Characteristics, Mechanism and Long-Term Ablation Outcome of Atrial Tachycardias After Mitral Valvular Surgery and Concomitant Cox-MAZE IV Procedure

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Summary

The incidence of atrial tachycardia (AT) after rheumatic mitral valvular (RMV) surgery has been well described. However, there have been few reports on the characteristics, mechanism, and long-term ablation outcome of ATs after RMV surgery and concomitant Cox-MAZE IV procedure.

The present study reviewed consecutive patients who underwent AT ablation between May 2008 and July 2013. All patients were refractory to antiarrhythmic drugs (AADs) and had a history of RMV surgery and Cox-MAZE IV procedure. A total of 34 patients underwent AT ablation after RMV surgery and concomitant Cox-MAZE IV procedure, and presented 57 mappable and 2 unmappable ATs. The 57 mappable ATs included 14 focal-ATs and 43 reentry-ATs. Ten of the 14 focal-like ATs were located at the pulmonary vein (PV) antrum and border of a box lesion. Of the 43 reentry-ATs, 16 were macro-reentrant around the mitral annulus (MA) and 16 around the tricuspid annulus. There were 41 atypical ATs (non-cavotricuspid isthmus related) including 16 ATs related to the box lesion and 21 ATs related to other Cox-MAZE IV lesions. The AT were successfully terminated in 33 (97.1%) patients. After mean follow-up of 46.9 ± 15.7 months, 25 (73.5%) patients maintained sinus rhythm without AADs after a single procedure and 28 (82.4%) patients after repeated procedures.

The recurrent ATs after RMV surgery and concomitant Cox-MAZE IV were mainly reentry mechanism, and largely related to LA. An incomplete lesion or re-conductive gaps in a prior lesion might be the predominant mechanisms for these ATs. Catheter-based mapping and ablation of these ATs seems to be effective and safe during a long-term follow-up.

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Atrial tachycardia (AT) is a very common tachyarrhythmia after rheumatic mitral valvular (RMV) surgery because of surgical substrate and the underlying substrate related to the disease. The Cox-Maze IV procedure was introduced in 2002, and it replaced most of the incisions of the “cut-and-sew” Cox-Maze III with linear lines by radiofrequency (RF) or other energy ablation during cardiac surgery.¹⁾ The incidence of ATs post-RMV surgery has been well-described.²⁻⁵⁾ However, reports about the electrophysiological characteristics of the ATs after RMV surgery and concomitant Cox-MAZE IV are very rare. The purpose of this study was to investigate

the mechanism and long-term outcome of this AT ablation procedure.

Methods

Study population: The present study reviewed consecutive patients who had undergone AT ablation at Guangdong General Hospital between May 2008 and July 2013. All patients were refractory to antiarrhythmic drugs (AADs) and had a history of RMV surgery and Cox-MAZE IV procedure. Patient data about clinical outcomes, echocardiographic findings, procedural details, and

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Figure 1. Diagram of Cox-MAZE IV procedure. Radiofrequency lesions (red dashed lines) were created to encircle the ipsilateral PVs, join the two circles in the roof and bottom of LA posterior wall, join the left PV to the base of the LA appendage after LA appendage resection (red full line). LA isthmus line was performed from right PV to the septal MA. The cavo-tricuspid isthmus in RA was ablated to join the TA, CS and inferior vena cava (IVC). Surgical incisions (green dashed lines) were performed at RA freewall and septum. RAA indicates right atrial appendage; and SVC, superior vena cava.

clinical profiles were obtained by medical record review, event monitor, and telephone follow-up. A diagram of the Cox-MAZE IV procedure is presented in Figure 1. The Ethics Study Committee at Guangdong General Hospital approved the study protocols and agreed that informed consent was not necessary because of the observational nature of the study. Patient data were anonymized and de-identified prior to analysis.

