Identifying the Origin of Right and Left Ectopic Atrial Beats Triggering Atrial Fibrillation before Atrial Transseptal Procedure

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Atrial premature depolarizations (APDs) triggering atrial fibrillation (AF) originate from mainly the pulmonary veins (PVs), but, in some cases, atrial ectopic beats (AEBs) triggering AF originate from the right atrium (RA) or the superior vena cava. Accurate identification of the origin of APDs in the PVs by means of RA and coronary sinus mapping is difficult.

Purpose: The aim of this study was to identify the origin of AEBs triggering AF before transseptal catheterization. Electrode catheters were placed in the posteroseptal RA (PSRA), right pulmonary artery (RPA), left pulmonary artery (LPA), and esophagus in 10 patients with paroxysmal AF. We analyzed endocardial electrograms from the PSRA, RPA and LPA, and epicardial electrograms from the esophagus. The origin of the AEBs in the PVs was determined before PV ablation by mapping 4 PVs simultaneously. Four AEBs originated from the left superior PV (LSPV), 2 from the left inferior PV (LIPV), 4 from the right superior PV (RSPV), 2 from the RA or superior vena cava. In AEBs originating from the RA, the PSRA activation was the earliest and it proceeded in a cranial to caudal direction. In AEBs originating from the RUPV, RPA was the earliest. The esophageal activation sequence was in a cranial to caudal direction. In AEBs from the LSPV, LPA was the earliest and the esophageal activation sequence proceeded in a cranial to caudal direction. In AEDs from LIPV, LPA was the earliest, and the esophageal activation sequence was nearly simultaneous. Atrial activation sequences from the PSRA, RPA, LPA, and esophageal catheters can accurately identify the location of the initiating foci of AF before a transseptal procedure.

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Introduction

Paroxysmal atrial fibrillation (AF) can be initiated by atrial ectopic beats (AEBs) originating from a focal area. Most AEBs originate from the orifices of pulmonary veins (PVs) or from the myocardial sleeve inside the PVs.1–6) Several investigations have shown that radiofrequency catheter ablation could
effectively eliminate this type of AF. However, an atrial transseptal procedure is necessary to localize the initiating foci of AF, and this procedure may increase the risk of cardiac perforation. Some AEBs triggering AF originate from right atrial foci such as the superior vena cava, crista terminalis (CT), and coronary sinus (CS) ostium. Thus, accurate localization of the initiating foci of AF before the transseptal procedure may help in the ablation procedure and in shortening the procedure and ablation times. However, use of combined endocardial and epicardial activation sequences from recording catheters in the posteroseptal right atrium (PSRA), right pulmonary artery (RPA), left pulmonary artery (LPA), and esophagus to identify the location of the initiating foci of AF has not been reported. The purpose of the present study was to develop an algorithm based on endocardial and epicardial atrial activation sequences to localize the initiating foci of AF before the atrial transseptal procedure.

Methods

Ten patients (9 men and 1 woman, mean age, 62 ± 8 years) with frequent, drug-refractory, symptomatic episodes of paroxysmal AF underwent isolation of arrhythmogenic PV(s) after providing informed consent. Transthoracic echocardiogram showed that left ventricular ejection fraction was 42–78% (mean, 67 ± 11.2%) and left atrial diamention was 18–42 mm (mean, 33.1 ± 7.5 mm). All procedures followed the Nihon University Hospital guidelines. All antiarrhythmic drugs except amiodarone were discontinued for at least five half-lives before the study. Sedation was achieved with intravenous administration of midazolam and fentanyl.

