Influence of Right Atrial Structure on Outcome of Radiofrequency Catheter Ablation for Common Atrial Flutter

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Radiofrequency catheter ablation (RFCA) targeting the cavotricuspid isthmus is usually an effective treatment for common atrial flutter (AFL), except in a small subset of patients and the reason for this has yet to be elucidated. The present study investigated the relationship between the outcome of RFCA for common AFL and the anatomy of the right atrium as seen on angiography. Twenty consecutive patients who underwent RFCA for common AFL were divided into 2 groups according to the results of RFCA. Group A comprised 13 patients whose AFL was abolished, fulfilling the criteria of success by the conventional catheter approach, and group B comprised 7 patients whose AFL could not be abolished according to the criteria for success ($n=4$) or was abolished following an additional superior vena cava approach ($n=3$). On angiography, the cavotricuspid isthmus was longer (3.5 ± 0.5 vs 2.2 ± 0.6 cm) and deeper (0.94 ± 0.35 vs 0.49 ± 0.19 cm) in group B than in group A (both $p<0.01$). The height of the eustachian valve was also greater in group B than in group A (1.4 ± 1.1 vs 0.48 ± 0.48 cm, $p<0.02$). These results suggest that the anatomical structure of the cavotricuspid isthmus affects the outcome of RFCA for common AFL. (*Jpn Circ J* 2000; 64: 741–744)

Key Words: Atrial flutter; Catheter ablation; Isthmus; Right atrium; Superior vena cava

Macro-reentry within the right atrium is the accepted cause of common atrial flutter (AFL)^{1–3} and the reentrant circuit involves the isthmus between the inferior vena cava and the posterior part of the tricuspid annulus.^{4,5} The application of a radiofrequency current to the cavotricuspid isthmus has been shown to interrupt this arrhythmia^{6,7} and radiofrequency catheter ablation (RFCA) has become the first line of therapy. Conventionally, the ablation catheter is introduced from the inferior vena cava to the right atrium in order to position the catheter tip on the isthmus. Although the success rate of conventional RFCA is greater than 80%^{8–9} in a small subset of patients numerous applications are required to terminate or prevent the recurrence of common AFL.^{10,11} The causal factor influencing the success of conventional RFCA for common AFL has yet to be identified and we hypothesized that the anatomical complexity of the right atrium, especially the size and shape of the cavotricuspid isthmus, may affect the outcome of RFCA. To test this hypothesis, we investigated the relationship between the outcome of RFCA and the anatomical right atrial structure observed on the right atrio-gram in patients with common AFL.

Methods

Patient Population

Twenty consecutive patients with common AFL who were referred for curative RFCA were enrolled (17 men, 3 women; age range 14–82 years, mean 51 ± 20 years). Written

informed consent was obtained from all the patients according to the protocol approved by the Committee on Human Research in Kyushu University.

Common AFL was defined as the presence of the characteristic surface ECG (ie, inverted sawtooth pattern of flutter waves in the frequency range 200–300 beats/min in inferior limb leads). AFL was chronic or incessant in 9 patients and paroxysmal in 11 patients. At least 1 episode of atrial fibrillation had been documented in 6 patients and episodes of uncommon AFL in 2 patients. Antiarrhythmic drugs had been unsuccessful. Eleven patients had associated cardiovascular diseases, such as hypertension (4), valvular heart disease (3), repaired congenital heart disease (3), and old myocardial infarction (1).

Electrophysiological Study and Right Atrio-gram

All the antiarrhythmic drugs were discontinued at least 5 half-lives before the electrophysiological study (EPS), which was performed in the fasting state under sedation with diazepam (10 mg) and pentazocine (15 mg). Five multipolar electrode catheters (2-mm interelectrode spacing) were inserted percutaneously into the right jugular and the right and left femoral veins and 3 of the catheters were advanced to the high right atrium, His bundle region and coronary sinus. A 7-French deflectable catheter with 20 electrodes spaced at 2–7–2 mm intervals (Halo catheter, Cordis-Webster, USA) was positioned around the tricuspid annulus. The 5th catheter was used for the ablation procedure. When common AFL occurred, the right atrial activation sequence was recorded and the ablation procedure was carried out. When the patient was in normal sinus rhythm, either double atrial extrastimuli at 3 different cycle lengths (600, 500 and 400 ms) or atrial burst pacing with isoproterenol infusion was done via the catheter positioned near the coronary sinus ostium and low right atrium for the induction of AFL. An initial bolus of heparin (5,000 U) was followed by repeat