Electrophysiological study: For all patients, antiarrhythmic and anticoagulant medications were discontinued at least 3 to 5 days prior to ablation. Anticoagulant medications were bridged with enoxaparin until post-procedure. Before the procedure, patients underwent transesophageal echocardiography⁶⁾ to exclude the presence of thrombus. Electrophysiological study (EPS) was performed using conscious sedation. All patients gave written informed consent to the study. Electrophysiological studies were performed under the state of conscious sedation. Twelve-lead surface electrocardiograms (ECG) (filtered 0.05-100 Hz) and bipolar intracardiac electrograms (filtered 30-500 Hz, sweep speed 100 to 200 mm/second) were amplified and displayed on a computer-based digital amplifier/recorder system (Bard Electrophysiology, Lowell, MA, USA).

A decapolar catheter was introduced into the coronary sinus (CS) with the proximal pole at the CS ostium via the left subclavian vein. A decapolar or 20-polar catheter was introduced into the right atrium (RA) around the tricuspid annulus (TA) with the distal pole at the CS ostium via the left femoral vein. P-wave morphology and the stability of tachycardia cycle length were evaluated before any further mapping. A decapolar circle mapping catheter (AFocusII™, St Jude Medical or Lasso SAS, Biosense Webster) was used to create the atrial activation and voltage mapping via the right femoral vein. Double

transseptal punctures were performed in all patients with a suspected LA originated AT. Regular doses of heparin were administered to maintain an activated clotting time range of 250 ~350 seconds throughout the whole procedure.

If spontaneous tachycardia was not present at the beginning of the EPS, a standard induction protocol was performed to induce atrial arrhythmia (AA). First, atrial burst pacing was used for AA induction with a pacing cycle length of 300, 250, or 200 milliseconds (ms) for 10 seconds. If no AA was induced, a ramp pacing protocol was carried out with decreasing pacing cycle lengths from 300 ms to the refractory period of local tissue, even to 200 ms, to induce AA.

Mapping and ablation strategy: The mapping and ablation procedures were guided by a 3-dimensional (3D) mapping system (Ensite Velocity system, St Jude Medical, MN or CARTO 3, Biosense, Webster, CA). All mapped atrial sites were checked manually for accurate annotation.

A reentrant AT (R-AT) was defined as follows: continuous sequence of atrial activation with earliest activation adjacent to latest activation and range of activation times $\geq 90\%$ of the tachycardia cycle length (TCL) under color-coded 3D mapping. Entrainment mapping was performed to locate the critical isthmus of the reentrant circle. A focal-like AT (F-AT) was defined as follows: activation mapping was performed to locate the earliest activation site with radial spread of activation.

An area with bipolar peak-to-peak voltage amplitude ≤ 0.1 mV was defined as a density scar (DS), and 0.1~0.5 mV as a low voltage area (LVA). When mapping was guided using an Ensite system, electrograms (EGMs) were acquired at high density using a decapolar circle mapping catheter (Inquiry™, AFocusII™, St Jude Medical). The LVA and DS were confirmed with a 3.5-mm externally

irrigated-tip ablation catheter (Therapy™ Cool Path™ Duo/ CoolFlex™, St Jude Medical, or Navistar ThermoCool/SmartTouch, Biosense Webster). Activation and voltage maps were analyzed to confirm isolation or detect a conduction gap from the above-mentioned epicardial lesions.

Ablation was applied to the earliest active site in F-AT, and a routine isthmus such as cavotricuspid isthmus (CTI), mitral isthmus (MI), LA roof line (RL), or alternative isthmus (connection to the closest anatomical barriers in order to prevent creating potential substrate for reentrant tachycardia) in R-AT, and those conduction gaps for Cox-MAZE IV lesions, pulmonary vein isolation (PVI) and Box lesion. RF energy was delivered under power control mode, with a maximum preset temperature of 43°C, power of 30–40 W, and flow rate of 15–30 mL/minute. All ablation lesions were validated with bidirectional block. Finally, the above-mentioned stimulation protocol was performed in order to induce AT/AF or to confirm noninducibility as an endpoint.

