A New Method of a Pulmonary Vein Map to Identify a Conduction Gap on the Pulmonary Vein Antrum Ablation Line

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Background: Electrical isolation of the pulmonary veins (PV) is crucial for atrial fibrillation (AF) ablation. Conduction gaps on the circumferential PV antrum ablation (CPVA) line sometimes remain, which are sometimes difficult to identify.

Methods and Results: CPVA of the ipsilateral superior and inferior PVs was performed during sinus rhythm or coronary sinus pacing using the NavX system in 22 AF patients, in whom 1 round of CPVA failed to disconnect 26 individual PVs (30%) in 18 patients. In these patients, a local activation map within the CPVA line (PV map) was created by a 20-pole circular mapping catheter with the use of the NavX, with 71±37 sampling points per PV antrum. The conduction gap was defined as a site on the CPVA line, from which the activation proceeded toward the entire PV. The mapped PV antra were comprised of the left superior PV in 11, right superior PV in 10, left inferior PV in 3, right inferior PV in 1 and a left common PV in 1 PV(s). The conduction gaps were identified at 1.4±0.7 sites per PV antrum, with an electrogram amplitude of 0.8±0.7 mV. A point ablation at the gap completely isolated 24 out of 26 PV antra (92%) with 1.9±1.3 applications.

Conclusions: The PV map was useful for quickly and accurately identifying the conduction gap(s) after 1 round of CPVA. (Circ J 2011; 75: 2363–2371)

Key Words: Atrial fibrillation; Circumferential pulmonary vein antrum ablation; Conduction gap; Pulmonary vein map
atrium dimension was 36±6 mm, and the mean left ventricular fractional shortening was 36±5%. Written informed consent was obtained from all patients and the session was performed under conscious sedation. All antiarrhythmic drugs were discontinued for at least 5 half-lives before the electrophysiological study and ablation procedure.

All patients underwent multislice computerized tomography with a 3D reconstruction 2 or 3 days before the AF ablation procedure to image the anatomy of the PVs and LA, and to understand the relationship of the location between the LA and adjoining structures like the esophagus. All patients underwent transesophageal echocardiography to exclude any presence of an LA thrombus.

**Electrophysiological Study and Image Acquisition**

Standard multielectrode catheters were positioned in the coronary sinus (CS) and right ventricular apex via the internal jugular and femoral vein respectively, for pacing and recording. Using a standard Brockenbrough technique, an atrial transseptal puncture was performed under fluoroscopic guidance, and a long transseptal sheath (SL0; St. Jude Medical) was introduced into the LA, through which a 20-pole deflectable CMC (Optima; St. Jude Medical) with a changeable diameter from 11 to 20 mm, 1 mm electrode width and an interelectrode spacing of 1 mm and between pairs of 2.5 mm, was introduced into the LA. In addition, 1 more transseptal long sheath (SL0) was introduced through the same atrial septal hole, and was used to introduce an ablation catheter into the LA for mapping, pacing and ablation. Intravenous heparin in a dose of 3,000 IU was initially administered after the insertion of the sheaths into the internal jugular and femoral veins, and heparin was additionally administered through the long sheath just after the Brockenbrough puncture to maintain an activated clotting time (ACT) between 300 and 400 s, the total of which usually came to approximately 100 IU/kg. The ACT level was monitored every 30 min, and if it was <300 s, an adequate amount of heparin was injected to maintain an ACT of >300 s. The long sheaths were constantly flushed with 5–10 ml of saline every 10–15 min to avoid any thrombus formation.

The 3D geometry of the LA and PVs was depicted by the CMC with the use of the NavX system. The function and method of the NavX system have been previously described in detail elsewhere. The geometry of the LA and PVs was integrated with a computerized tomography image using the NavX fusion software. The PV ostium and antrum were identified on the electroanatomical image, and/or integrated computerized tomography image. A standard quadripolar mapping catheter coated with a lubricant was inserted nasally into the

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**Figure 1.** Creation of a PV map. **(A)** To record a PV electrogram only, the roving acquisition interval was appropriately set to exclude both the atrial and ventricular electrograms and to record only PV electrograms. The clear zone indicates the acquisition interval and shaded zones indicate the intervals that were excluded. It was set from the timing after the latest atrial electrogram recorded by a CMC to the onset of the QRS complex while recording the P wave on the surface ECG. The PV activation time was measured relative to the atrial electrogram in the coronary sinus. **(B)** With the use of the Active EnGuide function, multipoint mapping was started while serial local activations were simultaneously displayed on the reconstructed LA image using the Auto color mapping mode. **(C)** ECG and intracardiac tracings from the proximal to distal coronary sinus, ablation catheter and CMC. PV, pulmonary vein; CMC, circular mapping catheter; ECG, electrocardiogram; LA, left atrium.
esophagus under fluoroscopic guidance. The entire course of the esophagus was depicted and superimposed on the posterior wall of the LA to avoid any esophageal injury.\textsuperscript{11}