Catheter positions

Study 1: A 7-French open lumen decapolar catheter with 2.5-2 mm interelectrode spacing (Daig Corp., Minnetonka, MN, USA) was inserted into the CS via the internal jugular vein. The CS ostium was identified by coronary sinus venography. A 7-French duodecapolar catheter with 1-3-1 mm interelectrode spacing (CRISTA CATH™, Cordis-Webster, Baldwin Park, CA, USA) was placed in the PSRA medial to the CT, with the most distal electrode pair at the caudal position and the proximal pair at the cranial position from the right femoral vein. Two 7-French deflectable quadripolar catheters with 2.5-2 mm spacing (EP Technologies, Sunnyvale, CA, USA) were positioned, one at the proximal portion of the RPA, and the other at the LPA, via the right and left femoral veins, respectively. A 6-French octapolar catheter with 2 mm spacing was placed in the His-bundle area via the left femoral vein. Finally, an 11-French hexapolar transesophageal catheter with 10 mm spacing (Medico Italia, Rubano, Italy) was positioned behind the left atrium (LA) through the esophagus so that the distal electrode was situated at the lower edge of the CS catheter with the position...
verified fluoroscopically. Bipolar esophageal electrograms were recorded from the 1–2, 2–3, and 3–4 electrode pairs (Figure 1).

**Study 2.** Transseptal puncture was performed twice with two 8F long introducer sheaths (SR0 and SL1, Daig Corp.) under fluoroscopic guidance to access the LA. In each patient, activation sequences of the CS, RPA, LPA, and esophageal electrograms of study 1 were compared during pacing from each of the four PVs. A 7F Trio™ guide sheath™ (Cardiac Pathway Co. Sunnyvale, CA, USA) with three ports was introduced into the SL1 sheath, and three 2-French quadripolar catheters with 5 mm interelectrode spacing (Ensemble™, Cardiac Pathway Co.) were positioned, one at the left superior pulmonary vein (LSPV), one at the left inferior pulmonary vein (LIPV), and one at the right superior pulmonary vein (RSPV). An 8-French deflectable quadripolar catheter with 2-5-2 mm spacing (EP Technologies) was positioned at the right inferior pulmonary vein (RIPV) through the SR0 sheath.

**Electrophysiological study**

Intracardiac and esophageal bipolar electrograms were displayed simultaneously with ECG leads I, II, III, V₁, and V₆ on a multichannel recorder (Cardiolab System, Prucka Engineering Inc., Houston, TX, USA). The filter was set from 30 to 500 Hz. We first attempted to locate spontaneous onset of AEBs initiating AF in the baseline condition or after infusion of isoproterenol (up to 4 μg/min). If spontaneous AF did not appear, intermittent atrial pacing (8 to 12 beats) with cycle length of 200 to 300 msec from the high RA or CS was used to facilitate spontaneous initiation of AF after the pause in atrial pacing. If spontaneous AF did not occur, burst pacing from the high RA or CS was used to induce sustained AF. After the pacing-induced AF was sustained for 5 to 10 minutes, external cardioversion was attempted to convert AF to sinus rhythm so that we could observe the spontaneous reinitiation of AF. A bolus of adenosine triphosphate (20 to 40 mg) was also used to provoke spontaneous onset of AF. Spontaneous initiation of AF was attempted at least twice to ensure reproducibility. We hypothesized that we could identify the location of initiating foci from multisite RA, pulmonary artery, and transesophageal mapping. Thus, we compared activation sequences of the AEBs between study 1 and study 2.

![Figure 2](https://example.com/figure2.png)

**Figure 2** Activation sequences of the CT, CS, RPA, LPA and esophageal catheters during pacing from each pulmonary vein (PV).

During pacing from left superior (LS) PV, activation sequence of the esophageal catheter was from the cranial to caudal direction, and the LPA electrogram was activated earlier than the RPA electrogram. During pacing from the left inferior (LI) PV, activation of the esophageal catheter was nearly simultaneous, and the LPA electrogram was activated earlier than the RPA electrogram. During pacing from the right superior (RS) PV, activation sequence of the esophageal catheter was from the cranial to caudal direction, and the RPA potential was activated earlier than LPA activation. During pacing from right inferior (RI) PV, activation sequence of the esophageal catheter was nearly simultaneous, and the RPA potential was activated earlier than LPA activation. Abbreviations as in Figure 1.
Radiofrequency catheter ablation
The LSPV, LIPV, RSPV, and RIPV were isolated under 20-pole Lasso™ catheter (Cordis-Webster, Baldwin Park, CA, USA) -guided PV ostium ablation with a 4-mm tip ablation catheter (EP Technologies). PVs that initiate APDs triggering AF were isolated first. Radiofrequency energy was applied for 60 to 120 seconds at a maximum power setting of 30 to 35 watts with maximal temperature setting of 55°C by using an EPT-1000 generator (EP Technologies).

