Simultaneous Catheter Mapping of the Pulmonary Veins in Focal Atrial Fibrillation

Significance of Rapid Focal Activation, Effectiveness for Catheter Ablation

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SUMMARY

Most focal atrial fibrillation (AF) is initiated by premature beats from the pulmonary veins (PV), and ablation of these foci can effectively cure AF. We investigated the efficacy of focal ablation and the role of rapid focal activation (RFA) in the maintenance of AF using simultaneous multisite catheter mapping in four PVs.

Forty-two patients with frequent attacks of paroxysmal AF were included in the study population. Bipolar electrograms were simultaneously recorded from all four PVs. RFA was determined at AF onset, during sustained AF, or just before the spontaneous termination of AF. RFA was continuously observed not only at a triggered PV, but also at all sites including an opposite non-triggered PV, coronary sinus and high right atrium in sustained AF (>10 minutes), whereas RFA was observed only in the triggered PV and not at the other sites in nonsustained AF. Once RFA ceased, AF terminated immediately. After a mean follow-up of 21 months, focal ablation had eliminated AF without drugs in 24 patients (57%).

The technique of simultaneous mapping of the PV using microcatheters is a feasible and effective method for mapping and ablation of focal AF originating from the PV. RFA arising from PVs is important not only as a trigger of onset, but also in the maintenance of AF. (Jpn Heart J 2002; 43: 357-365)

Key words: Atrial fibrillation, Pulmonary vein, Catheter ablation, Mapping

Most focal atrial fibrillation (AF) is initiated by premature beats from the orifices of the pulmonary veins (PVs) or from the myocardial sleeves inside the PVs, thereby ablation of triggered foci can effectively cure AF. However, it is difficult to find the focal origins, since all four PVs serve as the source of focal AF, or to map a PV using only one electrode catheter. Therefore, we developed a new method for the simultaneous mapping of all four PVs. Although the rapid focal

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activation (RFA) from PVs is important for the mechanism of spontaneous initiation of AF, the role of RFA in the maintenance of AF is unclear.

The purpose of this study was to investigate the electrophysiological properties of PVs, with special focus on the RFA from PVs, as well as possible mechanisms of AF and the efficacy of ablation of focal AF.

**METHODS**

**Study population:** The study population consisted of 42 patients (mean age 60±14 years) with symptomatic drug-refractory (number of drugs, 3±1) paroxysmal AF who were referred for an electrophysiologic study and catheter ablation. The patients had frequent (at least one episode of AF every two days) attacks of paroxysmal AF. All antiarrhythmic drugs were discontinued for at least five half-lives before the study. Informed consent was obtained from all patients before the study.

**Catheter positions:** Three multipolar electrode catheters (Daig Corp., Minnetonka, Minnesota, USA) were positioned in the right atrial appendage, His bundle area, and distal coronary sinus.

After an atrial transseptal procedure, a long sheath (8-French, Daig Corp. SL-1) was placed into the left atrium through the foramen ovale of the atrial septum from the right femoral vein. PV angiography was performed with an angiocatheter (6-French, Baxter, Deerfield, IL, USA) to determine the position of the catheters relative to the ostium of the PVs. A sheath for three microcatheters (Trio Guide™ and Ensemble™ System, Cardiac Pathways Corp., Sunnyvale, CA, USA) was then inserted into the SL-1 sheath and three 2-French quadripolar microcatheters were simultaneously placed into the left superior, left inferior, and right superior PVs through this sheath (Figure 1). After successfully placing the microcatheters in the PVs, only this long sheath was pulled out in the right atrium, leaving the microcatheters in place. A 7-French deflectable, quadripolar ablation catheter (Radii-T, Cardiac Pathways Corp.) was placed in the right inferior PV directly through the foramen ovale, guided by the microcatheters (Figure 1). Thus, electrograms were acquired from all four PVs simultaneously. Intravenous heparin was administered at 1,000 units per hour after the atrial transseptal procedure.

