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Original article

# Comparison of circumferential pulmonary vein anatomy mapping guided by 3D mapping *versus* a mesh mapping catheter

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**Abstract**

**Objective:** Catheter-based pulmonary vein isolation (PVI) is an established therapy for paroxysmal atrial fibrillation. The high-density mesh mapper (HDMM) guides circumferential PV-atrium isolation without the 3D electroanatomic mapping. This study aims to compare circumferential pulmonary vein (CPV) anatomy mapping between guiding by a 3D mapping system and the HDMM.
**Methods:** Forty-four consecutive patients with paroxysmal atrial fibrillation were scheduled for a first procedure for PVI. A CPV ostial anatomy map guided by HDMM was set up in the CARTO system while the operator was blinded to the CARTO screen. Then CARTO-guided ipsilateral PV maps were obtained and PVI was performed. This established another set of CPV ostial anatomy maps. The differences between the two mapping images were compared and analyzed.
**Results:** All 176 PVs in 44 patients could be mapped by both HDMM and CARTO. About 44.9% of the PV ostial anatomies were generally similar between the two different map images. The average point-to-point straight distance between the HDMM-guided map and the CARTO-guided map was 6.2 ± 1.4 mm. The area of the circumferential right PV (CRPV) in the HDMM map was larger than that in the CARTO map ($P = 0.013$). After a mean follow-up of 18.3 ± 4.3 months (6−24 months), 72.7% of patients (32/44) were free of atrial arrhythmia without anti-arrhythmic drugs (AADs).
**Conclusion:** Compared to the CARTO-guided CPV anatomy image, a highly similar figure could be achieved by mapping guided by the HDMM. (Clinical trial.gov number, ChiCTR-TNRC-11001390.)


*Keywords:* High-density mesh mapper (HDMM); Atrial fibrillation; Ablation; CARTO

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## Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia, and catheter ablation has been recommended as an important therapeutic strategy.[1,2] The latest guideline for AF ablation recommends that ablation of the target pulmonary veins (PVs) and/or PV antrum is the cornerstone for most AF ablation procedures. If the PVs are targeted, electrical isolation should be the acute clinical goal.[3] Currently, pulmonary vein isolation (PVI) is usually guided by 3D electroanatomic mapping by fluoroscopy, such as the CARTO or EnSite systems, which are only available at major hospitals.

The high-density mesh mapper (HDMM) is a 32-electrode high-density catheter, which has a variable diameter (Bard Electrophysiology, Lowell, MA, USA). The HDMM can maximize electrode-tissue contact and provide the ultimate in positioning and flexibility. With ultra-precise positioning, it is ideal for close mapping of the PV ostium, accurate identification of pulmonary vein potentials and the elimination of far field signals. Therefore it can provide an anatomic and electrical guide for PV isolation as a 3D mapping system, although with a 2D appearance.[4,5] Several laboratories have reported good clinical outcomes using HDMM as a pulmonary mapping catheter and ablated with an irrigated ablation catheter. Theoretically, using a mesh catheter to conduct both PV mapping and Radiofrequency (RF) energy delivery should be a desirable technology to simplify and optimize the PVI procedure. However, reports from different laboratories on their clinical results using the MESH catheter for both mapping and RF energy delivery have been inconsistent. While the acute clinical results are promising, the long-term follow up results have been less than satisfactory because of a higher AF recurrence rate.[6–8] The possible causes of a higher recurrence rate are yet to be elucidated. The present study compares the difference between the circumferential pulmonary vein (CPV) anatomy mapping in AF patients guided by a 3D mapping system and by the HDMM catheter. Results are expected to shed some light on the PVI outcome when performed by the mesh catheter, which may aid in improving the clinical outcome of the mesh catheter-based PVI procedure.

## Methods

### *Patients*

The study enrolled 44 consecutive AF patients whose AF was documented on at least one electrocardiogram within the previous three months. These patients had no history of prior ablation or of surgical procedures (Table 1).

