Extent of Atrial Deformation in Catheter Ablation of Atrial Fibrillation

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Summary

Anatomical atrial distortion during catheter mapping and ablation has not been elucidated in atrial fibrillation (AF) ablation. This study aimed to characterize the regional anatomical distortion in common ablation areas according to different contact forces (CFs) with radiofrequency and cryoballoon catheters.

Ten patients underwent distortion mapping with low (5-10 g) and high CFs (10-30 g) at the pulmonary vein (PV) antra, left atrial (LA) roof line, mitral isthmus line, cavotricuspid isthmus line, and superior vena cava (SVC)-right atrial (RA) junction. Fifteen patients underwent distortion mapping with a 28-mm second-generation cryoballoon surrounded by a decapolar catheter at each PV antrum following creating the LA geometry. High CFs distorted the PV antra as compared to low CFs and the extent was greater at the anterior PV aspect, and the catheter was located more inside the PVs. The inflated cryoballoon stretched the PV surface in the postero-superior direction in the upper PVs and posterior direction in the lower PVs. High CFs as compared to low CFs distorted the LA roof and cavotricuspid isthmus in the postero-inferior and inferior directions, respectively, but not the mitral isthmus line even with deflectable sheaths. High CFs distended the SVC-RA junction as compared to low CFs, and the extent was greatest at the lateral side and smallest at the antero-septal side.

Human atria significantly distend during radiofrequency and cryoballoon ablation, and there are regional heterogeneities of the extent of the distortion. This information might aid operators in performing safe and effective AF ablation procedures.

Key words: Distortion, Cryoballoon, Contact force, Pulmonary vein

Methods

Study population: This study consisted of 1) 10 patients who underwent distortion mapping with CF sensing catheters (SmartTouch; Biosense Webster, Diamond Bar, CA, USA) and a 3D mapping system (CARTO3; Biosense Webster) at the PV antra, left atrial (LA) roof line, mitral isthmus line, cavotricuspid isthmus line, and SVC-right atrial (RA) junction, and 2) 15 patients who underwent distortion mapping with 28-mm second-generation CBs (Arctic Front Advance; Medtronic, Minneapolis, MN, USA) and a 3D-mapping system (EnSite NavX; St. Jude Medical, Minneapolis, MN, USA) at the PV antra. All patients gave their written informed consent. The study protocol was approved by the hospital’s institutional review board. The study complied with the Declaration of Helsinki.

Procedure and distortion mapping: The surface electrocardiogram and bipolar intracardiac electrogrograms were
continuously monitored and stored on a computer-based digital recording system (LabSystem PRO; Bard Electrophysiology, Lowell, MA, USA). The procedure was performed under moderate sedation obtained with dexmedetomidine. A 100 IU/kg body weight of heparin was administered immediately following the venous access, and heparinized saline was additionally infused to maintain the activated clotting time at 300-350 seconds. A single transseptal puncture was performed using an RF needle (Baylis Medical, Montreal, QC, USA) and an 8-Fr long sheath (SL-0; St. Jude Medical).

In the mapping with an RF catheter, we created 3D geometries of the LA and RA with a fast anatomical mapping algorithm using the CARTO3 system and a 20-pole multielectrode mapping catheter arranged with five soft radiating splines (Pentaray; Biosense Webster). Then, point-by-point maps with a low CF (5-10 g) at the PV antra, LA roof, mitral isthmus, cavotricuspid isthmus, and SVC-RA junction were created with a CF catheter. Subsequently, point-by-point maps with a high CF (10-30 g) in the same area were created blindly (without seeing the low CF map). All mappings were performed with a fixed long sheath (SL-0); however, a deflectable long sheath (MobiCath; Biosense Webster) was also used during the mitral isthmus line mapping to obtain a higher CF. The extent of the anatomical deformation between the low and high CF maps was measured to obtain the regional distortion. Anatomical distortion was evaluated by measuring the distance between the low and high CF maps. The distortion of thoracic veins was evaluated in eight segments at PV antra (roof, anterior upper PV, anterior ridge, anterior lower PV, bottom, posterior lower PV, posterior ridge, and posterior upper PV) and SVC (posterior, posteroseptal, septal, antero-septal, anterior, antero-lateral, lateral, and postero-lateral SVC-RA junction). The distortion of linear lesions was evaluated in three segments in the LA roof (right-sided, middle, and left-sided LA roof), mitral isthmus (low, middle, and upper mitral isthmus), and cavotricuspid isthmus (distal, middle, proximal cavotricuspid isthmus) lines.