Postprocedural management and follow-up: Patients were discharged with antiarrhythmic and anticoagulant medications which they had been taking before the procedure. Patients were evaluated in a clinic and via 12-lead ECG and Holter monitor for 3, 6, and 12 months and then every 1 year after the procedure. Patients with symptom recurrence were evaluated immediately. Three months after a procedure, discontinuation of antiarrhythmic medications depended on no recurrence of arrhythmia or arrhythmia-related symptoms. Also, at this time, anticoagulant medications were discontinued and antiplatelet medications substituted if appropriate.

Statistical analysis: Continuous variables were tested for normal distribution by histogram analysis. Data with a normal distribution are presented as the mean $\pm$ SD. Data without a normal distribution are presented as the median and interquartile range. Categorical variables are expressed as the number and ratio. Student's *t*-test and the Mann-Whitney *U*-test were used to compare parametric and non-parametric continuous variables, respectively. The chi-square test was used to compare categorical variables. Kaplan-Meier analysis was performed to determine the probability of AT and atrial fibrillation (AF) recurrence at follow-up. A two-tailed *P* value < 0.05 was considered to indicate statistical significance. All statistical analyses were performed using IBM SPSS Statistics 19.0 (IBM Inc., NY, USA).

Results

Baseline characteristics: A total of 34 patients (16 males, mean age, 49.7 ± 11.8 years) underwent AT ablation after RMV surgery and concomitant Cox-MAZE IV procedure. Twenty-nine of 34 had AF history of 5.2 ± 4.4 years before RMV surgery, while the remaining 5 patients were hardly evaluated for AF duration due to asymptomatic AF. There were 18 patients with concomitant aorta valve replacement (AVR) and 25 patients with concomitant tricuspid valvuloplasty (TVP). The mean interval between cardiac surgery and the catheter ablation procedure was 2.0 ± 1.7 years. The mean LA and RA dimensions were $43.0 \pm$

6.4 mm and 46.3 ± 5.1 mm, respectively. The left ventricular ejective fraction was 62.1 ± 10.0 %. The mean catheter ablation procedure duration was 142.9 ± 73.1 minutes (60–300 minutes) and mean fluoroscopy time was 20.0 ± 11.5 minutes (5–50 minutes).

Electrophysiological characteristics: Thirty-four patients presented 57 mappable ATs (mean TCL of 255 ± 25 ms) and 2 unmappable ATs. The 57 mappable ATs included 14 F-ATs (24.6%) and 43 R-ATs (75.4%). The electrophysiology mechanisms of the ATs are summarized in the Table. Seventeen patients (50%) had only one single mechanism AT, 11 patients (32.4%) had 2 ATs, and 6 patients (17.6%) had ≥ 3 ATs. There were 35 ATs (61.4%) associated with LA.

Focal-like AT: Ten of the 14 (71.4%) F-ATs were located at the PV antrum and box lesion border (Figure 2). One AT originated from a distal portion of the left superior PV and the other 3 from the LA anterior wall, RA septum, and crista terminalis. The local potentials in the earliest activation center were usually very low voltage and fractional.

Reentry AT: Of the 43 R-ATs, 16 (37.2%) presented macro-R-AT around the mitral annulus (MA) (Figure 3) and 16 (37.2%) presented typical atrial flutter (AFL) around the TA. One presented a macro-R-AT around the bi-atrium. The other reentry loops were located at the LA appendage (1, 2.3%), LA roof (5, 11.6%), RA septum (1, 2.3%), LA septum (1, 2.3%), RA freewall incision (1, 2.3%), and RA posterior wall (1, 2.3%), respectively. Further analysis revealed 4 R-ATs in 4 patients presented dual-loop R-AT (Figure 4), which was confirmed by multi-site entrainment.

Mapping and ablation procedure: There were 41 atypical ATs (non-cavotricuspid isthmus related) including 16 ATs (39%) related to box lesions (PVI, roof line and bottom line lesion) and 21 ATs (51.2%) related to other Cox-MAZE IV lesions. Two ATs were recognized as incision-related AT, one at a septum incision and another at a RA freewall incision. Only 2 ATs (F-AT at RA crista terminalis, R-AT around RA posterior wall) might not have been associated with a Cox-Maze IV lesion or RMV surgery incision. The ATs were successfully terminated via RF delivery in 33 patients. Two patients with unmappable ATs were unstable and unsustainable for more than 30 s, therefore, it also reached the endpoint of noninducibility.