### *Procedure*

Before ablation: Three days before intervention, warfarin was stopped and replaced by subcutaneous low-molecular-weight heparin. All patients underwent trans-thoracic echocardiography to determine the left atrial diameter and transesophageal echocardiography to exclude a thrombus in the left atrium and left atrium appendage. A cardiac computed tomography (CT) image was obtained to assess pulmonary vein size and geometry.

HDMM guided mapping: The HDMM is composed of 32 crossing single wires. The maximum diameter of HDMM is 25 mm when it is full deployed. The crossing wires form a circular network of 6 mm in breadth in front of the equator umbrella where they are electrically conductive and serve as the mapping electrode. This allows high-density (HD) mapping inside a pulmonary vein and mapping at the antrum if fully spanned.[4,9] A 3.5 mm irrigated tip ablation catheter (ThermoCool Biosense Webster, USA) was used for getting the point map of the antral pulmonary vein. The operator was blinded to the CARTO mapping display screen, and mapped the antral pulmonary vein anatomy guided by the HDMM using fluoroscopy, which constituted Map-1 in the CARTO system (Fig. 1). The assistant could see both Map-1 in the CARTO system and the image from fluoroscopy.

CARTO-guided circumferential pulmonary vein isolation (CPVI) has been described in detail elsewhere.[10,11] Briefly, we used a 10-polar circular mapping catheter (Lasso, Biosense Webster, USA) and the same 3.5 mm irrigated tip catheter (ThermoCool Biosense Webster) to ablate the antrum of the pulmonary veins (PVs) and to achieve abolition of all electrograms. RF

Table 1
Patient characteristics.

| Patient characteristics | Values |
|---|---|
| Patient No. | 44 |
| Male (*n*) | 33 |
| Median age (years) | 57 |
| Duration of AF (years) | 4 |
| Cardiovascular disease (*n*) | |
| Hypertension | 19 |
| Hypertrophic cardiomyopathy | 2 |
| Atrial tachycardia | 1 |
| Atrial flutter | 2 |
| Others | 2 |
| Left atrial diameter (mm) | 40.6 ± 3.8 |
| Left ventricular ejection fraction (LVEF, %) | 63.8 ± 3.7- |

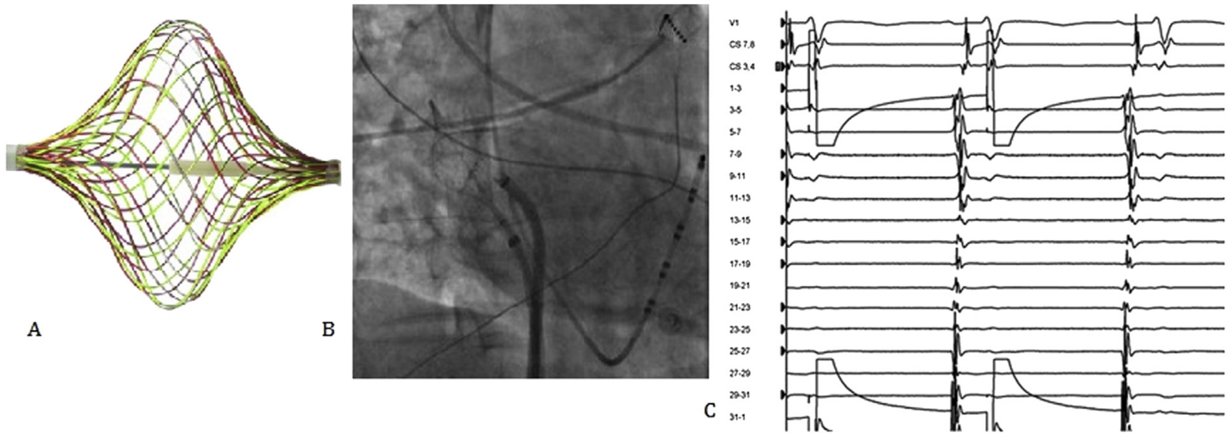


Fig. 1. Panel A. High-Density Mesh Mapper (HDMM) catheter. Panel B. HDMM catheter at the ostium of the RSPV. Panel C. The disturbance signals in the HDMM polars when the ablation catheter is nearby.