In the mapping with the CB catheter, the transseptal sheath was exchanged over a guidewire for a 15-Fr steerable sheath (Flexcath Advance; Medtronic). First, we created a 3D geometry of the LA (original map) with a 20-pole circular mapping catheter (Inquiry AFocus II EB catheter; St. Jude Medical) and Ensite NavX mapping system. The multiple electrodes on the CS catheter were defined as the reference. Then, a 20-mm spiral mapping catheter (Inquiry AFocus II EB; St. Jude Medical) and Ensite NavX mapping system were exchanged over a guidewire for a 15-Fr steerable sheath (Flexcath Advance; Medtronic). First, we created a geometry. The CB was inflated and we placed the straight mapping catheter around the inflated CB surface. Then, the CB surrounded by the mapping catheter was advanced to each PV ostium to occlude the vein (Figure 1A, B). The map of the distended PV antrum was obtained by carefully manipulating the mapping catheter around the inflated CB surface. The extent of the myocardial deformation was measured as the distance between the original LA map surface and the distortion map surface. In both RF and CB ablations, the mapping was performed by a single operator (S.M.).

**Statistical analysis:** Continuous data are expressed as the mean ± standard deviation for normally distributed variables and were compared using a Student’s *t*-test (2 variables) or analysis of variance (> 2 variables). A *P* value of < 0.05 was considered statistically significant.

**Results**

**LA distention during PV antrum mapping:** The patient characteristics are summarized in the Table. In the RF catheter mapping, a total of 32.5 ± 5.8 and 36.2 ± 6.1 points per patient were acquired at the PV antra with a mean of 5.2 ± 1.3 and 13.3 ± 3.0 g of CF in the low and high CF maps, respectively (Figure 2A). At the left PV antrum, the high CF map caused a distortion of 1.3 ± 1.7, 3.9 ± 2.1, 3.5 ± 1.7, 3.1 ± 2.1, 2.3 ± 1.7, 1.7 ± 1.3, 1.8 ± 1.0, and 2.2 ± 1.2 mm at the left superior PV (LSPV) roof, anterior LSPV, anterior ridge, anterior left inferior PV (LIPV), RIPV bottom, posterior RIPV, posterior ridge, and posterior LSPV, respectively, as compared to the low CF map (*P* = 0.02). At the right PV antrum, the high CF map caused an extension of 3.4 ± 3.0, 4.6 ± 3.1, 4.6 ± 2.9, 3.3 ± 3.3, 1.4 ± 2.2, 2.0 ± 1.5, 3.1 ± 2.3, and 3.3 ± 2.1 mm at the right superior PV (RSPV) roof, anterior RSPV, anterior ridge, anterior right inferior PV (RIPV), RIPV bottom, posterior RIPV, posterior ridge, and posterior RSPV, respectively, as compared to the low CF map (*P* = 0.04) (Figure 2B). On both sides of the PV antra, the extent of the distortion was significantly greater at the anterior aspect as compared to the posterior aspect (left PVs: *P* = 0.001, right PVs: *P* = 0.03) despite a similar CF between the anterior and posterior aspects.

With the CB catheter mapping, the PV antrum was distended by 7.2 ± 4.2, 6.6 ± 5.0, 4.5 ± 4.1, and 6.4 ± 4.8 mm from the original LA geometry in the posteroseptal, posterior, posteroseptal, and posterior direction when the CB occluded the LSPV, LIPV, RSPV, and RIPV, respectively (*P* = 0.42) (Figure 1C).

**Atrial distention during linear ablation:** On the right-sided, middle, and left-sided LA roof, a mean CF of 10.3 ± 7.0, 10.1 ± 7.1, and 12.0 ± 7.6 g with the low CF mapping, and 20.7 ± 8.5, 22.2 ± 9.6, and 23.0 ± 10.7 g with high CF mapping, were acquired, respectively. The extent of the anatomical distortion in the high CF map as compared to the low CF map was 3.6 ± 1.6, 3.9 ± 2.3, and 3.4 ± 1.6 mm in the posteroseptal-anterior direction at right-sided, middle, and left-sided LA roof, respectively (*P* = 0.87) (Figure 3A).

