0	20%
Szegedi/2015 [16]	30	61	NA	7	NA	NA	C	NA	60%	0	59.3%
	30	48	NA	9	NA	NA	E	–	90%	0	77.8%
Wang/2015 [52]	47	56	9	3	1	389	C 42 / E 5	37	95.7%	0	4.4%
Toniolo/2016 [53]	23	65	0	NCC	0	399	C 83% / E 17%	60	95%	0	0%
Yang/2017 [26]	91	NA	19	0	NA	NA	C 56 / E 35	27	94.5%	NA	NA
Lyan/2017 [27]	68	61	68	21	NA	388	C 38% / E 62%	40	92.6%	8**	12.7%
Busch (GAR)/2018 [23]	413	60	NA	141	7	NA	C 54% / E 46%	NA	84%	17	42%

Table 3 (continued)

Author/year	Patients	Age (years) (mean)	AAT	LA	TCM	TCL (ms)	Map	EAT (ms) (mean)	RFA success	Complications	Recurrence
Manolis/2018	63	42	48	17	12	376	C	41	96.8%	2	6.7%
All	1718	45 (7–65)			134 (12.4%)	375			89.5% / C 88.5% / E 90%		9.6% ‡ / C 9.6% / E 9.5%

AAT automatic atrial tachycardia, *C* conventional, *E* electro-anatomical, *EAT* earliest atrial activation, *GAR* German Ablation Registry, *LA* left atrium, *MF* multiple foci, *NA* not available, *NCC* non-coronary cusp, *RFA* radiofrequency ablation, *SF* single focus, *TCM* tachycardiomyopathy

*Thirteen atrial tachycardias (not patients)

**Four transient and four permanent AV block

† Had failed prior conventional ablation

‡ Median

patients had > 1 focus. In other series, ~ 4–17% have been reported as having more than one focus [25, 57].

Tachycardiomyopathy The incidence of TCM was 19.4% in this series and was encountered only in patients with incessant AT, although not all patients with incessant FAT developed TCM. Male preponderance, slower tachycardia rates, and longer procedures were noted in patients with TCM (Table 2). LV function returned to normal or near-normal in all patients with TCM during follow-up. The reported incidence of TCM in the literature ranges between 8 and 28%, with the higher rate observed in pediatric patients, always associated with incessant or very frequent runs of FAT [4, 45, 58].

The incidence of TCM was 10% in a large cohort of 345 patients with FAT [4]. Incessant or very frequent paroxysmal tachycardia was strongly associated with TCM, compared to patients without TCM (100% vs. 20%, $p < 0.001$). Patients in the TCM group were more frequently younger males and had a slower tachycardia and ventricular rate during tachycardia compared with patients who did not have TCM. Appendage sites are associated with a high incidence of incessant tachycardia (84%) and LV dysfunction (42%). After successful ablation, LV function was restored in the vast majority (97%) of patients at a mean of 3 months. Similar findings regarding the reversibility of TCM after successful ablation have been consistently reported in the literature [4, 7, 14, 45, 58].

In a study of 216 patients with FAT, the incidence of TCM was 8.3% (18 patients; 13 males) [58]. The TCM patients were younger (29.8 ± 20.1 vs. 45.9 ± 17.3; $p < 0.000$) and were more frequently males (13/18 vs. 80/198; $p = 0.014$). The FATs were more likely to be persistent (11/18 vs. 32/198; $p < 0.001$). There was no difference between the two groups in the tachycardia rate (144 bpm vs. 156 bpm; $p = 0.15$). In a multivariable analysis, the younger age and persistent nature were independently associated with TCM. Over a 56 ± 21-month follow-up, all TCM patients had improved LVEF after successful catheter ablation or medical therapy ($43.9 \pm 5.8\%$ vs. $61.1 \pm 3.5\%$; $P < 0.05$). However, one patient suffered sudden cardiac death due to unauthorized withdrawal of the drug and progressive heart failure.

In a pediatric series of 35 patients with FAT, 10 (28.6%) presented with TCM [45]. After RFCA, in all 10 patients, the LV function gradually recovered. The FAT causing TCM originated in the atrial appendage in 6 patients (RAA 3, LAA 3) and in the atrioventricular annulus in 4 patients (tricuspid annulus 2, mitral annulus 2).

Limitations The main limitation of the present study is the lack of a comparison group undergoing RFCA guided by EAM. However, the results are comparable or even better than some series using exclusively EAM [15, 16, 59]. Another limitation of the present and prior studies of FAT ablation guided by conventional mapping alone relates to potentially higher

radiation exposure compared to EAM-guided ablation; however, this may not always be the case [16, 24].

In *conclusion*, conventional mapping was highly effective in guiding successful RFCA in 63 patients with focal atrial tachycardia (FAT) with a procedural success of 96.8% with minimal number of complications (2) and low (6.7%) arrhythmia recurrence rate. The majority (12 of 14) of patients with incessant tachycardia developed TCM, which was fully reversible after successful RFCA of FAT. According to an up-to-date literature review (Table 3), these results are comparable to those achieved with use of the more expensive and tedious technique of electro-anatomical mapping, which may be reserved for more complex cases or for those failing the conventional approach.

Compliance with ethical standards All patients or patients' parents gave informed written consent for the procedures.

Conflict of interest The authors declare that they have no competing interests.

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