### Ablation Procedure

CPVA was performed during sinus rhythm (SR) for right ipsilateral PVs and during CS pacing for the left ipsilateral PVs. The ablation of the ipsilateral superior and inferior PVs was jointly performed by a continuous lesion at sites 1 cm away from the PV ostium under navigation using the NavX, while the CMC was placed at the ostium of the tubular portion of the PV to record the PV potentials (PVP). In patients with AF recorded before the beginning of the procedure, AF was converted to SR by an intracardiac DC shock of 5–10 J. RFA was performed with an irrigated 4-mm tip electrode catheter (Cool Path Duo; St. Jude Medical), which has the electrode widths of 4 mm, 1 mm, 1 mm, and 1 mm, respectively, and an inter-electrode spacing of 1.5 mm, 5 mm and 2 mm between the distal and 3 proximal electrodes. RFA using the ablation catheter was performed with a temperature limit of 40°C, power limit of 25–30 W and infusion rate of 13–20 ml/min for 20 s in general, but the power and duration were reduced to 20–25 W for 20 s at the LA posterior wall near the esophagus. The point of the energy application was moved to the neighboring site when the local electrogram amplitude decreased to less than 30%.\textsuperscript{12} Each energy delivery point was serially tagged by a colored circle with a diameter of 5 mm on the reconstructed 3D LA image. The primary endpoint of the ablation procedure was electrical PV isolation with elimination and/or dissociation of the PVPs. Pacing from the PV using the CMC was performed, and the absence of the electrical conduction from the PV to LA was also confirmed. RFA of the cavotricuspid isthmus was also performed in all 18 patients.

### PV Map

In all patients, 1 round of CPVA was completed irrespective of achievement of PV disconnection at the PV ostium level in the process of the CPVA. When 1 round of CPVA failed to electrically isolate the PV antrum, a local activation map of the PV and PV antrum (PV map) was created for the individual PV using bipolar electrograms simultaneously recorded by the CMC attempting to search for the conduction gap(s) on the CPVA line. The CMC was moved gently within the PV and PV antrum to record the PVPs so as to cover the entire PV antrum.
region, in which attention was paid not to apply excessive pressure by the catheter to cause premature contractions. When the CMC did not cover the entire PV antrum region, sampling points were taken by placing the ablation catheter in the missing area. The PV map was constructed during SR for the right PV antra and during CS pacing for the left PV antra in order to discriminate the PVPs from the atrial electrograms.

Ten bipolar electrograms from the PV were recorded simultaneously from 10 pairs of neighboring electrodes on the CMC and were projected on the recording site on the PV map using Simultaneous MultiPoint™ mapping software, which is equipped with the NavX system (Figure 1). The timing of the PV activations was automatically determined by the setting of the Diagnostic Landmark Map acquisition window, in which the roving acquisition interval was appropriately set to exclude both atrial and ventricular electrograms and to record only PV electrograms (Figure 1A). To achieve this, the roving acquisition interval was set from the timing after the latest atrial electrogram within the PV to the onset of the QRS complex while recording the P wave on the surface ECG. The maximal value of the –dV/dt of the PV electrogram was used to automatically detect the precise local activation, and the activation time was measured relative to the atrial electrogram in the CS, which was sharp enough to be automatically triggered. The Active EnGuide function was then selected, and the multipoint mapping was started while the serial local activations were simultaneously displayed on the reconstructed LA image using the Auto color mapping mode (Figures 1B, C).

The conduction gap was defined as a site on the CPVA line, from which the activation proceeded toward the entire PV. At the conduction gap, a point ablation was performed to close the gap. When the activation sequence of the PVPs recorded by the CMC changed after the point ablation to the conduction gap, the PV map was re-constructed attempting to look for another conduction gap, and an additional point ablation was performed at the newly identified conduction gap. When RFA to the gap(s) revealed by the PV map failed to eliminate the PVPs, additional RFA was performed at the site with the earliest PVP on the CMC located at the PV ostium to achieve a PV disconnection.