energy output was titrated to a maximum of 35 W while maintaining a catheter tip temperature of ≤42 °C. At each site, energy was delivered for 20 s. The maximum power was limited to 30 W if the catheter is close or over the esophagus. A 3D geometry of the left atrium (LA) was reconstructed with the CARTO system and used the CARTO-Merge technique with the CT image in every patient who received the procedure. The endpoint was elimination (or dissociation) of the PV potentials within the ipsilateral PVs. A pacing maneuver to confirm the exit block from the PV was also assessed. The tagged ablation points constituted Map-2 in the CARTO system.

*Post-procedural management*

We reviewed every patient's Map-1 and Map-2 simultaneously in the CARTO system. We compared the point-to-point straight distance of five different areas (superior/inferior, anterior, posterior, anterior triangle, and posterior triangle) in every pulmonary vein, measured the areas and perimeters of antral pulmonary vein anatomy both in Map-1 and Map-2, and compared the depth and angle between the two maps. In point-to-point distance measurements, one doctor randomly picked three points in every area of every pulmonary vein between the two maps. The point-to-point distance, areas and perimeters could be measured in the CARTO system. The depth and angle could be compared by the screenshots from the CARTO system.

*Statistical analysis*

The statistical analysis of this study was performed with an SPSS 14.0 (SPSS Inc., Illinois, USA) software package. For the description of the metric variables the results are expressed as number, mean, standard deviation (SD), extreme (minimum and maximum), and median. Continuous variables were analyzed with a paired *t*-test and analysis of variance (ANOVA) (N-group analysis). Comparison of proportions was performed using Fisher's exact test. A *P*-value ≤0.05 was considered statistically significant.

## Results

*Procedural data*

The data from the HDMM guided mapping procedure are summarized in Table 2. The mapping time and X-ray time used in the left superior pulmonary vein (LSPV) ostium anatomy mapping guided by the HDMM is longer than the time used in the left inferior pulmonary vein (LIPV), which is 6.5 ± 3.5 min and 3.6 ± 2.0 min respectively. While right superior pulmonary vein (RSPV) also needs a long time and X-ray time to be completed, 5.7 ± 2.5 min and 3.2 ± 2.2 min. There was no significant difference

Table 2
HDMM guided mapping data.

| | LSPV | LIPV | RSPV | RIPV |
|---|---|---|---|---|
| Mapping time (min) | 6.53 ± 3.46* | 4.64 ± 2.91 | 5.73 ± 2.52 | 4.73 ± 2.62 |
| X-ray time (min) | 3.63 ± 1.99* | 2.58 ± 1.57 | 3.21 ± 2.16 | 2.67 ± 1.27 |

HDMM: high-density mesh mapper; Data are presented as the mean value ± SD, sign * *means the group is significant, P* <0.05, compared with other groups. LSPV: left superior pulmonary vein; LIPV: left inferior pulmonary vein; RSPV: right superior pulmonary vein; RIPV: right inferior pulmonary vein.

