Characteristics of the conduction of the left atrium in atrial fibrillation using non-contact mapping

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KEYWORDS
Ablation;
Arrhythmia;
Atrial fibrillation;
Non-contact mapping

Summary
Background: We evaluated the conduction properties of the posterior left atrium (LA) using a non-contact mapping (NCM) system as well as the significance of linear ablation at the roof of the posterior LA (LA roof) and inferior region of the posterior LA (LA bottom).
Methods and results: In 133 patients with atrial fibrillation (AF) (83 paroxysmal type, 50 persistent/long-lasting persistent type), we performed complete isolation of the posterior LA including pulmonary veins (Box isolation) using NCM. Isochronal activation maps were analyzed during sinus rhythm (SR), during pacing from the proximal coronary sinus (CS), and during pacing within the posterior LA before and after ablation. In sinus rhythm, horizontal conduction along the LA roof line, but not into the posterior LA wall, was observed in 59% of the patients. During paroxysmal CS pacing, horizontal conduction along the LA bottom line was observed in 69% of the patients. Posterior wall pacing conducted vertically over the LA roof and bottom lines in 98% and 83% of the patients, respectively. During AF, rotor wave conduction into the posterior LA through the LA roof and bottom lines was observed in 85% of the patients. Heterogeneous conduction directions in the posterior LA at the LA roof and bottom lines were observed in 60% of the patients.

Abbreviations: AF, atrial fibrillation; AT, atrial tachycardia; LA, left atrium; RA, right atrium; MV, mitral valve; NCM, non-contact mapping; SR, sinus rhythm; HRA, high right atrium; CS, coronary sinus; PVs, pulmonary veins; LSPV, left superior pulmonary vein; LIPV, left inferior pulmonary vein; RSPV, right superior pulmonary vein; RIPV, right inferior pulmonary vein; LAD, left atrial dimension; LVEF, left atrial ejection fraction.

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Introduction

Atrial fibrillation (AF) is often due to premature beats from pulmonary veins (PVs) [1,2]. The electrical isolation or disconnection of the PVs from the left atrium (LA) can enable the radical cure of AF [3–6]. Although the electrophysiological properties of PVs have been evaluated in previous studies, the characteristics of conduction of the LA body are not well known. A non-contact mapping (NCM) system with a single-beat mapping capacity can facilitate the recognition of propagation patterns and demonstrate the characteristics of the relationship with underlying anatomical structures. Therefore, we conducted this study to evaluate the characteristics of conduction of the LA body using a NCM system as well as the significance of linear ablation of the LA roof and bottom.

Methods

Study population

A total of 133 consecutive patients (103 men and 30 women; mean age 58 ± 11 years) with symptomatic drug-refractory AF were enrolled from October 2006 to March 2008 in this retrospective study. All patients gave their written informed consent.

Electrophysiological study

Patients received oral anticoagulants for at least 1 month before ablation. Trans-esophageal echocardiography was performed to exclude any LA thrombi before ablation. Antiarrhythmic drugs were discontinued five half-lives before ablation. Three 5-French quadripolar electrode catheters (St Jude Medical, Minnetonka, MN, USA) were placed in the high right atrium, His bundle area, and coronary sinus (CS). Triple transseptal punctures were performed, and two 8-French SL0 sheaths (St Jude Medical) and a 10-French SL0 sheath (St Jude Medical) were advanced into the LA. After transseptal puncture, 100 IU heparin/kg was given intravenously. During the procedure, heparinization was continued to maintain an activated clotting time of >300 s. PV angiography was performed from a sheath to determine the size and shape of the PVs. Surface electrocardiograms (ECG) and bipolar endocardial electrograms were continuously monitored and stored on a computer-based digital amplifier/recorder system for offline analysis (LabSystemTM PRO, Bard Electrophysiology, Lowell, MA, USA). Intra-cardiac electrograms were filtered from 30 to 500 Hz and measured at a sweep rate of 200 or 400 mm/s. Atrial pacing was performed using a programmed stimulator (SEC-3102, Nihon Kohden, Tokyo, Japan).

Conclusions: Heterogeneous conduction was observed at the roof and inferior region of the posterior LA in most of these AF patients. The conduction properties of the posterior LA are affected by the direction of the wavefronts, and this may play an important role in the initiation and maintenance of AF. The complete isolation of the posterior LA may prevent AF.

