Intraoperative verification of conduction block in atrial fibrillation surgery

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Background: Atrial tachycardia is a troublesome and medically refractory complication after surgery for atrial fibrillation. Incomplete surgical ablation during atrial fibrillation surgery can result in residual conduction over the lesions and postoperative atrial tachycardia. Intraoperative verification of conduction block would detect incomplete ablation lesions and direct repeat ablations to prevent postoperative atrial tachycardia.

Methods: The incidence of postoperative atrial tachycardia was examined in 218 patients who underwent atrial fibrillation surgery between November of 1994 and October of 2007. No conduction block across any ablation lesions was confirmed intraoperatively in the first 128 patients (group C). Isolation of each pulmonary vein was verified by intraoperative pulmonary vein pacing in the following 72 patients (group PV). In the recent 18 consecutive patients, conduction block in the coronary sinus, in addition to pulmonary vein isolation, was confirmed by intraoperative coronary sinus pacing (group PV/CS). Postoperative atrial tachycardia was characterized by electroanatomic mapping.

Results: The incidence of postoperative atrial tachycardia in groups C and PV was 7% and 1%, respectively ($P = .0985$). No patients exhibited any postoperative atrial tachycardia in group PV/CS. The postoperative electroanatomic mapping revealed that the mechanisms of the atrial tachycardia were macro-reentry through incomplete coronary sinus and mitral valve ablation lesions ($n = 9$), and focal activation in the coronary sinus ($n = 1$). Intraoperative verification of conduction block directed the repeat ablation lesions to the pulmonary veins.

Conclusion: The majority of postoperative atrial tachycardia was associated with an incomplete coronary sinus ablation. Intraoperative verification of conduction block may be helpful to prevent the occurrence of postoperative atrial tachycardia.

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Creation of a conduction block is the rationale behind the surgical treatment of atrial fibrillation (AF). The “cut-and-sew” technique provides complete conduction block, and a line of conduction block prevents propagation of abnormal activation and interrupts reentrant circuits. Alternative ablation devices have been developed to replace the “cut-and-sew” lesions of the Maze procedure to simplify the surgical procedure, decrease the risk of bleeding, and shorten the cardiac arrest and operative times during the surgery.¹ However, ablation devices, such as traditional cryoablation or radiofrequency (RF) ablation, do not necessarily guarantee transmural and continuous necrosis.² The thermal sink effect or thick atrial tissue decreases the

Abbreviations and Acronyms

AF = atrial fibrillation
 AT = atrial tachycardia
 CS = Coronary sinus
 PV = pulmonary vein
 RF = radiofrequency

effect of the ablation, and incomplete ablation can result in reentrant atrial tachycardia (AT) postoperatively. If the amount of surviving atrial myocardium in the incomplete ablation is at a critical level, atrial activation can pass through the critical isthmus in the nontransmural or noncontinuous lesion with slow conduction.³

Our clinical experience has shown that the incomplete ablation of the coronary sinus (CS) is the most common cause of postoperative AT.⁴ The CS musculature, which is an extension of the right atrial myocardium surrounding the CS,⁵ anatomically and electrically connects the right and left atria.⁶ Complete circumferential ablation of the CS has never been proven intraoperatively because it is technically difficult, whereas the verification of the isolation of the pulmonary veins (PVs) can be easily performed. The purpose of this study was to determine the effectiveness of intraoperative verification of the conduction block in the CS to prevent postoperative AT.

Materials and Methods

Patient Characteristics

From November of 1994 to October of 2007, 218 patients underwent AF surgery, including the Maze III procedure, radial procedure, and PV isolation, at Nippon Medical School Hospital, Tokyo, Japan. They were enrolled after informed consent was obtained for their procedures, in accordance with the Human Studies Committee at the Nippon Medical School Hospital. The primary indication for AF surgery was permanent AF ($n = 170$) or symptomatic paroxysmal AF ($n = 48$) refractory to medical therapy. The average AF duration was 78 ± 72 months (3 months to 30 years).

There were 124 men and 94 women with a mean age of 62 ± 10 years. A total of 192 patients had heart failure caused by valvular heart disease with a New York Heart Association functional class grade of II or III preoperatively. The mean left ventricular ejection fraction was $59.6\% \pm 13.9\%$, and the mean left atrial diameter was 50.4 ± 10.4 mm. All patients were followed up every month after discharge until 6 months. After the 6-month checkup, patients were examined every 3 months at the Nippon Medical School Hospital. The postoperative cardiac rhythm was evaluated by an electrocardiogram at each follow-up. If the patients reported any palpitations, they were monitored by a Holter electrocardiogram.