Complications and follow-up: In one patient, the sheath went to the pericardial transverse sinus during transeptal puncture without serious outcome. None of the remaining patients had any other complications related to the ablation procedure. At a mean follow-up of 46.9 ± 15.7 months (28.6–89.2 months, median 41.9 months), 25 patients (73.5%) maintained sinus rhythm without AADs after a single procedure. Three patients (8.8%) had paroxysmal AF (patients #1 and #11, with amiodarone) and persistent AF (patient #6, with metoprolol). There were 5 patients with AT recurrence. Two of these 5 patients (patients #3 and #30) underwent redo-procedures at 6 months and 9 months after the first catheter ablation, respectively, and sinus rhythm was successfully maintained. The 3 other patients with recurrent AT were administered amiodarone. There were 28 patients (82.4%) in sinus rhythm

Table. Electrophysiological Characteristics of ATs After RMV Surgery and Cox-Maze IV Procedure

No.	Gender	Age	Surgery	Tachycardia mechanism	Acute success	Recurrence during follow-up
1	F	58	MVR + TVP	Focal in RSPV antrum (roof)	successful	Paroxysmal AF
2	F	50	MVR + TVP	Focal in distal of LSPV Reentry (MA) Reentry (TA) Reentry (LA roof)	successful	No
3	F	51	DVR + TVP	Reentry (TA)	successful	AT-REDO
4	M	52	MVR	Reentry (TA)	successful	No
5	F	58	MVR + TVP	Reentry (MA) Reentry (LAA)	successful	No
6	M	65	DVR + TVP	Focal in LSPV antrum (posterior roof); Focal in LIPV antrum (posterior) Reentry (MA)	successful	Persistent AF
7	M	57	DVR	Focal in RSPV antrum (roof)	successful	No
8	F	51	MVR + TVP	Focal in LSPV antrum (roof)	successful	No
9	F	55	DVR + TVP	Dual-loop: Reentry around RPVs Reentry (MA)	successful	No
10	F	71	DVR	Reentry (MA)	successful	No
11	F	62	MVR	Reentry (TA)	successful	Paroxysmal AF
12	F	32	MVR + TVP	Focal in LA anterior wall Focal in LSPV antrum (roof) Reentry (MA)	successful	AT (Amiodarone)
13	M	53	DVR	Reentry (TA)	successful	No
14	M	39	MVR + TVP	Reentry (MA)	successful	No
15	M	32	MVP + TVP	Reentry (TA)	successful	No
16	M	34	MVR + TVP	Reentry (TA)	successful	No
17	F	49	DVR + TVP	Focal in LSPV antrum (roof); Reentry (MA) Focal in crista terminal	successful	No
18	M	34	DVR + TVP	Reentry (LA septum) Reentry (TA)	successful	No
19	M	52	DVR + TVP	Focal in RSPV antrum (roof)	successful	No
20	F	34	MVR + TVP	Reentry (TA)	successful	No
21	F	39	DVR + TVP	Focal in RA septum Reentry (MA) Reentry (TA)	successful	AT (Amiodarone)
22	F	28	DVR + TVP	Reentry (TA)	successful	No
23	M	57	MVR	Dual-loop: Reentry around RA septum incision Reentry (TA)	successful	No
24	F	56	MVR + TVP	Reentry (MA); Reentry around RA posterior wall; Unmappable	successful	No
25	M	61	DVR	Reentry (MA)	successful	No
26	M	51	DVR + TVP	Reentry (MA) Reentry (TA) Unmappable	failure	No
27	M	61	DVR + TVP	Reentry (MA) Focal in LIPV antrum (Posterior)	successful	AT (Amiodarone)
28	M	54	MVR + TVP	Dual-loop: Reentry around RPVs Reentry (MA) Reentry around Bi-atrium	successful	No
29	F	61	DVR + TVP	Reentry (MA) Reentry (TA)	successful	No
30	M	42	MVR	Reentry (LA roof) Focal in LIPV antrum (Posterior)	successful	AT-REDO
31	F	63	MVR	Reentry (MA)	successful	Persistent AF
32	F	35	DVR + TVP	Dual-loop: Reentry around RA freewall incision Reentry (TA)	successful	No
33	F	31	DVR + TVP	Reentry (LA roof)	successful	No
34	M	63	DVR + TVP	Reentry (TA)	successful	No