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was performed during SR. Radiofrequency energy was delivered with a power of 30–40 W. The temperature was limited to 50 °C. When radiofrequency energy was delivered at the anterior aspect of the left PVs and the bottom line near the esophagus, the power was reduced to 30 W. Radiofrequency energy was delivered for 30 s at each point, and the application was prolonged for 60 s when a change in the morphology or sequence of PV potentials occurred as determined by circumferential mapping. When the bottom line crossed close to the esophagus, ablation was performed at a maximum power of 30 W and a temperature of 45 °C for 15 s. Continuous lesions at the anterior portions of the ipsilateral superior and inferior PVs were initially created under the guidance of a Lasso catheter and the NCM system. Ablation was started at the superior wall and continued around the anterior and inferior venous perimeter. When ablation was required at the anterior portions of the left PVs, the energy was delivered within the proximal millimeters of the vein ostium (rather than the posterior wall of the appendage) to achieve effective electrical disconnection. There was no vertical lesion line created at the posterior portions of the PVs along the esophageal aspect of the posterior LA. Ablation of the LA roof was then performed by creating a contiguous line of ablation lesions joining the superior PVs. Commencing at the lesion at the left superior PV, the sheath and catheter were rotated clockwise posteriorly and dragged toward the right superior PV. Local potential elimination or the formation of double potentials signified the local effectiveness of ablation. The stability of the catheter was monitored during radiofrequency application by proximal electrograms, real-time monitoring by NCM and intermittent fluoroscopy to recognize inadvertent displacement of the catheter. The radiofrequency applications were tagged on the NCM system. Finally, ablation of the LA bottom was performed by creating a contiguous line of ablation lesions joining the inferior PVs to isolate the posterior LA. Commencing from the lesion at the left inferior PV, the sheath and catheter were rotated clockwise posteriorly and dragged toward the right inferior PV. If AF did not terminate after Box isolation, SR was restored by transthoracic cardioversion. Box isolation was evaluated with NCM after the restoration of SR to allow pacing from the CS, posterior LA, and all PVs. Once residual conduction gaps were identified, additional radiofrequency applications were applied until all gaps were eliminated.

Bi-directional conduction block

The endpoint of Box isolation was defined as all PV isolations as indicated by circumferential PV and conduction block in the posterior LA confirmed by isochronal activation maps using NCM and contact bipolar catheter during pacing at an output of 5.0 V both inside (five sites) and outside (proximal CS and SR propagation) the posterior LA. The linear ablation line was confirmed by the non-contact and contact electrograms. Electrical potential in the posterior LA wall changed to low single potential or no-capture by completing a complete block.

Statistical analysis

All values are expressed as the mean ± SD. The P-wave duration and the activation time parameters from before and after ablation were compared using Student’s t-test. The results were considered to be statistically significant at a value of \( p < 0.05 \).

Results

Patient characteristics

Patient characteristics are shown in Table 1. Eighty-three patients had paroxysmal AF and 50 had persistent/long-lasting persistent AF. The mean duration of AF was 63 ± 58 months. A mean of 3.0 ± 1.1 antiarrhythmic drugs had been
administered unsuccessfully. Amiodarone was discontinued for at least 6 weeks prior to ablation, and all other antiarrhythmic drugs were discontinued 1 week before ablation. Oral anticoagulants were administered for at least 1 month prior to ablation. Trans-esophageal echocardiography was performed in all patients to exclude any LA thrombi. The mean LA diameter was 40 ± 6 mm, and the mean left ventricular ejection fraction was 63 ± 10% by echocardiography. No structural heart disease was present in 53 patients. Hypertension was documented in 56 patients, ischemic heart disease in 5, cardiomyopathy in 5, and valvular disease in 11.

Table 1 Patients characteristics.

<table>
<thead>
<tr>
<th>Study population (n)</th>
<th>133</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>58 ± 11</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>103/30</td>
</tr>
<tr>
<td>Paroxysmal AF</td>
<td>83</td>
</tr>
<tr>
<td>Persistent/long-lasting persistent</td>
<td>50</td>
</tr>
<tr>
<td>Duration of AF (months)</td>
<td>63 ± 58</td>
</tr>
<tr>
<td>LAD (mm)</td>
<td>40 ± 6</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>64 ± 13</td>
</tr>
<tr>
<td>Antiarrhythmic drugs (n)</td>
<td>3.0 ± 1.1</td>
</tr>
</tbody>
</table>

Structural heart disease
- Hypertension (n) 56
- No heart disease (n) 53
- Valvular disease (n) 11
- Ischemic heart disease (n) 5
- Cardiomyopathy (n) 5

AF: atrial fibrillation; LAD: left atrial dimension; LVEF: left ventricular ejection fraction.

