Comparison of 2 Mapping Strategies for Pulmonary Vein Isolation

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Background Pulmonary vein (PV) isolation using a circular catheter (CC) creates an entrance block from the left atrium (LA) to PV to eliminate paroxysmal atrial fibrillation (PAF). We describe a new approach for PV isolation during distal PV pacing using a basket catheter (BC). The purpose of the present study was to compare 2 mapping strategies for PV isolation.

Methods and Results Of 100 consecutive patients with PAF, 50 underwent CC-guided PV isolation and 50 underwent BC-guided PV isolation. During CC-guided ablation, the endpoint was the elimination of PV potentials based on the entrance block from the LA to PV. During BC-guided ablation during distal PV pacing, the endpoint was the elimination of bidirectional PV–LA conduction. At 12 months, 62% of patients who underwent CC ablation and 80% of patients who underwent BC ablation were free of symptomatic PAF without the use of antiarrhythmic drugs ($p<0.05$). The incidence of mild ($<50\%$) PV stenosis in BC ablation was significantly lower than that in CC ablation (12 vs 24%, $p<0.01$).

Conclusions This new approach for PV isolation during distal PV pacing using BC is useful for confirming a bidirectional PV–LA conduction block and is more effective than CC ablation. (Circ J 2005; 69: 1496–1502)

Key Words: Atrium; Catheter ablation; Fibrillation; Veins

Atrial fibrillation (AF) is the most common arrhythmia in humans^{1,2}. Most AF is initiated by premature beats from the orifices of the pulmonary veins (PV) or from the myocardial sleeves inside the PV. Therefore, radiofrequency catheter ablation that targets PV could cure AF.^{3,4} A circular mapping catheter pioneered by Haïssaguerre and others facilitates identification of the conduction pathways from the left atrium (LA) to the PV and permits segmental ablation to achieve PV isolation.^{5,6} However, PV isolation usually creates an entrance block from the LA to PV and an exit block from the PV to LA is not usually confirmed. Moreover, in the right PV, it is sometimes difficult to discriminate PV from LA potentials during sinus rhythm.

Therefore, we developed a new approach for PV isolation during distal PV pacing using a multipolar basket catheter to confirm bi-directional conduction blocks between the PV and LA. The purpose of the present study was to evaluate this new technique by comparing its efficacy and safety with that of the circular catheter mapping technique.

Methods

Patients

The study population consisted of 100 consecutive patients (75 men, 25 women; mean age 57 ± 11 years) with symptomatic drug-refractory paroxysmal AF, who were

referred for an electrophysiological study and catheter ablation. The clinical characteristics of the patients are described in Table 1. A mean of 3.0 ± 1.1 antiarrhythmic drugs had been administered unsuccessfully. None of the patients had been treated with amiodarone during the preceding 6 months.

Study Protocol

One hundred patients were randomized to undergo PV isolation using circular mapping catheter-guided ablation ($n=50$) or basket catheter-guided ablation ($n=50$). These 2 techniques were performed in an alternative way. The clinical characteristics of the patients in the 2 groups were not significantly different (Table 1).

Electrophysiological Study

The present study was approved by the Ethics Committee of Fukuoka University Hospital, and written informed consent was obtained from all patients. Patients received oral anticoagulant for at least 1 month before ablation. Antiarrhythmic drugs were discontinued 5 half-lives before ablation. Three 6-French quadripolar electrode catheters (Daig, USA) were placed in the right atrial appendage, His bundle area and coronary sinus (CS). A transseptal approach was performed with an 8.5F sheath both for puncture and to introduce a circular 20-electrode catheter (Lasso, Biosense-Webster, USA) or a 31 mm, 64-pole basket catheter (Constellation, Boston Scientific, USA) dedicated to PV mapping (Fig 1). After the transseptal puncture, 100 IU heparin/kg was given intravenously. During the procedure, heparinization was continued to maintain an activated clotting time of 250–350 s. A 4-mm-tip conventional ablation catheter (EP Technologies, USA) was also introduced into the LA for ablation. PV angiography was performed with

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Table 1 Clinical Characteristics of Patients Who Underwent Circular Catheter-Guided Ablation or Basket Catheter-Guided Ablation

	Circular catheter-guided ablation (n=50)	Basket catheter-guided ablation (n=50)	p value
Age (years)	58±9	57±11	0.5
M/F (n)	40/10	35/15	0.4
Duration of AF (months)	89±101	69±65	0.5
No. of episodes of AF/month	11±10	12±9	0.6
Left atrial diameter (mm)	40±7	38±5	0.2
LVEF (%)	66±9	65±6	0.8
Structural heart disease, n	2	2	1.0

Data are mean ± SD. AF, atrial fibrillation; LVEF, left ventricular ejection fraction.