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Fig 1. Measurement of the structure of the right atrium on the atrigram in the right anterior oblique view. A, Length of the tricuspid annulus; L, length of the isthmus; D, depth of the isthmus; H, height of the eustachian valve; RA, right atrium; HBE, His bundle electrogram; RV, right ventricle; IVC, inferior vena cava.

doses (1,000 U/h) until completion of the ablation. Blood pressure was monitored continuously, as were the 12-lead standard ECG and bipolar intracardiac local electrograms, which were digitized and displayed on a high-resolution video monitor at 200 mm/s (Cardiolab System, Prucka Engineering, USA). (The intracardiac electrograms were filtered at 30–500 Hz.) Data were stored on optical disk for retrieval and off-line analysis.

The right atrigram was performed during sinus rhythm in 11 of the 20 patients and during AFL in the remaining 9 patients. Thirty milliliters of contrast agent (Iomeprol, Eisai, Japan) was injected over 2 s through the 7-F catheter positioned at the junction of the inferior vena cava and low right atrium and the biplane cineangiogram was taken in the right anterior oblique (RAO) 30° and the left anterior oblique (LAO) 60° views. The diameter of tricuspid annulus, the length and depth of the isthmus between the inferior vena cava and inferoposterior tricuspid annulus, and the height of the eustachian valve were measured in the RAO 30° view during atrial presystole using calibration (Fig 1). The measurements were performed manually by 3, who were blind to the procedure, and the mean of the 3 measurements was adopted. The left ventricular ejection fraction, calculated from the left ventriculogram, and cardiac output, calculated by the thermodilution method, were also obtained.

Catheter Ablation

The 7-F ablation catheter (4-mm tip electrode, EP technologies, USA) was inserted into the right femoral vein and advanced toward the right ventricle until the distal bipolar electrogram recorded a low-amplitude atrial potential and a high-amplitude ventricular potential, indicating that the catheter tip was positioned at the tricuspid annulus. Temperature-controlled RF current (500 Hz, EP technologies, USA) was delivered to the electrode tip for 30 s (ie, power limit of 40 W with a target temperature of 60°C). Then the catheter was withdrawn toward the inferior vena cava by 2–3 mm and RF current was delivered until the distal bipolar electrogram showed only a low-amplitude atrial potential, indicating that the ablation catheter tip was located at the junction of the inferior vena cava and right atrium. A successful procedure was defined as the inability to induce common AFL by means of atrial extrastimulation or burst pacing under isoproterenol infusion^{5,6} or the achievement of bidirectional isthmus conduction block.^{12,13}

If these criteria for success was not obtained after 3 or more sequential applications of RF energy, then the ablation catheter was re-inserted through the right jugular vein (ie, superior vena cava approach) and the ablation catheter tip was positioned at the floor of the cavotricuspid isthmus (Fig 2), and RFCA was repeated. If the arrhythmia was still inducible or the bidirectional conduction block was not achieved in the isthmus after 3 or more sequential RF applications, then the superior vena cava approach was also considered unsuccessful.

Based on the criteria for success and the feasibility of performing RFCA by means of the inferior as well as the superior vena cava approach, the patients were divided into 2 groups: Group A included the patients with common AFL that was ablated successfully by the conventional inferior vena cava approach, and group B included the patients in which the arrhythmia was ablated successfully by the additional superior vena cava approach, was terminated by the additional approach without satisfying the criteria for success or continued even after RFCA by the conventional as well as the additional approach.

Statistical Analysis

Quantitative values are expressed as mean $\pm$ standard deviation. Comparisons between different groups were assessed by Student's *t* test. A level of $p < 0.05$ was considered to be statistically significant.

Results

In 9 of the 20 patients incessant common AFL was observed at the beginning of the EPS, and in the remaining 11 patients common AFL was induced by atrial burst pacing or extrastimulation. Endocardial mapping showed a counterclockwise activation sequence around the tricuspid annulus, and in all 20 patients concealed entrainment was obtained by atrial pacing from the low right atrium or coronary sinus ostium.