**Electrophysiological study:** Bipolar intracardiac electrograms were recorded at a filter setting of 30 to 500 Hz and stored digitally on an EPLab system (Quinton Electrophysiology, Inc., Canada) simultaneously with the surface ECG. A unipolar electrogram was recorded from the distal electrode of the ablation catheter using a filter ranging from 0.05 to 500 Hz. A programmed stimulator (SEC-3102, Nihon Kohden Tokyo) was used to deliver electrical stimuli at twice the diastolic
threshold and 2 ms long. If AF was not spontaneously present, burst atrial pacing (10 to 20 beats), pharmacologic agents (isoproterenol or adenosine triphosphate), or both were used to facilitate spontaneous AF. When the episode of induced AF was sustained for >10 minutes, external cardioversion (with 100 to 300 J) was attempted to defibrillate AF, and the spontaneous re-initiation of AF was monitored. The beat-to-beat atrial activation intervals were measured, and the mean cycle length of AF was determined as the mean value for two seconds. The RFA was defined as rapid disorganized activation with a very short cycle length (<200 msec) originating from a focal site. In 20 episodes of sustained AF which were cardioverted after 10 minutes, the mean cycle lengths of AF were determined at the onset and after 5 minutes of sustained AF. In 22 episodes of non-sustained AF which terminated spontaneously within 2 minutes (mean duration: 60±55 seconds, range: 5-120 seconds), the mean cycle lengths of AF were determined at the onset and just before the spontaneous termination of AF. The regional differences in the RFA were compared between the sustained AF group and non-sustained AF group.

**Catheter ablation:** The presumed ablation site was selected on the basis of the earliest bipolar activity and/or a local unipolar QS pattern of the trigger atrial pre-
mature beats preceding AF from the PVs. Three microcatheters that were used to map the trigger point of AF were left in the PVs to guide ablation, and the ablation catheter which was inserted into the right inferior PV was moved to the microcatheter with the earliest activity (Figure 2). Moreover, one of the microcatheters with delayed activity was moved to the roof or bottom wall of the PV with the earliest activity if necessary. If the patients had two or more trigger points in two or more PVs, ablation was performed sequentially. Radiofrequency pulses were delivered with the temperature preset to 50°C (CABL-IT, Central Inc. Tokyo, Japan) for 30 to 60 seconds. The protocols used to induce spontaneous AF before ablation were repeated, and the effects of ablation were evaluated under isoproterenol infusion. Procedural success was defined as the inability to reinitiate atrial premature beats or AF with the same protocols used to induce AF as before ablation. Heparin (500 U/hour) was continuously administered for 24 hours, and oral coumadin was continued for 1 month with an international normalized ratio level of about 2.0. Follow-up was obtained in the patients at this institution, initially at 1 week and subsequently at 1-month intervals. Clinical examination, ECG and 24-hour Holter recordings were made every 3 months and when symptoms suggested a recurrence of an arrhythmia. A transesophageal echocardiogram was obtained at 1 week, 3 months, and 6 months after ablation to assess thrombus or stenosis of the PVs. Ablation was considered successful if no recurrence of AF was present without drugs during the follow-up.
RESULTS

Comparison of RFA between sustained AF and non sustained AF: A representative episode of spontaneous onset of sustained AF is shown in Figure 3. In this case, an RFA occurred in the right superior PV, and was observed in all PVs. The mean cycle lengths of RFA were similarly short in all PVs (Figure 3A). After 5 minutes of sustained AF, the RFA spikes were continuously observed in all PVs, and their mean cycle lengths were very short in all sites (Figure 3B). This pattern

Figure 3. A: R representative spontaneous onset of an episode of sustained atrial fibrillation. Rapid focal activation began in the right superior pulmonary vein (*) and was observed in all pulmonary veins. B: After 5 minutes of sustained AF, rapid focal activation persisted in all pulmonary veins. HRA=high right atrium; HBE=His bundle electrogram, CS=coronary sinus, d=distal, p=proximal. Other abbreviations as in Figure 1.
was observed in 16 episodes (80%) of sustained AF. Another example of sustained AF is shown in Figure 4. In this case, during sustained AF, the RFA was observed only in the left superior and inferior PVs. The RFA disappeared, however, AF still persisted (Figure 4A). After a few seconds of this sustained AF, the RFA resumed in the same sites (Figure 4B). This pattern was observed in 4 episodes (20%) of sustained AF.

In Figure 5, a representative episode of spontaneous onset of non-sustained AF is shown. In this case, RFA occurred in the left inferior PV, and was observed only in the left inferior and superior PVs, but not in the right superior PV or other sites (Figure 5A). Once the RFA disappeared, the AF terminated immediately (Figure 5B).