The bipolar intracardiac electrograms were filtered with a bandpass filter setting between 32 and 300 Hz. The following definitions were used for the analysis. The amplitude represented the contact bipolar voltage difference between the highest and lowest deflections in each electrogram (peak-to-peak voltage). Fractionated potentials were defined as complex activity lasting for >50 ms.13,14

**Segmentation of the PV Antrum Isolation Site on the CPVA Line**

To categorize the location of the conduction gap, each PV antrum was divided into anterior, posterior, superior, and inferior parts.12 The inferior parts of the superior PVs and superior parts of the inferior PVs were classified into the carina region. The electrogram recorded at the conduction gap was also analyzed.

**Statistical Analysis**

The continuous variables were expressed as the mean±SD or numbers and percentages, as appropriate.

**Results**

**Creation of the PV Map**

Out of the 86 PV antra (a left common PV was present in 2 patients) in the 22 patients, 1 round of CPVA failed to elec-
cally disconnect an individual PV in 26 PVs (30%) in 18 patients (82%). All 4 or 3 PVs were isolated by 1 round of CPVA in the remaining 4 patients. The PV map was created after 1 round of CPVA in all 26 PVs and the antra. A second PV map was created to identify another conduction gap after a point ablation of the first conduction gap in 3 PV antra and a third PV map in 2 PV antra. The PV map was constructed in all PV antra without any difficulties or complications. The mean PV mapping time was 101±46 s.

**PV Antrum Isolation Guided by the PV Map**

The mapped PV antra were comprised of right superior PV (RSPV) antra in 10, left superior PV (LSPV) antra in 11, right inferior PV (RIPV) antra in 1, left inferior PV (LIPV) antra in 3, and left common PV antrum in 1. An average of 71±37 sampling points was taken to construct each PV map.

**Figure 2** shows a representative PV map in a patient with a left common PV. The PV map clearly revealed the conduction gap at the posterior part of the antrum. Furthermore, the propagation of the excitation was anisotropic within the PV, which

**Figure 4.** A PV map exhibiting a wrongly identified conduction gap due to a deficiency of sampling points. (A) The conduction gaps were wrongly identified at the mid-posterior and anterior-inferior LSPV antrum. (B) Additional mapping points were collected around the roof and anterior LSPV antrum and superimposed on the previously constructed PV map. The revised PV map exhibited the true conduction gap at the superior LSPV antrum. (C) A point ablation at the newly identified gap on the CPVA line eliminated the PVPs. (A, B) were obtained in the LL view, and (C) in the LL and LAO views, respectively. PV, pulmonary vein; LSPV, left superior pulmonary vein; CPVA, circumferential PV antrum ablation; PVP, PV potentials; LL, left lateral; LAO, left anterior oblique.

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LL view

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LL view

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LAO view

PVPs were eliminated
was shown by the inhomogeneous progression of the color-coded isochronal line. Figure 3 shows a PV map of the RSPV and the antrum exhibiting 2 conduction gaps both at the anterior and anterior-inferior parts. Simultaneous activations from the 2 conduction gaps to the entire PV were observed, which suggested a similar conduction time over the 2 gaps.

The PV map sometimes requires tips and tricks to create and interpret it. To begin with, when the sampling point does not cover the entire area, the accuracy would be reduced. Figure 4 shows a PV map exhibiting wrongly identified conduction gaps at the infero-anterior and mid-posterior PV antrum due to a deficiency of sampling points (Figure 4A). The RFA to both conduction gaps failed to eliminate the PVPs. After that, we noticed the lack of sampling points at the roof and anterior LSPV antrum. Therefore, additional mapping points were taken around those regions, and were superimposed on the previ-
PV Map for Identifying a Conduction Gap

Previously constructed PV map. The revised PV map exhibited the true conduction gap at the superior LSPV antrum (Figure 4B) and a point ablation at the newly identified gap eliminated the PVPs (Figure 4C).

When there are more than 2 gaps with different conduction times over the gaps, conduction over a gap with a long conduction time was frequently masked by another gap with a short conduction time. Figure 5 shows a PV map of the RSPV antrum created during SR, in which the activation sequence changed after the RFA to a conduction gap. In the initially constructed PV map (Figure 5A), the conduction gap was identified at the posterior carina between the RSPV and RIPV. The RFA to the conduction gap resulted in a sudden change in the activation sequence on the CMC. The PV map was then re-created, and a new conduction gap at the anterior carina was identified with a delay in the timing. The point ablation at the gap eliminated all the PVPs (Figure 5C).