At the low (close to the mitral annulus), middle, and upper (close to the left PVs) mitral isthmus, a mean of 7.6 ± 2.5, 7.0 ± 2.2, and 8.4 ± 4.4 g with the low CF mapping, 11.8 ± 3.5, 12.8 ± 3.6, and 15.3 ± 4.4 g with the high CF mapping, and 19.2 ± 5.2, 17.8 ± 2.7, and 18.2 ± 3.7 g with the high CF mapping with a deflectable sheath were obtained, respectively. No anatomical distortion with the high CF map as compared to the low CF map was observed (Figure 3A-C).

At the cavotricuspid isthmus line, a total of 9.1 ± 2.3 and 14.5 ± 3.3 points per patient were acquired with 4.9
Image 1. The CB surrounded by the mapping catheter (red arrows) was advanced to the LSPV (A) and RSPV (B) to create distortion maps during the vein occlusion. The original LA geometry (gray) and distortion maps of each PV (red, green, yellow, blue) during the CB procedure are shown (C). A representative image of the different CF maps at the SVC-RA junction is shown. The pink and blue tags indicate the high and low CF maps (D). The extent of the distortion in the high CF map as compared to the low CF map at each segment of the SVC-RA junction is shown as a bar graph and red circle (E). Ant indicates anterior; AP, antero-posterior; CF, contact force; LA, left atrium; Lat, lateral; LI (S) PV, left inferior (superior) PV; PA, postero-anterior; Post, posterior; RI (S) PV, right inferior (superior) PV; Sep, septum; and SVC, superior vena cava.

Table. Patient Characteristics

|        | CB group | RF group |
|--------|----------|----------|
| n      | 15       | 10       |
| Age, years | 59.4 ± 11.6 | 62.0 ± 10.5 |
| Paroxysmal AF, n (%) | 14 (93.3%) | 7 (70.0%) |
| Female, n (%) | 3 (20.0%) | 2 (20.0%) |
| Hypertension, n (%) | 7 (46.6%) | 4 (40.0%) |
| Body mass index, kg/m² | 24.6 ± 3.7 | 23.4 ± 1.7 |
| LA diameter, mm | 37.0 ± 3.3 | 38.1 ± 6.2 |
| LV ejection fraction, % | 65.8 ± 6.0 | 66.2 ± 5.4 |

AF indicates atrial fibrillation; CB, cryoballoon; LA, left atrial; LV, left ventricular; and RF, radiofrequency.

± 2.5 and 18.5 ± 4.2 g of CF in the low and high CF maps, respectively. The extent of the anatomical distortion in the high CF map as compared to the low CF map was 4.3 ± 1.8, 10.5 ± 4.2, and 8.2 ± 2.8 mm in the inferior direction at the distal (close to tricuspid annulus), middle, and proximal (close to inferior vena cava) cavitricuspid isthmus, respectively (P = 0.0005) (Figure 3D-F). At the majority of the points, the ablation catheter needed to be placed perpendicularly to the isthmus to obtain a high CF (Figure 3E, F). The magnitude of the anatomical distortion significantly differed between the LA roof, mitral isthmus, and cavitricuspid isthmus (P < 0.0001).

RA distention during the SVC isolation: At the SVC-RA junction, a total of 12.5 ± 4.4 and 15.0 ± 2.9 points per patient were acquired with 6.5 ± 1.5 and 20.8 ± 4.7 g of CF in the low and high CF maps, respectively. The extent of the anatomical distortion in the high CF map as compared to the low CF map was 3.9 ± 1.4, 3.2 ± 0.8, 1.5 ± 1.7, 1.2 ± 1.6, 3.2 ± 2.0, 4.9 ± 2.2, 2.6 ± 1.3, and 4.7 ± 2.5 mm at the posterior, postero-septal, septal, antero-septal, anterior, antero-lateral, lateral, posterolateral SVC-RA junction regions, respectively (P < 0.0001) (Figure 1D, E).

Discussion

The present study characterized the regional anatomical distortion in common ablation areas in response to the different CFs using RF catheters and the anatomical distortion using 28-mm CB catheters.
LA distention during PV antrum mapping with an RF catheter: A previous study elegantly showed that catheter manipulation distorted the LA tissue surface during PV isolation. However, the extent of the myocardial deformation in response to the varying CF has not been well studied. The present study clarified that 1) a high CF map distorted the geometry of the PV antrum as compared to a low CF map, 2) the extent of the anatomic distortion was greater at the anterior aspect of the PVs than at the posterior aspect of the PVs with regional heterogeneity, and 3) the catheter in the high CF map was located more inside the PVs as compared to that in the low CF map on the anterior side of the left PVs. The regional heterogeneity of the anatomic distortion may variably be modified by the underlying non-cardiac tissue and inhomogeneous elastic properties of the atrial myocardium. Since increasing the CF will increase the area of the contact footprint of the electrode on the myocardial tissue by embedding it deeper within the soft myocardium, the lesion size created should differ at sites with different distensibilities despite a constant power. This information is important when predicting the lesion size created. Also, excessively stretched atrial tissue might lead to tissue penetration. It is not surprising that the catheter location was more inside the PVs when a high CF was obtained because a stable high CF cannot be obtained at the edge of the anterior aspect of the left PVs during a patient’s respirations. A stable high CF can be obtained by slightly advancing the catheter inside the PV. This suggests that a high CF ablation potentially has a higher risk of PV stenosis than a low CF ablation.