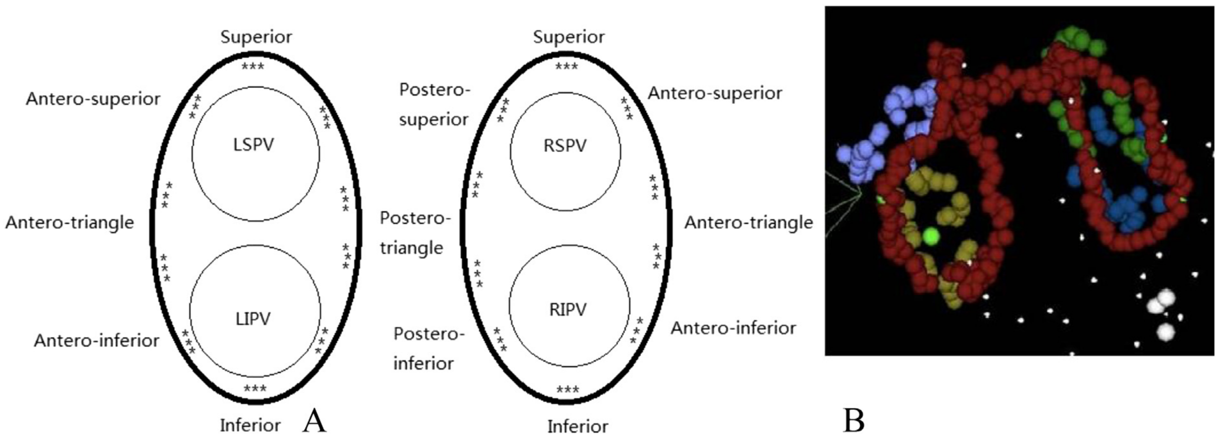


Fig. 2. Panel A. The distribution of the tagged points which had been picked-up. Sign * indicates the point. Panel B. Map-1 and Map-2 were superimposed in the CARTO system; colored tagged points in Map-1 represent the antral pulmonary vein anatomy guided by the High-Density Mesh Mapper (HDMM). Red tagged points were the ipsilateral circumferential pulmonary vein isolation (CPVI) line in a real ablation procedure guided by the CARTO system.

between the mapping time and X-ray time LIPV and right inferior pulmonary vein (RIPV) mappings.

*Outcome of comparison between Map-1 and Map-2*

*Point-to-point distance*

After the procedure, we added Map-1 into Map-2 in the CARTO data, randomly picking three points from the two maps everywhere we measured, as shown in Fig. 2. The straight line distance was measured by the CARTO system itself. The data are absolute values, and are collected in Table 3. All the distance means are less than 10 mm. The average is 6.2 ± 1.4 mm, and most of them are less than 6 mm. Only in all the PVs antero-triangle and LS/LI/RS anterior does the means of the distance exceed 6 mm, where they are nearly 7.2 mm and 8.7 mm respectively.

*Image similarity between Map-1 and Map-2*

We superimposed the two maps and compared the image's similarity from different angles, and we present the similarities in Table 4 and Fig. 3. There are 176 PVs in 44 patients, excluding the PV anatomical variation. A total of 79 PVs (LSPV 17, LIPV 17, RSPV 19, and RIPV 26) can be taken as generally similar between the two maps, with about 44.9% (79/176) participation. Only 9/

Table 3
The point-to-point distance between two maps in different areas of PVs.

| Indices | Superior/Inferior | Anterior | Posterior | Antero-triangle | Postero-triangle |
|---|---|---|---|---|---|
| LSPV (mm) | 6.17 ± 3.76* | 9.14 ± 11.82* | 4.72 ± 2.33 | 7.31 ± 4.61* | 4.44 ± 2.64 |
| LIPV (mm) | 4.93 ± 3.02 | 8.37 ± 4.10* | 4.37 ± 2.41 | 7.86 ± 4.58* | 4.47 ± 2.61 |
| RSPV (mm) | 5.46 ± 4.90 | 8.62 ± 10.41* | 5.41 ± 3.04 | 6.60 ± 3.92* | 5.79 ± 3.62 |
| RIPV (mm) | 5.92 ± 4.09 | 5.68 ± 3.43 | 5.57 ± 3.41 | 7.12 ± 3.85* | 5.86 ± 3.18 |

Data are presented as the mean value ± SD. * indicates the mean value is over 6 mm. LSPV: left superior pulmonary vein; LIPV: left inferior pulmonary vein; RSPV: right superior pulmonary vein; RIPV: right inferior pulmonary vein.