Finally, when the wall thickness at the conduction gap is very thick, making a transmural lesion would be challenging even if the PV map provides an accurate location. Figure 6 shows a PV map of LSPV and antrum in a patient in whom the PV map accurately identified the gap, but a point ablation at the gap failed to disconnect the PV due to the thick wall thickness. The earliest activation was observed just distal to the conduction gap, and thus ablation was performed at a slightly more distal site, which again failed to disconnect the PV (indicated by the blue dots in Figure 6B). Finally, a point ablation was performed at the ostium of the tubular portion of the LSPV where the CMC suggested an electrical connection between the LA and PV (indicated by the red point in Figure 6B). RFA to that site eventually eliminated the PVPs. Overall, the point ablation at the conduction gap resulted in complete disconnection in 24 of 26 PV antra (92%). The average number of RF applications delivered at the gap was 1.9±1.3. In the remaining 2 PVs, additional RFA at the earliest activation site on the CMC located at the ostium of the tubular portion of the PV was required to eliminate the PVPs.

Figure 6. A PV map showing the accurate gap location, but ablation at that site failed to disconnect the PV. (A) A PV map was created during CS pacing, which revealed a conduction gap at the superior LSPV antrum. The electrogram at the gap was a single potential. (B) Several RF applications to the conduction gap failed to eliminate the PVPs (blue circle). The earliest site on the 20-pole circular catheter within the LSPV was located just above the site of the conduction gap. Therefore, additional RFA to the site where the CMC suggested the electrical connection between the LA and PV was performed and eliminated the PVPs (red circle). (A, B) were obtained in the RAO view. PV, pulmonary vein; CS, coronary sinus; LSPV, left superior pulmonary vein; RF, radiofrequency; PVPs, PV potentials; CMC, circular mapping catheter; LA, left atrium; LAA, left atrial appendage; RAO, right anterior oblique.

Regional Distribution of the Conduction Gaps

The conduction gaps were identified at 34 sites in 24 PV antra. There were 1.4±0.7 conduction gaps per PV antrum and more than 1 gap was identified in 8 of 24 PV antra. The mean electrogram amplitude at the gap was 0.8±0.7 mV. The morphology of the electrogram at the conduction gap was fractionated in 14 sites (41%), and simple in 20 sites (59%). The earliest activation site on the CMC located at the ostium of the tubular portion in the PV was straight and distal to the conduction gap in 23 PV antra and diagonal and distal in 3 PV antra. For the RSPV antrum, 15 gaps were observed in 10 PV antra, including 1 superior gap (7%), 4 anterior gaps (27%), 4 posterior gaps (27%) and 6 inferior (carina) gaps (40%). For the LSPV antrum, 11 gaps were observed in 11 PV antra, including 1 superior gap (9%), 2 anterior gaps (18%), 2 posterior gaps (18%) and 6 inferior (carina) gaps (55%). For the left common PV antrum, 3 gaps were observed in 1 PV antrum, including 2 gaps at the anterior part, and 1 gap at the posterior part. For the RIPV antrum, 2 gaps were observed in 1 PV antrum, both of which were located at the posterior part. For the LIPV antrum, 3 gaps were observed in 3 PV antra, including 3 gaps at the anterior part. Overall, conduction gaps were observed at the carina in 12 of 24 PV antra (50%).

Discussion

Main Findings

There were several new findings in this study. First, the PV map constructed by the NavX system was useful to quickly and accurately identify a residual conduction gap(s) on the
ablation line after 1 round of CPVA within a few minutes without any difficulty or complications. Second, a point ablation at the conduction gap(s) on the CPVA line disconnected the PV in most cases. Third, the conduction gap(s) was frequently observed at the carina in both the right and left PVS.

Strength of This Method
The strength of this method was to accurately identify the conduction gap within a few minutes, and a point ablation at the gap resulted in complete PV isolation. We noticed that the earliest PV electrogram recorded by the CMC, located at the ostium of the tubular portion, was sometimes diagonal and distal to the conduction gap located on the CPVA line because the activation within the PV did not travel straight from proximal to distal but rather propagated along a course that snaked away to the distal PV. Therefore, it is sometimes difficult to deduce the location of the conduction gap on the CPVA line from the location of the earliest PV electrogram recorded by the CMC.