Confirmation of Conduction Block During Atrial Fibrillation Surgery

In 128 of the 218 patients, no conduction block in either the PV isolation or CS ablation was confirmed intraoperatively (group C). In the following 72 patients, isolation of each PV was verified by intraoperative PV pacing (group PV). To confirm the integrity of the PV isolation, each of the 4 PVs was paced by a custom-made hand-held bipolar pacing electrode before and after the PV ablation after conversion of AF to sinus rhythm by DC cardioversion if necessary (Figure 1). Stimulation was performed using a programmable pulse generator (Cardiac Stimulator, Fukuda Denshi Corp, Tokyo, Japan). Continuous pacing was conducted at a rate of approximately 120% of the intrinsic heart rate. The stimulus output was set at maximum (20 mA). Conduction block between the PVs and the left atrium was determined by the failure of atrial capture despite the maximum output of the stimuli of the PV pacing. If any atrial capture was demonstrated by the PV pacing, the PVs were ablated repeatedly until a complete conduction block was confirmed. Table 1 shows the energies used to achieve the PV isolation and conduction block in the CS in each group.

In the most recent 18 patients, conduction block in the CS was also confirmed by CS pacing intraoperatively, in addition to the PV pacing (group PV/CS). To evaluate the conduction block in the CS, an electrode catheter with 10 bipolar electrodes (CSL 6F; St Jude Medical, St Paul, Minn) was placed in the CS through a right atrial incision before the cardiopulmonary bypass was discontinued (Figure 2). The tip of the catheter was positioned approximately 10 cm from the orifice deep in the CS. After completion of the cardiopulmonary bypass, the activation sequence around the mitral valve was examined during continuous pacing at a cycle length of 600 to 700 ms

Figure 1. Confirmation of PV isolation. Each of the 4 PVs is paced using a bipolar electrode after the PV ablation. Conduction block between the PVs and left atrium is determined by the failure of atrial capture despite the maximum output of the stimuli of the PV pacing. If any residual conduction is demonstrated between any of the PVs and left atrium, repeat ablation is performed until a complete conduction block is confirmed. Pacing sites (rectangles). Rt. PVs, Right pulmonary veins; Lt. PVs, left pulmonary veins.

TABLE 1. Energy used to create the ablation lesions

Groups	PV isolation	CS block
C	Cryoablation (n = 97) Unipolar RF (n = 12) Bipolar RF (n = 19)	Cryoablation (n = 121)
PV	Bipolar RF (n = 71) Microwave (n = 1)	Cryoablation (n = 33) Pen-type RF device (n = 23)
PV/CS	Bipolar RF (n = 18)	Cryoablation (n = 4) Pen-type RF device (n = 14)

PV, Pulmonary vein; CS, coronary sinus; RF, radiofrequency. Pen-type ablation device includes unipolar RF and bipolar RF pen devices.

from the distal or proximal pairs of electrodes to the ablation lesion. The data were recorded by a personal computer-based data-acquisition and analysis system (PowerLab 5.3, ADInstruments, Colorado Springs, Colo). The bipolar electrograms were recorded at a gain of 4000 with a frequency response of 50 to 1000 Hz along with a limb lead electrocardiogram. The local activation time was defined

as the time of the absolute maximum amplitude of the bipolar electrograms. Bidirectional conduction block was defined as no conduction leaking across the ablation lesion as determined by examining the activation sequence during pacing both from the proximal and distal pairs of electrodes to the ablation line. The incidence of postoperative AT in groups PV and PV/CS was compared with group C. The average follow-up period was 86 ± 36 months in group C, 30 ± 14 months in group PV, and 17 ± 10 months in group PV/CS.

Definition of Supraventricular Tachycardia

The incidence of postoperative supraventricular tachycardia was examined by electrocardiograms or Holter electrocardiograms in all patients during the follow-up. All electrocardiograms were reviewed by a cardiologist (Y.M.). AT was defined as a regular narrow QRS tachycardia with a heart rate greater than 100 beats/min and a different morphology and axis of the P waves from those during sinus rhythm. AF was defined as a rapid irregular rhythm with disorganized atrial activity in which distinct P waves were absent. Atrial flutter was a regular atrial arrhythmia with negative flutter waves in the inferior leads and positive flutter waves in lead V₁ at an atrial cycle length of 200 to 280 ms. The incidence of

Figure 2. Confirmation of conduction block in the CS. A multi-electrode catheter is placed in the CS through a right atrial incision before termination of the cardiopulmonary bypass. The activation sequence in the CS is examined during continuous pacing from the distal or proximal pairs of electrodes to the ablation lesion. A, If the CS ablation is complete, the clockwise wavefront of the paced activation is blocked between electrodes 6 and 7. The other wavefront of the paced activation propagates around the mitral valve in a counterclockwise fashion and activates electrode 6. B, If the CS ablation is not complete, the clockwise activation can conduct across the ablation lesion and activate electrode 6. This activation collides with the counterclockwise activation propagating around the mitral valve.

postoperative AT in groups PV and PV/CS was compared with that in Group C.