Activation pattern of the posterior LA; prior to ablation

Before ablation, horizontal conduction along the LA roof was observed in 59% of the patients (34/57) during SR, and along the LA bottom in 66% (38/55) during CS pacing. During AF, rotor wave activation conducting through the LA roof or bottom was observed in 86% (44/51) of the patients. No structural heart disease was present in 53 patients. Hypertension was documented in 56 patients, ischemic heart disease in 5, cardiomyopathy in 5, and valvular disease in 11.

Activation pattern of the posterior LA; after Box isolation

After Box isolation, conduction pattern in all patients changed to either horizontal conduction along the LA roof or along the bottom line during SR and CS pacing. The entrance block demonstrated no conduction into the posterior LA in all cases (119/199). Exit block was achieved in 88% (93/105) of cases during posterior pacing (Table 2B and Fig. 2B).

P-wave duration and LA activation time

The P-wave duration before and immediately after ablation was 135 ± 21 ms and 127 ± 22 ms (p = 0.003), and LA activation time before and after was 99 ± 17 ms and 95 ± 18 ms (p = 0.085) (Table 3).

Table 2 Conduction properties of the posterior LA before and after the ablation.

<table>
<thead>
<tr>
<th></th>
<th>Not passed the LA roof line</th>
<th>Not passed the bottom line</th>
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</thead>
<tbody>
<tr>
<td>The LA roof and bottom line (before)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR</td>
<td>59% (n = 34/57)</td>
<td>63% (n = 36/57)</td>
</tr>
<tr>
<td>CS pacing</td>
<td>64% (n = 35/55)</td>
<td>69% (n = 38/55)</td>
</tr>
<tr>
<td>Passed the LA roof line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The LA roof line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The LA bottom line</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>The LA roofline</th>
<th>The LA bottom line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance block into the posterior LA (after)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR</td>
<td>100% (n = 119)</td>
<td>100% (n = 116)</td>
</tr>
<tr>
<td>CS pacing</td>
<td>100% (n = 119)</td>
<td>100% (n = 116)</td>
</tr>
<tr>
<td>Exit block from the posterior LA (after)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior pacing</td>
<td>92% (n = 97/105)</td>
<td>88% (n = 93/105)</td>
</tr>
</tbody>
</table>

AF: atrial fibrillation; CS: coronary sinus; LA: left atrium; SR: sinus rhythm.

* Conduction heterogeneity is defined as no conduction into the posterior LA during the SR and CS pacing, but conductibility is admitted to the posterior LA by posterior pacing and AF.

Table 3 P-wave duration and LA activation time during SR (n = 42).

<table>
<thead>
<tr>
<th></th>
<th>Before ablation</th>
<th>After ablation</th>
<th>p</th>
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<tbody>
<tr>
<td>P-wave duration</td>
<td>136 ± 21 ms</td>
<td>127 ± 22 ms</td>
<td>0.003</td>
</tr>
<tr>
<td>LA activation time</td>
<td>99 ± 17 ms</td>
<td>95 ± 18 ms</td>
<td>0.085</td>
</tr>
</tbody>
</table>

LA: left atrium; SR: sinus rhythm.
Discussion

The arrhythmogenic substrate of the posterior LA wall

In addition to sites other than the PVs, the posterior LA wall is a frequent site for premature beats, and is also a site where arrhythmias occur [12]. The posterior LA wall is further complicated by the atrial anatomical architecture [13] and the high degree of autonomic innervation of the PVs and near the LA roof and bottom line [14]. Thus, AF can be promoted by electrophysiological, anatomical, and autonomic nerves within the posterior LA. LA posterior wall isolation has been successful in eliminating AF during the surgical Maze procedure [15,16], and the results are similar to those with LA posterior wall isolation including PVs [17] by catheter ablation. Box isolation was effective to control AF, however, the clinical cause was unclear. We hypothesized that the heterogeneous conduction of the LA roof and bottom was causative of AF and that the LA posterior wall plays an important role in the occurrence and maintenance of AF. With division of the anterior and posterior LA wall and the creation of a complete line of block, the LA can be isolated, and this may control the continuation of AF.

Necessity of non-contact mapping system

A previous study showed that it is possible to evaluate an arrhythmia by mapping the epicardium in surgical procedures, but such an evaluation performed endocardially requires a 3D mapping system. In particular, NCM is essential for evaluating an arrhythmia in just one heartbeat and for analyzing the conduction by pacing. While contact mapping is accurate, it is of limited value in non-sustained rhythm [18,19].