Application of the RF current to the cavotricuspid isthmus resulted in the conversion of common AFL to sinus rhythm in 19 of the 20 patients, but the criteria for success, defined as the inability of inducing AFL under the continuous infusion of isoproterenol^{5,6} or the formation of bidirectional blockline at the isthmus^{12,13} were only met in 16 patients (ie, the overall rate of success was 80%). In 3 of the 16 patients, the initial conventional inferior vena cava approach

Fig 2. The superior vena cava approach in a patient from group B. ABL, catheter for RF application; HBE, His bundle electrogram; RV, right ventricle; CS, coronary sinus; IVC, inferior vena cava.

was not successful, so the superior vena cava approach was tried (Fig 2) and was successful in all 3 cases. In the 4 patients the criteria for success were not obtained (ie, 1 patient still had common AFL and 3 patients were converted to sinus rhythm at the end of the session without satisfying the criteria, even with the additional superior vena cava approach). Therefore, the 13 patients with common AFL that was successfully ablated by the conventional inferior vena cava approach were included in group A, and the 3 patients with common AFL that required the additional superior vena cava approach to achieve the criteria for success and the 4 patients who did not satisfy the criteria for success were included in group B (n=7). There were no major complications during or after the procedure in any of the patients of the 2 groups.

Table 1 shows the patients' characteristics, RFCA data, isthmus as well as eustachian valvular morphologies and left ventricular function. Body size and mean age were similar in the 2 groups. The total delivered RF energy was greater in group B than in group A.

Of note is the different morphology of the cavotricuspid isthmus and eustachian valve in the 2 groups. On angiography, the cavotricuspid isthmus was longer (3.5 ± 0.5 vs 2.2 ± 0.6 cm) and deeper (0.94 ± 0.35 vs 0.49 ± 0.19 cm) in group B (both groups $p < 0.01$). The height of the eustachian valve was also greater in group B (1.4 ± 1.1 vs 0.48 ± 0.48 cm, $p < 0.02$), but the length of the tricuspid annulus did not significantly differ between the 2 groups ($p = 0.47$). The left ventricular systolic ejection fraction tended to be lower in group B than in group A ($p = 0.09$), but the cardiac index did not reach statistical significance ($p = 0.42$).

Discussion

It is now well accepted that the cause of common AFL is reentry in the right atrium and that the cavotricuspid isthmus between the inferior vena cava and the tricuspid annulus is the critical site of this reentrant circuit. RFCA targeting the isthmus is the first line of therapy for common AFL,^{6-9,14,15} but in a small subset of patients with common AFL, conventional RFCA is unsuccessful!^{0,11} Although the reason is still unclear,¹¹ it is thought to be due to local anatomical complexity of the cavotricuspid isthmus. To our knowledge, ours is the first study to focus on the relationship between the angiographically evaluated structure of the

Table 1 Comparison of Clinical Variables, Catheter Ablation and Local Right Atrial Structure Between the 2 Groups

	Group A	Group B	Difference
No. patients	13	7	
Age (years)	49 ± 20	51 ± 22	NS ($p = 0.68$)
Height (cm)	158 ± 14	161 ± 7	NS ($p = 0.65$)
Weight (kg)	57 ± 14	56 ± 12	NS ($p = 0.94$)
EF (%)	61 ± 9	54 ± 9	NS ($p = 0.09$)
CI ($L \cdot min^{-1} \cdot m^{-2}$)	2.9 ± 1.4	2.5 ± 0.33	NS ($p = 0.42$)
Total RF energy ($\times 1000$ Joule)	15.5 ± 13.8	38.2 ± 18.9	$p < 0.02$
TVA-L (cm)	3.4 ± 0.6	3.6 ± 0.7	NS ($p = 0.47$)
Isth-L (cm)	2.2 ± 0.6	3.5 ± 0.5	$p < 0.01$
Isth-D (cm)	0.49 ± 0.19	0.94 ± 0.35	$p < 0.01$
EV-H (cm)	0.48 ± 0.48	1.4 ± 1.1	$p < 0.02$

TVA-L, length of tricuspid valve annulus; Isth-L, length of isthmus; Isth-D, depth of isthmus; EV-H, height of eustachian valve on right atrigram in RAO view; EF, left ventricular ejection fraction on left ventriculogram; CI, cardiac index calculated by thermodilution method.

right atrium and the outcome of RFCA for common AFL. Moreover, the present study postulates that the superior vena cava approach for RF current delivery may be a promising approach in cases of AFL resistant to conventional RFCA.