Fig 1. (Left) Fluoroscopic anteroposterior view of a transseptal position of the basket catheter in a left superior pulmonary vein (LSPV). (Right) A 64-pole basket catheter (Constellation) with 8 splines of nitinol and 8 electrodes per spline for a 3-dimensional high-density mapping. The distal pulmonary vein (PV) pacing was performed from the distal electrode pair (bipoles 1–2) and the proximal electrode (bipoles 7–8) of the basket catheter was located at the PV–left atrium (LA) junction.

an angiocatheter (6-French, Baxter, USA) to determine the ostium of the PV. The proximal part of the PV was defined as the ostial side of the veins, while distal referred to the lung side of the veins.

A programmed stimulator (SEC-3102, Nihon Kohden, Japan) was used to deliver electrical impulses of 2 ms duration at twice the diastolic threshold, with the negative pole connected to the distal electrode of the pacing catheter. ECG leads and intracardiac electrograms filtered at 30–500 Hz were recorded simultaneously with a polygraph (EPLab System DUO, Bard, USA).

Circular Catheter-Guided PV Isolation

A circular 20-electrode catheter was deployed in the PV through a transseptal sheath. Circumferential PV electrograms were acquired simultaneously and used to guide ablation at ostial sites with the earliest PV potentials during sinus rhythm for right PV or CS distal pacing for left PV. Radiofrequency pulses were delivered within the first few millimeters of the PV with the earliest PV potentials and monitoring of distal PV potentials. If the activation sequence around the PV ostium changed, the bipole that showed the new shortest LA–PV conduction was targeted. The endpoint was considered the elimination of all PV potentials based on a complete entrance block from LA to PV.

Basket Catheter-Guided PV Isolation

After transseptal access was gained, the basket catheter was inserted directly into the upper PV. For introduction into the inferior PV, the sheath was inserted first with the help of a steerable ablation catheter. Once the sheath was in place in the PV, the steerable catheter was removed and

replaced by the basket catheter. The basket catheter was then deployed in the PV by slowly advancing the basket catheter while simultaneously withdrawing the sheath. The proximal electrode (bipoles 7–8) of the basket catheter was located at the PV–LA junction. The location of the ostium was determined both by electrogram morphology and noting the shape of the basket catheter as it conformed to the PV and ostial anatomy as confirmed using angiography. When the basket catheter could not be deployed in the right inferior PV, the PV isolation was not performed using the circular catheter.

The Astronomer system (Boston Scientific) was used for navigation inside the basket catheter. This system consists of a switching/locating device and an off-the-shelf laptop computer. The device and the laptop communicate via a standard RS-232 interface. The device delivers AC current (32 kHz, 320 μA) between the ablation catheter-tip electrode and a reference (skin patch) electrode, and the resulting electrical potentials are sensed at each basket catheter electrode. Based on the voltages sensed at each of the basket catheter electrodes, the Astronomer device determines whether the roving electrode is in close proximity to a basket catheter electrode and lights the corresponding electrodes of the basket catheter displayed on the laptop. Guided by the basket catheter and the Astronomer system, ablation was performed at the PV–LA junction, as far as the ostial catheter stability allowed.

The PV pacing was performed from the distal (bipoles 1–2) electrode pair of all splines of the basket catheter that could be captured. The ostial sites with the earliest PV potentials (electrical entrance breakthrough points) during distal CS pacing (for left PV) or sinus rhythm (for right PV), and the ostial sites with the earliest LA potentials (electri-

Fig 2. Detection of exit breakthrough points by distal pulmonary vein (PV) pacing. Proximal (bipoles 7-8) electrograms from all splines of the basket catheter placed in the left superior PV are shown. (Left) During pacing from the distal coronary sinus (CS), the earliest activation sites (*)—that is, the entrance breakthrough points—are A 7-8 and H 7-8. (Right) During pacing from the distal PV, the earliest activation sites (*)—that is, the exit breakthrough points—are D 7-8 and E 7-8. Thus, in this case, the exit breakthrough points are different than the entrance breakthrough points.