The conduction properties of the posterior LA

In this study, conduction heterogeneity was observed 60% of the time at the roof and inferior region of the posterior LA in most of these AF patients. The conduction properties of the posterior LA were affected by the direction of the wavefronts, which were presumably influenced by the anatomical structure and the musculature layer. We confirmed the activation pattern of the LA roof during SR. Activation during CS...
Figure 3  (A) We could confirm the conduction in 59% of cases is not across the left atrium (LA) roof to the posterior LA. The white arrow is direction of activation. This propagation is in a horizontal direction along the LA roof line. Yellow color (wave form No 14—18) is intra-cardiac virtual unipolar electrograms of LA roof line. Green color (wave form No 19—23) is intra-cardiac virtual unipolar electrograms of LA bottom line. The large number is LA septum side. The true contact bipolar catheter position is located on the LA roof near 16. This bipolar electrogram (wave form No 11) shows the double potential of the limit part. (1 and 2) Right superior pulmonary vein (RSPV) anterior—superior side (near the No 18) is start to LA activation and QS pattern shows LA breakthrough site. (3) Horizontal propagation along the LA roof line. (4 and 5) Turning point was left superior pulmonary vein (LSPV) anterior—superior side (wave form No 14). RS pattern showed approach and return propagation. (6) Non-contact single potential showed that there was no excitation of the posterior LA wall. (B) Conduction of the anterior LA wall to the posterior LA wall was confirmed in 41% of patients. Yellow color (wave form No 6—10) is intra-cardiac virtual unipolar electrograms of LA roof line. Green color (wave form No 11—15) is intra-cardiac virtual unipolar electrograms of LA bottom line. It seems the activation moves anterior—superior part of RSPV site to LSPV site (horizontal propagation) and then, across the LA roof line (vertical propagation). (1—3) On the vertical unipolar electrograms mean the horizontal propagation of the LA anterior—superior. (4 and 5) Across the LA roof line. It shows change of polarity and the incomplete double potential of virtual unipolar electrograms mean the conduction of the LA anterior—superior wall to the LA posterior wall. Unipolar potential show excitement of the posterior LA wall. (C) No conduction of the posterior LA wall during coronary sinus (CS) pacing. Green color (wave form No 19—23) is intra-cardiac virtual unipolar electrograms of the LA bottom line. Yellow color (wave form No 14—18) is intra-cardiac virtual unipolar electrograms of LA roof line. This propagation collides by the LA bottom line and separates to the anterior part of the LSPV and the RSPV (looks like a horizontal direction). The ablation catheter is placed in the LA bottom wall (near the No 23). It shows true contact bipolar electrograms (wave form No 13). The contact bipolar position is located on the LA bottom near 23. (1) White vertical line means CS pacing spike. We can see the separate activation to the right side of LA and left side of LA, at the white character 2 and 3. It seems to have a horizontal direction along the bottom line. The white characters 4 and 5 mean turn up, both lateral side, and the white character 5 means end of the LA activation. The posterior LA wall is not excited. (D) Conduction of the posterior LA wall during atrial fibrillation (AF). Yellow color (wave form No 14—18) is intra-cardiac virtual unipolar electrograms of LA roof line. Green color (wave form No 19—23) is intra-cardiac virtual unipolar electrograms of LA bottom line. (1) AF rotor wave passed between 16 and 14, down
to vertical direction. We can see the virtual unipolar electrograms show RS pattern. (2) The wavefront separates to up and down with left inferior pulmonary vein (LIPV). (3) Two rotor waves appeared. (4) They passed between 23 and 21, up to vertical direction. (5) Virtual unipolar electrograms show RS pattern between 14 and 16. (6) AF rotor wave is in a horizontal direction along the LA roof. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)
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Figure 4  
(A) No conduction of the left atrium (LA) roof and bottom line during the sinus rhythm (SR). The SR activation is not invasion into the posterior LA wall. Entrance block was achieved by all the cases. Yellow color (roof line No 10—6) and Green color (bottom line No 11—15) shows intra-cardiac virtual unipolar electrograms. (1—3) This propagation is in a horizontal direction along the LA roof and bottom the ablation line. (4) End of activation. The roof and bottom virtual unipolar electrograms show single potential. The posterior LA wall is not excited. (B) After Box isolation, no conduction of the LA roof and bottom line during posterior pacing. The posterior pacing activation did not spread to anterior and inferior wall. It suggests completion of exit block from the posterior LA. Yellow color (roof line No 10—6) and green color (bottom line No 15—11) shows intra-cardiac virtual unipolar electrograms. (1) White vertical line is posterior pacing spike and noise. (2) Small R wave shown capture the posterior LA wall. (3) The wavefront has collided with the roof and bottom line. P-wave and QRS-wave do not conduct after pacing spike, because the activation does not leak from the posterior LA box. The colors scale represent the peak instantaneous negative potential, white is the earliest and is red, yellow, green and blue. The purple color is set with anatomical geometry. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Pacing was also investigated as confirmation of the activation pattern close to the CS was difficult during SR. Previous studies have shown that left-to-right interatrial conduction occurred through Bachmann’s bundle, the limbus of the fossa ovalis, and from the CS ostium [20]. The isochronal activation mapping during SR was similar to that reported in a previous NCM investigation [21]. We hypothesize that activation during the SR is delayed as it approaches the posterior wall as a result of the muscle layer extending from the right superior PV (RSPV). The musculature layers intersect in a complicated manner, and conduction is further complicated by an anatomical barrier [22,23]. Specifically, the anatomical structure of the LA roof is formed by extending RSPV myocardial sleeves (criss-crossing) [24], Bachmann’s
bundle (horizontal aspect), and the septopulmonary bundle of the endocardium (vertical aspect). The present study has shown that about 60% were the horizontal conduction of Bachmann’s bundle dominant during SR (Fig. 3A), may be not electrically excite in the posterior LA over the roof line. We thought that not to transfer to muscle layer in the vertical direction. And about 40% were changed the vertical conduction near the LSPV side roof line. The conduction transferred to the vertical muscle layer like septopulmonary bundle (Fig. 3B). The anatomical structure of the LA bottom is formed by the CS musculature that covers the CS and is connected with epicardium of the left atrium (criss-crossing), myocardial layer along the mitral valve (horizontal aspect), and septopulmonary bundle (vertical aspect). The CS pacing wavefront confirmed horizontal conduction in 60% of cases along the bottom line (Fig. 3C). Conduction heterogeneity of the LA bottom was similarly recognized in about 60% of the patients. During AF, conduction through the LA roof and bottom was observed in 85% of the patients (Fig. 3D). Entrance conduction of the posterior LA was likely affected by the complex musculature arrangement of the LA roof and bottom line. Exit conduction from the posterior wall occurred vertically through the LA roof and bottom was observed in 98% and 83% by the posterior pacing method (Fig. 3E), respectively. We suggest that the conduction irregularity of the LA roof and bottom promote the maintenance of AF.