MVR indicates mitral valve replacement; DVR, double valve replacement; TVP, tricuspid valve prosthesis; RSPV, right superior pulmonary vein; LSPV, left superior pulmonary vein; LIPV, left inferior pulmonary vein; MA, mitral annulus; TA, tricuspid annulus; AT, atrial tachycardia; and AF, atrial fibrillation.

Figure 2. Representative case of focal-like ATs located at pulmonary vein antrum and border of Box lesion (Patient #6). **A:** Twelve-lead ECG during AT (25 mm/second). **B:** The activation mapping indicated a focal-like origination from posterior antrum of left superior PV (yellow square) during AT1 (TCL = 310 ms). **C:** AT1 translated to AT2 (TCL = 470 ms) by RF at target site (brown dot). The focal-like activation pattern presented a fragmented signal was identified at the earliest area (yellow circle). The atrial tachycardia was terminated by RF at the earliest area.

without AADs after repeated procedures.

Discussion

Main findings: The present study has demonstrated that the recurrent ATs after RMV surgery and concomitant Cox-Maze IV occurred mainly via a reentry mechanism, and were largely related to LA. An incomplete lesion or re-conductive gaps in a prior lesion might be important mechanisms for these ATs. F-ATs were mostly located at the PV antrum and border of a box lesion. Reentry circuits commonly involved the MA and TA.

Focal and reentry ATs: Recurrent ATs are very common after catheter ablation or surgical Maze procedure.^{1,7)} It was reported that recurrent ATs after a surgical “cut and sew” Maze were the reentry mechanisms in a majority of the patients.^{8,9)} Previous studies reported that the R-AT in RA were mostly related to a posterior atriotomy and the F-ATs were mostly located in the CS, atrial septum, and RA.^{5,10)} However, in our study, the F-ATs were located mostly in the PVs antrum and the border of a box lesion. We deduced that the initial lesion lines encircling PVs

were not extended to the LA antrum during the surgical procedure and that the focal “trigger” at these sites could not be eliminated. Another cause for this difference might be related to the intrinsic etiology. In the present study, all of the patients suffered from RMV disease with serious atrial remodeling. This would generate “triggers” for ATs.¹¹⁾ Compared with previous reports,^{3,5)} R-ATs in the RA were located mostly around the TA in our study. The present Cox-Maze IV procedure in these patients did not include a posterior intercaval incision as in the Cox-Maze III procedure. This suggested that an intercaval incision might be unnecessary. We also found that 84.8% of all the mappable ATs were related to incomplete lesion of the initial lesion set, indicating that electrically complete linear lesions are difficult to achieve. The possible causes are as follows. First, the so-called transmural lesion of RF energy still was less effective than “cut and sew” from the Cox-Maze III. Second, RF delivery during the Cox-Maze IV procedure was relatively conservative near the annulus, PVs and CS in order to avoid coronary injury and acute cardiac tamponade. Therefore, possible gaps might exist between the connecting lines. Chavez, et al showed electrical PV conduction in the majority of patients with recurrent atrial tachy-arrhythmias, indicating that these non-“cut and sew” scar lesions may not be transmural.¹²⁾ This is in agreement with another study demonstrating histologically the incompleteness of intra-operatively induced irrigated RF linear lesions.¹³⁾

Bi-atrial related macro-R-AT is only very rarely reported. In patient #20, the right atrial active sequence varied after the initial LA macro-reentry tachycardia. The arrhythmia mechanism was confirmed via entrainment at multiple sites in the bi-atrium. The mapping catheter in the RA positioned around the TA would provide essential information during the complex AT ablation. Furthermore, concealed entrainment to confirm the reentry mechanism was very important. Ablation based on multi-electrodes mapped active and voltage mapping data.