LA distention during CB ablation: An adequate CB occlusion with good balloon-tissue surface contact is essential for a successful PV isolation. A higher CF leads to a wider balloon-tissue area contact, which results in a larger and deeper lesion formation. Theoretically, concentric PV distention is achieved when the CB is positioned coaxially to the target vein. However, this is challenging in the majority of the PVs. The present study showed a regional heterogeneity in the anatomical distortion of each PV. The inflated balloon stretched the PV surface in the postero-superior direction in the upper PVs, and in the posterior direction in the lower PVs. This indicated that pushing the CB for the upper and lower PVs for vein occlusion likely resulted in creating a larger lesion at the postero-superior and posterior PV antra, respectively. This could be explained by the direction from the transseptal hole to each PV. The operator needs to manipulate the CB with the Flexcath sheath to minimize this regional heterogeneity and to create a circumferential lesion at the PV antra.

Atrial distention during linear ablation: In LA roof line mapping, a high CF could be easily obtained and distort the LA in the postero-inferior direction as compared to a low CF map. The extent of the distortion was similar at the right-sided, middle, and left-sided LA roof line. On the contrary, with the mitral isthmus line mapping, a high
Figure 3. Representative images of the different CF maps at the LA roof line, mitral isthmus line (A), and cavotricuspid isthmus line (D) are shown. The pink, blue, and yellow tags indicate the high CF map, low CF map, and high CF map with a deflectable sheath. A higher CF was obtained when using a deflectable sheath (C, yellow arrow) as compared to a fixed sheath (B, yellow arrow) during the mitral isthmus line mapping. Please note that the catheter was placed perpendicularly to the cavotricuspid isthmus to obtain a high CF (D-F, yellow arrows). AP indicates antero-posterior; CF, contact force; CTI, cavotricuspid isthmus; L (R) AO, left (right) anterior oblique; and MI, mitral isthmus.

CF did not yield a significant anatomic distortion. Moreover, it was challenging to obtain a high CF with an SL-0 sheath (non-deflectable sheath), and a deflectable sheath enabled a higher CF, especially at the low mitral isthmus (close to mitral annulus). In cavotricuspid isthmus line mapping, a high CF distorted the isthmus in the inferior direction. However, in the vast majority of the cases, the catheter needed to be placed perpendicularly to the isthmus to obtain a high CF. That was presumably due to the pouch of the isthmus and Eustachian ridge at the proximal isthmus.

RA distention during SVC mapping: The present study showed that a high CF distended the SVC-RA junction as compared to a low CF, and that there was a significant regional heterogeneity in the extent of the distortion. The extent was greatest at the lateral SVC-RA junction, and smallest at the antero-septal SVC-RA junction. This could be explained by the underlying structures, which was the ascending aorta located close to the antero-septal SVC-RA junction.

Study limitations: This study was a relatively small and single center study. The CF cannot be measured by the current CB system. However, mapping was performed along with the standard CB procedure as much as possible. The study population consisted of patients with paroxysmal and short-lasting persistent AF, and therefore, the LA size was relatively small. Reproducibility is one of the limitations of this study due to the difficulty to create completely identical geometry twice and because the data was acquired by a single investigator. Further study is required to clarify the anatomical distortion in patients with LA remodeling, and to show whether this information would improve the clinical outcome after catheter ablation of AF.

Conclusions

Human atria significantly distend during RF and CB ablation, and there is a regional heterogeneity in the extent of the distortion. This information might aid operators in performing safe and effective AF ablation procedures.

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Disclosure

Conflicts of interest: Dr. Miyazaki has received consulting fees and speaker honoraria from Medtronic, and belongs to the endowed departments of Medtronic, Boston, Abbott, and Japan Lifeline. There are no other conflicts of interest.

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