Fig 3. Detection of exit breakthrough points in the right superior pulmonary vein (PV) by distal PV pacing. Proximal (bipoles 7-8) electrograms from all splines of the basket catheter placed in the right superior PV are shown. (Left) During sinus rhythm, atrial and PV potentials approach each other. (Right) During PV distal pacing from A 1-2, these potentials are discriminated. The exit breakthrough point is B 7-8.

cal exit breakthrough points) during PV distal pacing were determined. Fig 2 shows the exit breakthrough points of a left superior PV disclosed by PV distal pacing. In this case, during distal CS pacing, the entrance breakthrough site was A-H 7-8. In contrast, the exit breakthrough point was detected at D-E 7-8. The exit breakthrough point was first targeted for segmental PV isolation. Fig 3 shows the electrograms around the PV-LA junction of an right superior PV. In this case, during sinus rhythm, the PV and LA potentials approach each other. However, the distal PV pacing discriminated between these potentials and disclosed the exit breakthrough point.

Circumferential electrograms around the PV-LA junc-

tion were used to guide ablation at the ostial sites with the earliest atrial potentials during distal PV pacing (Fig 4). If a unidirectional conduction block between the PV and LA was observed, ablation was continued until a bi-directional conduction block was created (Fig 5). The endpoint was considered to be a bidirectional conduction block between the PV and LA based on both the inability to capture the LA during distal PV pacing and the abolition of distal PV potentials (Fig 6).

Radiofrequency Ablation

All PV were targeted for isolation. However, when the PV diameter was <12 mm, ablation was not performed to

Fig 4. Pulmonary vein (PV) isolation during distal PV pacing using a basket catheter. Only ostial electrograms at bipoles 7–8 from all splines of the basket catheter placed in the left superior PV are shown. (Left) Before ablation, the earliest atrial potential is located in bipole A7–8. After local ablation at this site, the earliest potential changed to bipole C7–8. After ablation of this secondary breakthrough, the earliest potential changed to bipole E7–8. Finally, the ablation of this third breakthrough blocked the conduction from the PV to left atrium (LA) and eliminated all atrial potentials.

Fig 5. An entrance block remaining after an exit block between the pulmonary vein (PV) and left atrium (LA). Electrograms from ECG lead II, an E-spline of the basket catheter placed in the left superior PV, ablation catheter and distal coronary sinus (CS) during ablation are shown. In panel A, segmental ablation at the exit breakthrough points during distal PV pacing blocked conduction from the PV to LA. However, conduction from the LA to PV remained (panel B). Additional ablation at the entrance breakthrough points blocked conduction from the LA to PV (panel C). A, atrial potential.

avoid PV stenosis. In both ablation groups, radiofrequency energy was delivered with a temperature-controlled, 4-mm-tip, deflectable catheter (EP Technologies). Radiofrequency energy (EP Technologies, Inc) was delivered at a target temperature of 50°C and a maximum output of 30 W for 30–60 s at each ostial site. If the activation sequence around the PV–LA junction was changed, the bipole that showed the new earliest atrial potentials was targeted (Fig 5). After PV isolation, if premature atrial contractions were present

or provokable using isoproterenol or pacing maneuvers (incremental pacing or programmed stimulation), the origin of the premature atrial contractions was localized using activation mapping, and ablation was performed at this site.

Follow-up

Warfarin was readministered and continued for 3 months with an international normalized ratio level of approximately 2.0. Follow-up was performed at the institution,

Fig6. Conduction block from the pulmonary vein (PV) to left atrium (LA) during the delivery of radiofrequency energy. Electrograms from ECG lead III, a C spline of the basket catheter placed in the right superior PV and ablation catheter are shown. Segmental ablation at the exit breakthrough points during distal PV pacing blocks the conduction from the PV to LA. Bidirectional conduction block between the PV and LA is confirmed by PV–LA dissociation. A, atrial potential.

initially at 1 week and subsequently at 1-month intervals. Clinical examinations, ECG and 24-h Holter recordings were made every 3 months and when symptoms suggested the recurrence of an arrhythmia.

3-dimensional (D) computed tomography (CT) was performed at 6 months and 12 months after ablation to assess the stenosis of the PV. A change in the PV diameter, as measured by a 3-D CT before and 12 months after the ablation, that showed a decrease in PV diameter of more than 25% was considered significant. The success of the procedure was defined as the absence of clinical symptoms of AF without the need for antiarrhythmic drugs and the documentation of stable sinus rhythm on 24-h Holter monitoring.