Electroanatomic Mapping of Postoperative Atrial Tachycardia

In the patients with postoperative AT, the tachycardia was characterized by an electrophysiologic study using an electroanatomic mapping system (CARTO, Biosense Webster, Diamond Bar, Calif) by the electrophysiologist (Y.M.). Standard multielectrode catheters were placed in the CS and right ventricular apex. Both bipolar and unipolar electrograms were recorded by the electroanatomic mapping system. An RF ablation catheter was introduced from the femoral vein and advanced into the right atrium and CS. After the anatomic landmarks were outlined, entrainment mapping was performed from the right atrium, left atrium, and CS to determine the critical site of the reentrant circuits. The isthmus of the reentrant circuit or focal activation detected by the electroanatomic mapping was ablated by RF catheter ablation.

Statistical Analysis

All continuous values were expressed as the mean $\pm$ 1 standard deviation. The continuous variables were compared by an unpaired *t* test (Stat View 5.01; SAS Institute Inc, Cary, NC).

Results

Postoperative Cardiac Rhythm

There were 3 in-hospital deaths. Of the patients who were discharged from the hospital (*n* = 215), sinus rhythm was confirmed by an electrocardiogram in 184 patients (85.5%) at the latest follow-up. A permanent pacemaker was implanted in 7 patients (3.3%) for sick sinus syndrome. As a result, 88.8% of the patients were free from atrial tachyarrhythmias. Fourteen patients (6.5%) remained in AF, and AT developed postoperatively in 10 patients (4.7%). No antiarrhythmic drugs were taken in 73% of all patients. Antiarrhythmic drugs, such as amiodarone, sotalol hydrochloride, verapamil, or pilsicainide, were taken in 20%, 4%, 2%, or 1% of the patients, respectively. Sinus rhythm was maintained in 70% of all patients without any antiarrhythmic drugs.

Incidence of Postoperative Atrial Tachycardia

The overall incidence of postoperative AT was 4.7% after AF surgery (10 patients). All patients had undergone the radial procedure, in which the CS was ablated endocardially by cryoablation. Postoperative AT (Figure 3) occurred in 9 patients in group C, and in 1 patient in group PV (*P* = .0985, odds ratio, 0.19; 95% confidence interval, 0.02–1.50). Almost all of the patients (9/10 patients) who had postoperative AT underwent AF surgery in the first half of the cases in our experience (September 1998 to February 2003). Although there were patients with postoperative AT in groups C and PV, no patients had postoperative AT in group PV/CS (Figure 4). All ATs were successfully ablated by RF catheter ablation except in 1 patient who refused RF catheter ablation.

Confirmation of Pulmonary Vein Isolation

In all the patients in groups PV and PV/CS, PV pacing from the right and left PVs was performed intraoperatively and complete isolation of each PV was confirmed in all patients. The RF ablation was applied 2.8 ± 0.5 times to the right PVs and 2.9 ± 0.4 times to the left PVs before confirming conduction block. No residual conduction between any of the PVs and the left atrium was demonstrated in any of the patients who underwent a postoperative electrophysiological study.

Intraoperative Confirmation of the Coronary Sinus Ablation Lesion

Complete conduction block across the ablation lesion in the CS was proved during pacing from the proximal and distal CS in all the patients in group PV/CS (Figure 5). The activation propagated around the mitral valve clockwise or counterclockwise from the pacing site to the ablation lesion in the CS. The activation sequence revealed that the paced activation was completely blocked at the ablation lesion and did not conduct across the ablation lesion to the opposite side. None of the patients demonstrated a residual conduction across the CS ablation lesion and thus did not require any additional ablation in the CS or around the mitral valve annulus after the procedure.

Discussion

The postoperative electroanatomic mapping revealed that the majority of the ATs after surgery for AF were associated with an incomplete CS ablation, resulting in macro-reentrant activation around the mitral annulus. The intraoperative verification of the conduction block provided information to direct repeat ablation to complete the ablation lesion and may prevent the occurrence of postoperative AT.