Results
Baseline data
AF initiated by AEBs originating from the LSPV was found in 4 patients; from the LIPV in 2 patients, from the RSPV in 4 patients, and from the RA near the CT in one patient. Nine patients had one ectopic focus, and one patient had two foci (total, 11 foci).

PV pace mapping
Activation sequences of the RPA, LPA, and esophageal electrograms were compared during LSPV, LIPV, RSPV, and RIPV pacing (Figure 2). LSPV pacing resulted in the earliest activation of the LPA, and the activation sequence of the esophageal electrogram was craniocaudal. LIPV pacing resulted in the earliest activation of the LPA, and the activation sequence of the esophageal electrogram was nearly simultaneous. RSPV pacing resulted in the earliest activation of the RPA, and the activation sequence of the esophageal electrogram was caudocranial. RIPV pacing resulted in the earliest activation of the LPA, and the activation sequence of the esophageal electrogram was nearly simultaneous.

Figure 3 Atrial premature depolarization from LSPV. Note that esophageal activation proceeded from the cranial to caudal direction, and the LPA electrogram (asterisk) was activated earlier than the RPA electrogram. Abbreviations as in Figure 1.

Figure 4 Atrial premature depolarization from LSPV. Same patient as in Figure 4. Left panel shows that LSPV 3–4 electrogram showed the earliest activation (asterisk). Right panel shows anteroposterior view of the catheter position during left atrиography. Abbreviations as in Figures 1 and 2.
sequence of the esophageal electrogram was cranio-caudal. RIPV pacing resulted in the earliest activation of the RPA, and the activation sequence of the esophageal electrogram was nearly simultaneous.

Initiating foci from the left PVs
AEBs originating from the left PVs showed earlier activation of the LPA than of the RPA. The activation sequence of the esophageal catheter at AEBs originating from the LSPV was caudocranial in 4 of 4 patients (Figure 3), and the earliest activation sites in these patients was located in the LSPV (Figure 4). The activation sequence of the esophageal catheter of AEBs originating from the LIPV showed a caudocranial pattern in 1 patient and straight pattern (Figure 5) in 1 patient, and the earliest activation sites in these patients were located in the LIPV (Figure 6).

Initiating foci from the right PVs
AEBs originating from the right PVs showed earlier activation of the RPA than of the LPA. The activation sequence of the esophageal catheter at AEBs originating from the RSPV showed a caudocranial pattern in 5 of 6 patients (Figure 7), and the earliest activation sites were located in the RSPV (Figure 8).

Initiating foci from the RA
AEBs originating from the RA showed earlier activation of the CT than of the RPA in 2 of 2 patients (Figure 9).

Discussion
Major findings
AEBs originating from the PVs are now recognized as triggers of AF. Conventional methods for mapping these AEBs include the placement of several multielectrode catheters into the RA and LA. This approach may have disadvantages, including prolongation of the procedure time and unnecessary exposure of the patient to the risk of instru-
mentation in the LA. Furthermore, the catheters used for mapping may produce mechanical catheter-induced premature contractions, especially when administration of isoproterenol is required to provoke firing of the triggering foci. The recording configurations used in this study amount to a simple method of determining the site of origin of AEBs, i.e., LSPV origin: LPA → RPA, CT, and ESO proximal → distal; LIPV origin: LPA → RPA, CT, and ESO distal → proximal or simultaneous; RSPV origin: RPA → LPA, CT, and ESO proximal → distal; RIPV origin: RPA → LPA, CT, and ESO distal → proximal or simultaneous; RA origin: CT → RPA → LPA. The approach described herein is easier than the traditional biatrial mapping technique and does not appear to produce mechanical catheter-induced premature contractions that can occur with administration of drugs or during maneuvers performed to elicit AEBs. In addition, using a catheter configuration that is minimally susceptible to dislodgment could facilitate assessment of the subsequent ablation and recognition of elusive sources of ectopy.