**Figure 4.** A: Another example of sustained atrial fibrillation. In this case, rapid focal activation was confined to the left superior and inferior pulmonary veins. Despite its transient disappearance (arrow), atrial fibrillation persisted. B: A few seconds later, rapid focal activation reappeared at the same sites (arrow). Abbreviations as in Figures.
Results of ablation: Of 104 foci identified, 94 triggers (90%) originated from the PV (single focus in 47% and multiple foci in 53%) and 10 originated from the atrial tissue. AF recurred in 23 patients and re-ablation was performed in 10: 7 from sites near the previous source, 2 from a different part of the same PV, and 1 from a different PV. During a mean follow-up period of 21±5 months, ablation eliminated AF without drugs in 24 (57%) patients. Two patients had pericardial effusion after successful ablation. No PV stenosis was observed.
DISCUSSION

The multiple reentrant wavelet hypothesis has been widely accepted to explain the mechanism of the maintenance of AF.4,5) Maze surgery and maze catheter ablation have been performed in some institutes based on this hypothesis, and these procedures are targeted toward the maintenance of AF.6) In contrast, Haïssaguerre and co-workers1,2) first evaluated the mechanism of the spontaneous onset of AF and demonstrated that AF occurred from atrial premature beats originating in the ostium and inside PVs, and ablation of these triggered foci could cure AF. This focal ablation is targeted toward the initiation of AF.

Role of rapid focal activation in the maintenance of AF: It is clear that RFA arising from PVs is an important trigger of onset.1-3) In sustained AF, RFA was observed not only in the PV at the source of RFA, but also at all other sites, including an opposite PV, coronary sinus, and high right atrium. This pattern was observed in 80% of episodes of sustained AF. If an abnormal substrate is present in the atrial free wall, RFA may induce sustained AF, playing a major role as a trigger, and probably a minor role in its sustenance. In 20% of sustained AF, RFA was limited to one or two PVs, and was not observed at all sites. RFA either fired continuously, or disappeared and reappeared, thus maintaining AF. Thus, if an abnormal substrate is not present in the atrial free wall, AF could be perpetuated by continuous RFA. If RFA disappears, though reappears before spontaneous termination of AF, AF can be maintained. In such cases, RFA would play a role in the maintenance of AF.

In non-sustained AF, RFA was seen only in the PV which was at its source, and not at the other sites. If RFA was confined to its origin, and other sites could not be activated in a 1:1 manner due to exit block, discontinuity of RFA may be a mechanism for the spontaneous termination of AF. Thus, RFA arising from PVs may be important not only as a trigger of onset, but also in the maintenance of AF.

Simultaneous catheter mapping of PVs for focal ablation: In the focal ablation procedure, it is difficult to map the earliest local activation around a PV from a proximal to a distal site using only one mapping catheter. It is also difficult to find the focal origins because all four PVs serve as the source of focal AF. When AF occurs frequently, not much time is required for mapping. However, when AF occurs infrequently, mapping can take a long time. Therefore, we developed a new method for the simultaneous mapping of all four PVs using microcatheters. Our simultaneous mapping technique could map all four PVs using only one sheath advanced to the left atrium. In addition, microcatheters are soft and safer for manipulation in PVs than standard multielectrode catheters. Moreover, the simultaneous acquisition of electrograms from all four PVs could rapidly identify the earliest activation region or multiple sites, and provide a visual reference for
positioning the ablation catheter.

**Limitations:** The recurrence rate is relatively high and a repeated ablation is sometimes required due to the recurrence of AF from a nearby or another focus in the same PV or other PVs. Localization of the exact focus may be difficult because atrial premature beats may be infrequent, or each extrasystole may induce AF, necessitating repeated cardioversion. Therefore, present mapping and ablation techniques seem to have significant limitations. Given the difficulty in precisely locating and ablating these triggers, an alternative approach that simply seeks to isolate electrically the PV from the left atrium seems logical.

**Conclusions:** The present study has demonstrated that the simultaneous mapping of PVs using microcatheters can be used safely in patients with focal AF. Simultaneous mapping aids in the rapid identification of the sites of the origin of focal AF and facilitates radiofrequency ablation procedures. The widespread conduction of RFA from a PV at its source to the other sites may be necessary for the sustenance of AF. RFA arising from PVs is important not only as a trigger of onset, but also in the maintenance of AF.

**REFERENCES**