Table 4
Image similarity between Map-1 and Map-2.

| PV | Similar | Deeper | Shallower | ANT deeper | Post deeper | SUP deeper | INF deeper | ANT shallower | POST shallower | SUP shallower | INF shallower |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RS | 19 | 12 | 0 | 7 | 0 | 0 | 5 | 0 | 1 | 0 | 0 |
| RI | 26 | 7 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LS | 17 | 0 | 10 | 2 | 1 | 0 | 0 | 11 | 1 | 2 | 0 |
| LI | 17 | 0 | 7 | 0 | 2 | 0 | 0 | 13 | 0 | 1 | 1 |

PV: pulmonary vein; RS: right superior; RI: right inferior; LS: left superior; LI: left inferior; ANT: anterior; POST: posterior. SUP: superior; INF: inferior.

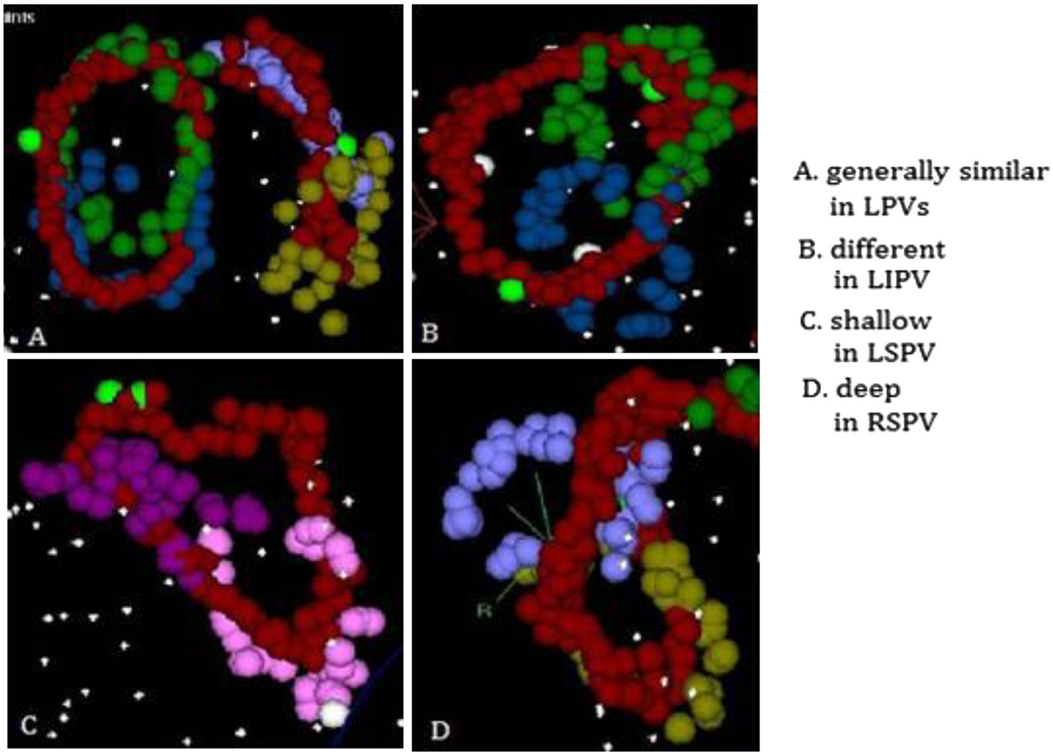


Fig. 3. Map-1 and Map-2 were superimposed in the CARTO system; colored tagged points in Map-1 represented the individual antral pulmonary vein anatomy guided by the High-Density Mesh Mapper (HDMM). Red tagged points were the ipsilateral circumferential pulmonary vein isolation (CPVI) line in a real ablation procedure guided by the CARTO system. Panel A illustrated that maps from left pulmonary veins (LPVs) were generally similar. Panel B illustrated that maps from left inferior pulmonary vein (LIPV) were anatomically different. Panel C illustrated that the HDMM generated map from left superior pulmonary vein (LSPV) was more proximal (shallower). Panel D illustrated that HDMM generated maps from right superior pulmonary vein (RSPV) were more distal (deeper).