This approach appears to be highly reliable for determination of the site of AEB origin in both the RA and LA. Moreover, the site of the AEB origination can be isolated to the RSPV, RIPV, LSPV, or LIPV.

Previous studies

Ashar et al. reported that activation sequence mapping from multipolar catheters placed in the CS and along the posterior medial CT rapidly differentiates AEB sites of origin in the right and left PVs. Lee et al. reported that atrial activation sequences from the high RA, His-bundle, and CS catheters can accurately predict the location of initiating foci of AF originating from the RA versus the LA and also right versus left PV sites. Schweikert et al. reported that analysis of the atrial activation sequences obtained with an esophageal catheter and a multipolar catheter with recordings from the high RA and CS can identify the AEB sites of origin from the RA and LA and, more importantly, from right and left PV foci. Yamada et al. developed a more detailed algorithm for detecting the origin of AEB triggering AF. Multipolar catheters were placed in the posterior RA and esophagus, and double potential amplitude and the activation sequence of the posterior RA and the
Figure 7  Atrial premature depolarization from RSPV.
Note that esophageal activation was from the cranial to caudal direction, and the RPA 3–4 electrogram (asterisk) was activated earlier than the LPA electrogram. CT 1–2 was located in the caudal position. Abbreviations as in Figure 1.

Figure 8  Left panel: Atrial premature depolarization from the RSPV. Same patient as in RSPV 3–4 electrogram showed the earliest activation (asterisk). Other abbreviations as in Figures 1 and 2. Right panel shows anteroposterior view of the catheter position during left atriography.
Activation sequence of the esophageal electrograms were compared. When the earliest atrial activation site of AEB is located in the posterior RA, double potential amplitude is compared, and if the fast component amplitude is larger than the second component amplitude, the AEB is located in superior vena cava or CT. If the second component amplitude is larger than the first component, the AEB originates from the right PV, and the activation sequence of the first component is compared. If the activation sequence of the first component is from the cranial to caudal direction, AEB originated from RSPV, and if from caudal to cranial, AEB originated from RIPV. If the earliest atrial activation site of AEB is located in the esophagus, AEB originated from left PV. In this situation, if activation sequence of the esophageal electrograms is from cranial to caudal, AEB originated from LSPV and if from caudal to cranial, AEB originated from LIPV.

Unlike previous reports, the present study recorded left atrial electrograms from the right and left pulmonary arteries. Previous papers have shown that atrial electrograms recorded from the main pulmonary artery trunk correspond to local activation of the left atrial appendage, that atrial electrograms recorded from the proximal left pulmonary artery correspond to local activation of the left lateral atrium, and that atrial electrograms recorded from the RPA correspond to local activation of Bachmann’s bundle. Thus, atrial electrograms of the LPA represent left lateral atrial activation, and atrial electrograms of the right pulmonary artery represents left septal activation.

Clinical implications
The algorithm described herein can accurately predict the location of initiating foci of AF before an atrial transseptal procedure. If the algorithm suggests that the foci are from the superior vena cava to CT, atrial transseptal puncture can be avoided. Furthermore, predicting whether the left or right PVs are the origin of AEBs initiating the AF may be important in avoiding the need for placement of catheters into all four PVs.

Study limitations
Our results did not include spontaneous AEB from the RIPV thus, the RIPV algorithm was based on pacing from the RIPV and the numbers of APDs from the LSPV, LIPV, and RSPV were small. Second, we did not compare APDs from the left PVs and right PVs using activation sequences of the CS and the RPA and LPA. Thus, additional investigations are required to more completely characterize the patterns of activation from the four PVs and superior vena cava-CT from atrial activation of the LPA and RPA, esophagus, and right posterior atrium.

Conclusions
Atrial activation sequence mapping from catheters placed in the LPA and RPA, in the esophagus, and along the posterior medial right atrium can distinguish AEBs of right versus left atrial origin, right versus left PV origin, and superior and inferior PV origin. These findings have important implications for facilitating catheter placement for subsequent mapping and ablation of focal triggers in patients with AF.

References
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