From the comparison of the 2 distinctive groups in the present study, it is evident that the structure of the cavotricuspid isthmus is probably affecting the result of RFCA for common AFL. In group B in which conventional RFCA was unsuccessful, the cavotricuspid isthmus was significantly longer ($p < 0.01$) and deeper ($p < 0.01$), and the eustachian valve more prominent ($p < 0.02$), than in group A (Table 1). The formation of a line of block at the cavotricuspid isthmus is the critical prerequisite for successful RFCA for common AFL,^{12,13} and positioning the catheter tip at the isthmus under fluoroscopic guidance has been suggested!^{4,15} However, intraoperative observations following RFCA for atrial fibrillation have revealed that it is difficult to create a continuous transmural line of block¹⁶ and the success of RFCA is related to the anatomical variation of the right atrium as well as the technique. With respect to the anatomical factor, a narrow isthmus can theoretically be ablated easily,¹⁷ but the linear ablation would be more complicated in cases with a broader isthmus. With regard to technique, it is standard practice for the deflectable ablation catheter to be introduced from the inferior vena cava to the right atrium from where it curves sharply within the right atrium toward the cavotricuspid isthmus. If the eustachian valve is prominent and the isthmus is deep, it may be difficult to achieve parallel contact of the catheter tip with the isthmus surface and in fact contact would be perpendicular. In this situation, the topography of the site associated with an entrapped catheter may prevent convective cooling by local blood flow and not result in lesion formation!¹¹ However, the superior vena cava approach may accomplish satisfactory and parallel contact of the catheter tip with the isthmus in such a situation because the ablation catheter will not curve as it does with the conventional approach. The additional approach was proposed conceptually in 1998 by van Asseldonk et al¹⁸ and we have found that this approach useful in cases of common AFL in which there is a deeper and broader cavotricuspid isthmus.

The present study also found anatomical variation in the size of the right atrium. Body size and that of the right atrium did not correlate with the depth and length of the isthmus, or with the height of the eustachian valve. The

right atrium has a complex structure consisting of the sinus venosus and the trabeculated atrium, and it is the size of the remnant of the sinus venosus that varies among patients!⁹ Because the success of RFCA for common AFL is affected by the structure of the right atrium, the right atrigram and the additional RFCA approach are procedures that can maximize successful treatment of the arrhythmia. The development of a catheter or sheath that ensure good contact between the catheter tip and tissue would be another promising step towards increasing the success rate of RFCA for common AFL.

Study Limitations

The first limitation is the study's design. Group B was heterogeneous, including patients with common AFL that was ablated successfully by the additional superior vena cava approach, patients with common AFL that was terminated by this approach, but without fulfilling the criteria for success, and 1 patient with common AFL that could not be terminated by either approach. We did not analyze the difference between these subgroups of group B. Moreover, this study was retrospective and so a prospective randomized study is required to compare the effectiveness of the conventional and additional RFCA approaches. The second limitation is the uncertainty of the evaluation of anatomical variation of the right atrium by means of the right atrigram. Radiographical anatomical evaluation, especially of the eustachian valve, may be influenced by small differences in the projection angle and, moreover, the biplane right atrigram has limited value for the 3-dimensional understanding of the complex structure of the right atrium. An intracardiac echocardiogram may be better choice for this purpose.²⁰ The final limitation is that we did not evaluate the electrophysiological properties of the cavotricuspid isthmus. Not only the anatomical complexity, but also the electrophysiological characteristics of the right atrium, such as the 3 dimensional fiber orientation and anisotropic conduction, may affect the outcome of RFCA for common AFL. Therefore monitoring the local electrogram during RF current delivery, for example, may help achieve successful RFCA in cases with a longer and deeper isthmus.²¹ Further studies are essential to clarify these potential electrophysiological problems.

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