Statistical Analysis

Continuous variables are expressed as the mean $\pm$ SD. Between-group comparisons were evaluated with the unpaired Student's *t*-test. To analyze nonparametric data, we used the chi square test as appropriate. The statistical significance was set at a value of $p < 0.05$.

Results

Circular Mapping Catheter-Guided PV Isolation

The PV isolation was performed in all PV except 4 right inferior PV (mean 3.9 per patient) that were successfully electrically isolated. The entrance block from the LA to PV was confirmed by the elimination of PV potentials in all PV.

Basket Catheter-Guided PV Isolation

The PV isolation was performed in all PV, except 8 right inferior PV (mean 3.8 per patient) that were isolated successfully. Segmental ablation at the exit breakthrough points during distal PV pacing blocked conduction from the PV to LA. After the exit block from the PV to LA was isolated, the conduction from LA to PV was observed in 18% of the PV; that is, the unidirectional block. A bidirec-

tional conduction block between the PV and LA was confirmed by PV–LA dissociation in all PV.

Total Ablation, Procedure and Fluoroscopy Times

The mean total ablation time and application number required to achieve complete isolation was 28 ± 4 min and 48 ± 8 applications for the circular catheter group, and 31 ± 5 min and 49 ± 8 applications for the basket catheter group ($p = 0.2$). The mean total duration of the procedure was 260 ± 71 min for the circular catheter group and 242 ± 70 min for the basket catheter group ($p = 0.2$). The mean total fluoroscopy time was 86 ± 34 min for the circular catheter group and 69 ± 25 min for the basket catheter group ($p < 0.01$).

Recurrence of AF

After the first ablation procedure, paroxysmal AF recurred in 25 of the 50 patients (50%) in the circular catheter group and in 14 of the 50 patients (28%) in the basket catheter group ($p < 0.05$). A repeat ablation procedure was performed 38 ± 7 days after the initial procedure in 22 patients in the circular catheter group and in 12 patients in the basket catheter group. During the repeat procedures, the recovery of LA–PV conduction was noted in 63 of the 88 PV (72%) in the circular catheter group and 24 of the 48 PV (50%) in the basket catheter group ($p < 0.02$). Of the 24 PV with the recovery of conduction in the basket catheter group, 5 PV (21%) had a unidirectional block.

Follow-up

After 134 procedures in 100 patients, 62% of the patients who underwent circular catheter-guided ablation and 80% of those who underwent basket catheter-guided ablation ($p < 0.05$) were free from symptomatic paroxysmal AF at the 12-month follow up (after the most recent ablation) without the need for antiarrhythmic drug treatment. An additional 5 patients (10%) in the circular catheter group and 6 patients (12%) in the basket catheter group were in sinus rhythm with the aid of antiarrhythmic drug treatment, which had been ineffective before ablation.

Complications

One patient in the circular catheter group developed pericardial effusion. The effusion was drained percutaneously. Also, 1 patient in the circular catheter group had unilateral quadrantopsia. Mild PV stenosis ($\leq 50\%$) was seen in 24% of the patients in the circular catheter group and in 12% of the patients in the basket catheter group ($p < 0.01$). However, no PV stenosis $> 50\%$ was detected using 3-D CT at 12 months after the procedure.

Discussion

Main Findings

In the present study, symptomatic paroxysmal AF was eliminated more reliably using basket catheter-guided PV isolation than by circular catheter-guided PV isolation. While there was no significant difference in the total procedure time between the 2 approaches, there was a tendency toward a shorter duration of fluoroscopy with basket catheter ablation using the nonfluoroscopic Astronomer navigation system. Complications were rare, and the incidence of mild PV stenosis with basket catheter-guided PV isolation was lower than that with the circular catheter approach. These findings suggest that basket catheter ablation may be preferable to circular catheter ablation as the first approach in patients with symptomatic paroxysmal AF who are appropriate candidates for catheter ablation.