Technical Points
NavX allows for an acquisition of multiple 3D anatomical points along with the local activation time, which are projected on the corresponding sites on the 3D reconstructed geometry on a color-coded basis. There might be some concern that among all the electrodes of the CMC, some electrodes were touching the endocardium and others were floating within the PV. To collect accurate sampling points from the endocardial surface, the location of the sampling point was automatically checked in relation to the corresponding endocardial surface by strictly setting the interior and exterior projection function of the NavX system. When the sampling point was away from the endocardial surface of the reconstructed geometry over the predetermined range, the point was automatically excluded from analysis and not shown on the PV map. We usually set the internal and external projection ranges at 3 mm.

There is another technical point to be emphasized, which is the setting of the time window to annotate the PV electrogram. We carefully set the time window to pick up only the PV electrograms from the electrograms recording by the CMC, which contained both atrial and PV electrograms. To make it easy to distinguish the PV electrograms from the atrial electrograms in the recordings, we applied this method only after 1 round of CPVA because the PV electrograms usually appeared late after the atrial electrogram due to the effect of the CPVA. Furthermore, the time window was set from the point after the latest atrial electrogram, among the atrial electrograms obtained from the CMC, to the onset of the QRS complex. When discrimination between an atrial and PV potential was difficult at a conduction gap due to low amplitude, and/or fractionated morphology, we made additional efforts to accurately determine the initiation of the PV electrogram from the recordings obtained from the CMC. First, the end of atrial electrogram at the conduction gap was deduced from other atrial electrograms at sites adjacent to the conduction gap where a distinct atrial electrogram was recorded. The component following the end of the latest atrial electrogram was suggested to be the PV potential. Second, the activation sequence of PV electrograms was tracked back using an animated propagation map function from the end to the initial PV activation at the conduction gap. This method allowed us to have visual identification of the conduction gap and provided an estimated activation timing and anatomical location of the conduction gap. According to this estimation, the electrogram morphology at the conduction gap was reexamined and the PV activation time was confirmed. Finally, the local electrogram at the conduction gap was reexamined with the ablation catheter, which sometimes provided different electrogram morphology leading to easy discrimination between atrial and PV potentials because the paired electrodes position relation was different from the CMC.

Comparison With Previous Studies
Arenal et al reported that the conduction gap on the CPVA line can be identified by a multicomponent electrogram without an isoelectric line. In the present study, however, fractionated electrograms at the conduction gap were observed only in 41%. First of all, we think that the difference in the ablation device was partly contributed to the inconsistency. They used a non-irrigated 8-mm tip ablation catheter while we used an irrigated 4-mm tip ablation catheter. It has been known that RF energy application by the 8-mm tip ablation catheter sometimes resulted in non-transmural lesion formation. The mechanism of a conduction gap might be partly explained by the non-transmural lesion formation, which leads to complex electrograms. In contrast, an irrigated 4-mm tip ablation catheter allowed us to make deeper lesions with higher energy compared with a non-irrigation catheter, and thus was expected to create a transmural lesion, albeit not in all cases. Therefore, the simple morphology of the electrogram at our conduction gap might simply represent a missing point of energy application in some cases. Second, the use of an 8-mm tip resulted in a broader view of endocardial activation compared with a 4-mm tip ablation catheter or CMC, possibly leading to inclusion of activations at adjacent sites. Finally, we think that the fractionated potential is not always recorded at a conduction gap. In the ablation of a common atrial flutter, we frequently witnessed that a simple potential recorded at the conduction gap was changed into double potentials by successful application of RF energy along with the completion of a block line at the tricuspid valve-inferior vena cava isthmus.

Study Limitations
There were some limitations. First, this PV map did not always guarantee a successful PV antrum isolation even if it provided an accurate location of the conduction gap. When the wall thickness at the conduction gap was too thick, it might have been difficult to make a transmural lesion like that shown in Figure 6, which resulted in an unsuccessful ablation on the CPVA line. Second, when there were 2 or more gaps along the CPVA line and the conduction times over the conduction gaps differed like that shown in Figure 5, 1 gap might have been masked by the other due to the difference in the activation times. In such a situation, a remap might be required to reveal the second gap with a longer conduction time after eliminating the first gap.

Conclusion
A new method for a PV map was useful to quickly and accurately identify a residual conduction gap(s) on the ablation line after 1 round of CPVA. The point ablation to the gap(s) revealed by the PV map could eliminate the PVPs with a few RF applications. The PV map was very useful for improving the success rate and safety of the AF ablation.

Disclosure
Conflict of Interest: Dr Tsuchiya has served as a speaker and consultant for Nihon Kohden and St. Jude Medical.
References