After Box isolation

Post ablation, the entrance conduction of the LA activation at the LA roof and LA bottom changed to a horizontal pattern along the linear ablation in all cases. The vertical conduction parallel to the septopulmonary bundle disappeared. Entrance block into the posterior LA during SR and CS pacing was achieved in all patients. The exit block during pacing inside the box area was achieved in 88% of the patients. 88% cases no-capture the posterior LA wall 5.0 V pacing. This means indicates the excitation of the posterior LA wall disappears. The confirmation of linear ablation linear was performed with virtual bipolar signals and contact ablation catheter. Bi-directional conduction block of the LA roof and bottom line was achieved in 88% of the patients (Fig. 4A and B).

The effect of P-wave after creating linear lines

P-wave duration prolongation was assumed to be caused by linear ablation. However, the P-wave duration and LA activation time were shortened. P-wave duration shortening may be due to a decrease in the conduction delay from the RA to LA with right-sided PV ostium isolation, and an absence of conduction in the posterior LA. A previous study indicated that successful PV isolation had the effect of creating a narrow P-wave duration [24]. LA activation time was not significantly changed, but showed a tendency to be shorter. The LA activation pattern that progressed horizontally at the LA roof and bottom line (RA to LA side) in SR occurred in approximately 60% of cases, and the activation in the vertical direction across the LA roof and bottom line occurred in about 40% of the cases. Conduction in the vertical direction disappeared after Box isolation. Box isolation may have minimized the change in SR conduction.

Study limitations

Previous studies have validated the accuracy of using NCM to map areas of interest during SR and AF in humans, and it is well known that its accuracy is limited by the distance from the array center [25–27]. The accuracy of reconstructed electrograms is decreased at a distance >40 mm from the center of the array, particularly during AF. In this study group of AF patients, the average parasternal long-axis LA diameter was only 40 ± 6 mm on transthoracic echocardiography. However, due to the eccentric geometry of the LA, the septum to lateral wall diameter was much greater than this measurement and therefore the PVs may be >40 mm from the center of the array. Our investigation of the posterior LA was based on a group of AF patients. A future comparison study in a non-AF group may help to clarify our findings. AF was induced by premature atrial stimulation in some patients, thus conduction could not be examined from all directions.

Conclusions

Heterogeneous conduction was observed at the roof and inferior region of the posterior LA in most of these AF patients. The conduction properties of the posterior LA are affected by the direction of the wavefronts, and this may play an important role in the initiation and maintenance of AF. The complete isolation of the posterior LA may prevent AF.

References