It has been controversial whether transmural lesions are necessary to cure AF with surgical ablation. Some studies have argued that transmural lesions were not necessary in their clinical experience using alternative ablation devices.^{7,8} However, it has been described that a nontransmural or noncontinuous necrosis causes a conduction gap in the ablation lesion and results in an atrial reentrant tachycardia in clinical and experimental studies.^{3,9,10} A small amount of viable myocardium can propagate conduction across the ablation lesion with slow conduction. The presence of slow conduction in the reentrant circuit allows sufficient time for the myocardium to recover, allowing a stable reentrant activation for AT to occur. The only guarantee of complete conduction block is a cut-and-sew lesion or fully transmural ablation lesion.

Ninety percent of the patients who developed AT postoperatively were those who underwent AF surgery in the first half of the period of our experience. This suggested that the CS might not have been ablated completely in our early experience, resulting in incomplete conduction block at the CS. In those patients, the CS had been cryoablated from

Figure 3. Typical postoperative AT resulted from an incomplete CS ablation. **A**, Electrocardiogram of a postoperative AT. AT developed in the patient (72-year-old man) 2 months after the radial procedure and mitral valve replacement. The cycle length of the AT is 250 ms. **B**, Postoperative electroanatomic mapping (CARTO) exhibits a macro-reentrant activation conducting through the incomplete CS ablation (*left*). Reentrant circuit (*black arrows*). The lesion set of the surgical procedure with the reentrant circuit of the postoperative AT is shown in the right panel. **AP**, Anteroposterior; **PA**, posteroanterior; **SVC**, superior vena cava; **IVC**, inferior vena cava; **LA**, left atrium; **LSPV**, left superior pulmonary vein; **RSPV**, right superior pulmonary vein; **RA**, right atrium; **MV**, mitral valve; **TV**, tricuspid valve; **LAA**, left atrial appendage; **RAA**, right atria appendage; **FO**, fossa ovalis; **CS**, coronary sinus.

only the endocardium. In the patients in the last half of the period of our experience, the CS had been more carefully ablated by cryothermia or an RF ablation device both endocardially and epicardially to make a complete circumferentially necrotic lesion. Thorough CS ablation could reduce the inci-

dence of postoperative AT. In light of this concept, conduction block at the ablation lesion should be confirmed during AF surgery to reduce the risk of surgical failure.

Completeness of the PV isolation is most essential in AF surgery. Repetitive activations that originate in the myocardial sleeves in the PVs are thought to trigger and maintain the AF.¹¹ Because of the thick tissue at the left atrial antrum, only 1 application of ablation energy may not be enough to create a transmural and continuous lesion. Therefore, several applications of ablation energy would be necessary for complete conduction block,¹² and PV pacing should be effective to confirm complete PV isolation.

Although the PV pacing can easily be performed, verification of conduction block in the CS has not been performed. This is because the CS block lesion is not an isolation lesion as in PV isolation, so that the activation sequence in the CS needs to be examined. Intraoperative CS pacing is one of the methods to verify conduction block at the CS. As illustrated in Figure 2, a paced activation slowly conducting through the incomplete ablation lesion can be detected by examining the activation sequence in the CS. However, in the case with extremely slower conduction in the incomplete ablation lesion, an extremely delayed activation may be

Figure 4. Incidence of postoperative AT. **PV**, Pulmonary vein; **CS**, coronary sinus.

Figure 5. Typical activation sequence around the mitral valve after a complete CS ablation. The paced activation from the proximal (electrode No. 9) or distal (electrode No. 3) electrode to the CS ablation lesion is completely blocked at the ablation lesion. The activation propagated around the mitral valve in a counterclockwise (A) or clockwise (B) fashion from the pacing site to the opposite side across the ablation lesion. The activation sequence is shown (right). Propagation of the conduction (arrows). Conduction block (double bars).

confined to a limited area in the CS across the ablation line and thus may not be detected by recording the activation sequence in the CS with a normal catheter electrode. The differential pacing method, in which double potentials across the incomplete ablation line are compared between the different pacing sites, may be helpful in detecting such slow conduction through the ablation line.^{13,14} If conduction across the ablation lesion is demonstrated by intraoperative CS pacing, additional applications of ablation should be performed at the insufficient ablation lesions epicardially to prevent postoperative AT.

Conclusions

The present study was a nonrandomized study, and the number of patients in group PV/CS was smaller than that in the other groups. However, the study showed that the conduction block could be verified intraoperatively both for the PVs and CS. Postoperative AT was prevented by additional ablation applications to the incomplete ablation site proved by intraoperative verification of conduction block. The concept of intraoperative verification of conduction block may

lead to the development of more reliable ablation devices in the future.

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