176 (5%) PVs in the two maps are different. The other PVs show varying degrees of similarities, such as LSPVs guided by the HDMM were more inclined to be shallower (10/44, 22.7%) or anterior shallower (11/44, 25%). A similar situation appears in the LIPVs: 15.9% (7/44) shallower and anterior shallow at 29.5% (13/44). On the other hand, the right PVs tend to be deeper. Compared with Map-2, there are 12/44 (27.3%) deeper RSPVs in

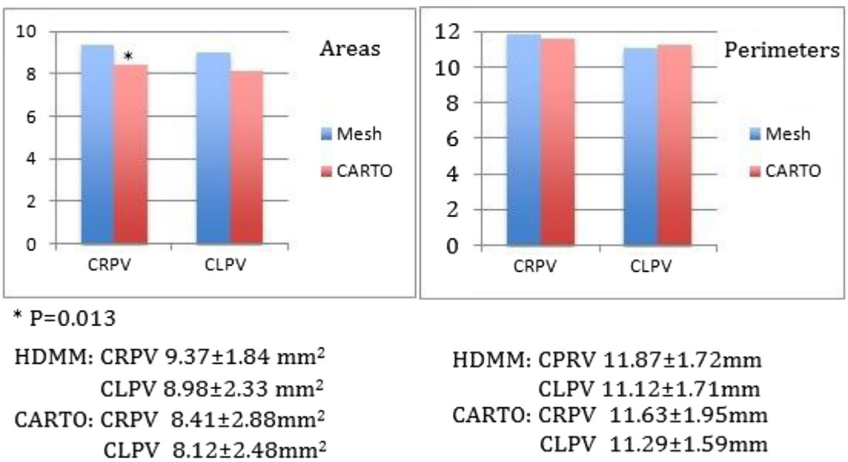


Fig. 4. The left chart is the anatomic areas generated from High-Density Mesh Mapper (HDMM) and CARTO. The right chart is the perimeters generated from HDMM and CARTO perimeter results. CRPV: circumferential right pulmonary vein; CLPV: circumferential left pulmonary vein

Map-1, 15.9% (7/44) anterior deeper, and 11.4% (5/44) inferior deeper. There were 15.9% (7/44) and 9% (4/44) RIPVs in Map-1 that appeared deeper and anterior deeper.

*Areas and perimeters*

The data of CPVs areas and perimeters are shown in Fig. 4. CPV areas in the HDMM maps are much larger than in the CARTO maps, especially in the circumferential right PV (CRPVs) ($P = 0.013$). Circumferential left PV (CLPV) areas in the HDMM maps tend to be bigger than in the CARTO maps, but there is no significant difference between them. In addition, there is no significant difference in the CPV perimeters between the two maps.

*Clinical outcome*

Oral anticoagulation was restarted on the same day as the ablation and continued for three months. Pulmonary vein entry and exit conduction block, as well as decreased local electrode amplitude, were endpoints for successful acute ablation. All 176 PVs in 44 patients were achieved with a successful acute endpoint. After a mean follow-up of $18.3 \pm 4.3$ months (6—24 months), 32 of the 44 enrolled patients (72.7%) were free of atrial arrhythmia without anti-arrhythmic drugs (AADs). Two patients underwent a second ablation procedure, and the other 10 patients with symptomatic recurrence of paroxysmal AF taking AADs.