The ATs after RMV surgery and the Cox-Maze IV procedure are very complex and several separate ATs usually occur in one patient. LVA was very common in the RA and LA due to the lesions by intrinsic etiology, surgical incision, and Cox-Maze IV lesion. Fractionated or low amplitude potentials were usually recorded at the prior lesion setting site. Conventional “point-by-point” mapping would be time-consuming and easy to miss some essential EGMs.

Activation and substrate mapping: Matsuo, et al.¹⁴⁾ recently reported a case with peri-mitral AFL mapped using a 20-polar AFocus-II (St. Jude Medical, MN). The clearer electrogram provided by the catheter, which has 1-mm electrodes, was also advantageous in finding small potentials as well as covering a large mapping area in comparison to a 3.5-mm ablation catheter. The detailed mapping could avoid unnecessary RF applications. It is still unclear whether additional ablation based on voltage mapping is useful to prevent late recurrent ATs. Patient #3 in our study had undergone two ablation procedures within two years. Electro-anatomic mapping indicated different R-ATs around the RA incision, TA, and late potentials, respectively. Preventative ablation targeting substrates to elimi-

Figure 3. Representative case of macro-R-AT around MA (Patient #25). **A** and **B**: Activation and substrate mapping of LA (TCL = 240 ms) indicated the R-AT around MA with counter-clockwise pattern (rainbow circular arrow). Entrainment mappings from the proximal CS, distal CS, and LA appendage base showed good post pacing interval (PPI). **C**: RF energy was delivered at LA anterior wall (red dot) according to LA substrate (**B**). **D**: The tachycardia was prolonged and terminated by ablation applied.

Figure 4. Representative case of dual-loop R-AT around TA and RA freewall incision (Patient #32). **A**: Twelve-lead ECG during AT (25 mm/s); **B**: Activation and substrate mapping of RA indicated show dual-loop R-AT (TCL = 230 ms) around TA and RA freewall incision. **C**: The tachycardia was terminated by successive RF ablation at ca-votricuspid isthmus (red dot) and freewall incision to inferior vena cava (green dot).

nate all the possible “slow-conductive” areas in the first ablation procedure seemed to be necessary in this patient. Voltage data is very useful when the arrhythmia is unstable or the tachycardia cycle length varies frequently. Stable AT with 2 alternating cycles was induced in patient # 24 after the initial clinical AT cessation by ablation. Recently, Mikhaylov, *et al.* reported mapping methods for such ATs.¹⁵⁾ They created 2 maps for each patient. Consecutive activation mapping of both AT cycles is feasible for AT mechanism determination in some patients. According to the results of the study, fractionated electrogram-guided ablation appears to be a reasonable approach in the termination of this type of AT. The fractionated potential is very common in AT in patients with previous AF ablation and cardiac surgery. This might indicate the “slow-conduction” pathway or local-reentry mechanism and was usually the successful target for terminating tachycardias.

Limitations: We used a decapolar circle catheter as a high density mapping catheter. It could not highlight the local-reentry mechanism like the HDM catheter with 20-polar PentarayTM in CartoTM, 20-polar Double loop AFocus-IITM in EnsiteTM, and 64-polar basket catheter OrinoTM in RhythmiaTM. Thus, we could not clearly distinguish the “focal” and “local reentry” concepts in these patients. We just defined the radial spread of activation as “focal” in general terms. Bi-directional block in linear lesion for LA R-ATs was difficult in some patients, therefore, we defined the procedure endpoint as ATs noninducibility. Finally, it was a retrospective, single center experience and subject to the inherent limitations of this design.

Conclusions

The recurrent ATs after RMV surgery and concomitant Cox-MAZE IV were mainly reentry mechanism, and largely related to LA. Incomplete lesions or re-conductive gaps in a prior lesion might be predominant mechanisms for these ATs. The combination of activation, substrate, and entrainment mapping as an overall strategy could efficiently guide the ablation procedure. The catheter-based mapping and ablation of these ATs seems to be effective and safe during a long-term follow-up.

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Disclosures

Conflicts of interest: None.

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