Comparison of Technical Aspects

There are isolated fascicles that travel from the LA into the muscle sleeves that surround the PV and ablation of these fascicles, as opposed to circumferential ablation at the ostium, may be sufficient to isolate the veins.⁵ Segmental ostial ablation electrically isolates the PV, thereby eliminating the arrhythmogenic activity in the PV that triggers and/or perpetuates episodes of paroxysmal AF.^{3,8-11} Arentz et al reported that basket catheter-guided PV isolation is a feasible and safe procedure for curing patients of AF by integrating PV anatomy and electrophysiology with a navigation system for the ablation catheter.¹² Using basket-catheter mapping, we analyzed the activation map for PV and found that the entrance breakthrough points were sometimes different from the exit breakthrough points, and the PV-LA junctional reentrant circuits involving the exit and entrance breakthrough points were formed.¹³ However, no previous studies have directly compared the basket catheter and circular mapping catheter for PV isolation. A circular mapping catheter can record circumferential PV potentials within the PV. In contrast, a basket catheter provides the following potential advantages: (1) the 3-D reconstruction of PV activation from the ostium to deep inside the PV; (2) the identification of the location of the PV ostium; (3) the nonfluoroscopic Astronomer navigation system enables the precise and reproducible guidance of the ablation catheter; and (4) the possibility of simultaneous distal pacing and proximal mapping.

Regarding the practical aspect of procedures, the basket catheter-guided PV isolation and the circular catheter-guided PV isolation were comparable. Our experience with the basket catheter-guided PV isolation was similar to that with the circular catheter-guided PV isolation. We have performed more than 50 procedures each using the respective techniques. This suggests that the comparison of procedure times between the 2 techniques in the present study was valid.

Mechanistic Considerations

In PV isolation, conduction from the LA to PV is usually blocked during sinus rhythm or CS pacing.^{5,6} It is possible that conduction from the PV to LA may remain after an entrance block from the LA to PV. A recovery of conduction over a previously ablated PV fascicle was a consistent finding among patients who underwent a repeat procedure, and it is likely that incomplete ablation was related to unidirectional conduction block. However, it is sometimes difficult to confirm the position of a conduction block from the PV to LA. We have described a new approach for PV isolation during distal PV pacing using a basket catheter. Moreover, in right PV, it is sometimes difficult to discriminate PV and LA potentials during sinus rhythm. However, distal PV pacing can easily discriminate these potentials. Segmental ablation at the exit site during distal PV pacing created a conduction block from the PV to LA, and bidirectional conduction block between the PV and LA was also confirmed. This may explain the higher efficacy of basket catheter-guided ablation compared to circular mapping catheter ablation.

In addition, because of its length and structure, the basket catheter achieves a more proximal recording from the LA-PV junction and permits a more proximal, outside PV isolation, which may also be important for the greater success. The other significant difference between the 2 groups is the use of the localization facilities of the basket catheter-Astronomer navigation system. The basket catheter, by allowing both circular and longitudinal mapping, offers significant advantages over the more simple circular catheter.

Safety

Pericardial effusion and unilateral quadrantopsia developed after circular catheter-guided ablation. No instances of significant PV stenosis ($> 50\%$) occurred. When radiofrequency energy is delivered at the ostium and the maximum power is limited to 35 W, the risk of PV stenosis is reportedly low ($\sim 3\%$).¹⁴ The instance of mild PV stenosis ($< 50\%$) with basket catheter-guided PV isolation in the present study was lower than that with circular catheter ablation. A circular mapping catheter is usually placed inside the PV, and ablation is performed inside the PV due to the targeting of the PV potentials.^{5,6} In contrast, a basket catheter guided-ablation is performed outside the PV due to the targeting of the atrial potentials. This technology may minimize the risk of PV stenosis by avoiding ablations inside the PV. Therefore, the use of complementary navigation systems or intracardiac echos may not be necessary when a basket catheter is used for PV isolation.^{15,16} Recently, Oral et al demonstrated that left atrial catheter ablation to encircle PV is more effective than segmental ostial catheter ablation.¹⁷ However, left atrial catheter ablation sometimes has complications, including left atrial flutter and atrio-esophageal fistulas.¹⁸ In contrast, such severe complications were not observed in the present study. Therefore, basket catheter-guided ostial ablation may be an alternative to left atrial catheter ablation.

Conclusions

In conclusion, basket catheter-guided PV isolation is an effective and safe procedure for curing patients of AF by integrating PV anatomy and electrophysiology with a navigation system for the ablation catheter. Also, this new

approach for PV isolation during distal PV pacing using a basket catheter is feasible and can easily confirm a bidirectional conduction block between the PV and LA. PV isolation that creates not only entrance block but also exit block at the PV–LA junction may be required to cure AF. Therefore, when the circular catheter is used, PV isolation should be performed at a more proximal PV and a bidirectional conduction block between the PV and LA should be confirmed.

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