## Discussion

Several authors have reported a reasonably good clinical outcome using the HDMM as a higher resolution pulmonary vein mapping catheter for the PV isolation procedure in the treatment of atrial fibrillation. This prospective, single center clinical study was the first attempt to use the HDMM as an anatomic template to guide the PV isolation procedure and to further elucidate the differences and similarities of CPV anatomy mapping guided by either the HDMM catheter or the CARTO 3D mapping system. The principal findings from the study were that the point-to-point straight line distance analysis from Map-1 guided by the HDMM was close to Map-2 guided by the CARTO mapping system. The HDMM-guided CPV images were very similar to the images from the CARTO-guided mapping, but they were usually deeper (more distal) in the RPVs and shallower (proximal) in the LPVs. The areas of CPVs guided by the HDMM were much bigger than by the CARTO, but the perimeters were approximate. Finally, the mapping time and X-ray time spent in the HDMM guided CPV ostium mapping were about 5 min and 3 min respectively.

The CPV ostium, antrum of the PV, is defined as a structure connected to the funnel proximal part of a pulmonary vein. It stretches mostly in a more posterior direction similar to the form of a cup. The connection to the LA is not flat but rather oblique.[12,13] There is some individual variation in different patients' PV anatomy, such as diameter and direction. These anatomical characteristics lead to deviations in the maps by the different guiding methods. In our study, Map-2 showed the real ablation line circumferential PVs, guided by the CARTO system. We used CARTO-Merge technology in the ablation procedure in order to make Map-2 more approximate to patient's CPV ostium anatomy. The HDMM is a novel guiding CPV ostium catheter by 2D fluoroscopy, without 3D electroanatomic mapping. The maximum diameter of the HDMM is 25 mm. Because of the existence of non-coaxial examples in the CPV ostium in relation to the PV funnel part,[14] the difference between the two maps in our study is acceptable.

The points, consisting of two different maps, were acquired by the CARTO system, mostly in CARTO-XP, while only in the last three patients were they acquired in CARTO-3. Additionally, the image guided by the CARTO-XP system cannot avoid the influence of respiration. Thus, there are some errors in the image itself. The point diameter is the default 2 mm. We found the average point-to-point straight line distance was $6.20 \pm 1.44$ mm, and most of them are less than 6 mm, but no more than 10 mm. The average value was nearly three times the point diameter that we consider to be technically acceptable.

The interesting finding of the study was that the images of the LPVs ostium guided by the HDMM tended to be placed more proximal (shallower) than by the CARTO system; on the other hand, RPVs were more distal (deeper) in the targeted PV from the HDMM maps. By reviewing these image data, we uncovered some possible explanations. The LPV directions were more posterior, which could make a non-coaxial between the HDMM and the LPVs. The RPV ostiums were more approximate to the LA septum puncture, which resulted in the HDMM catheter being placed more distally.

It was hypothesized that another reason leading to the bias between the two maps might be the mechanical traction from the HDMM catheter. We compared the PV angiographies before and after inserting the HDMM catheter. The angiographies showed that there were no changes in the PVs' direction, but the HDMM catheter was non-coaxial in some PVs.

T. Neumann and his colleagues reported the acute and long-term results of PVI using the HDMM in AF patients.[15] They enrolled 250 consecutive patients with paroxysmal or chronic AF, with follow-up in 16–21 months. They used a 3.5 mm irrigated tip ablation catheter guided by the HDMM with fluoroscopy without the 3D mapping system. They achieved clinical results at a rate of free from paroxysmal AF (71%) and persistent AF (49%). The cornerstone of the highly successful rate is the accurate location on the CPV ostium. Our study elucidated the relationship between the maps guided by the HDMM and the CARTO system that indicated that the HDMM catheter was targeting similar anatomic regions as the CARTO mapping. According to the clinical outcome of the CARTO-guided procedure in this study, it is reasonable to speculate that there would be similar results from the HDMM-guided ablation.

Several limitations should be acknowledged. The findings were based on a single-operator experience. In consideration of the cost of the testing device, the study sample size was small, which could further affect the power of the data and analysis. In order to generalize the study findings, a further well controlled and larger sample size study is warranted. Furthermore, there was noticeable respirational movement from the mapping catheter of the CARTO system. The results could be more valid if the respirational interference could be limited or subtracted.

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