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ORIGINAL ARTICLE

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Fast anatomical mapping of the carina and its implications for acute pulmonary vein isolation

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Abstract

Background: Fast anatomical mapping (FAM) of the left atrium and pulmonary veins (PV) during PV isolation (PVI) generates anatomical information about the carina region additionally. We aimed to investigate the utility of these data in relation to conduction abilities of the intervenous carina.

Methods: We investigated 71 patients with drug-refractory atrial fibrillation (AF) who underwent first-time circumferential PVI using an electroanatomical mapping system. Carina width between ipsilateral PV was measured using FAM and an integrated distance measurement tool. Encirclings were divided into carina ablation and noncarina ablation groups based on the necessity of carina ablation to achieve PVI.

Results: In total, 142 encirclings were analyzed and first-pass isolation was observed in 102 (72%) encirclings. Nonfirst-pass PVI solely due to a gap on the line or persistent carina conduction was observed in 10 (7%) and 30 (21%) encirclings, respectively. Encirclings were classified into a carina ablation group (n = 30, 21%) and noncarina ablation group (n = 112, 79%). Carina width was significantly larger in the carina ablation vs nonarina ablation group (right: 11.9 ± 1.5 mm vs 8 ± 1.4 mm, $P < .001$/left: 12.1 ± 1.3 mm vs 8.1 ± 1.1 mm, $P < .001$) requiring additional carina ablation.

Conclusion: Carina-related PV conduction is a common finding after the first-pass ablation during PVI. Measurement of carina width using FAM is feasible and its value correlates with the necessity of carina ablation to achieve PVI.

KEYWORDS

atrial fibrillation, carina conduction, catheter ablation, pulmonary vein isolation

1 | INTRODUCTION

Pulmonary vein isolation (PVI) has been established as a standard procedure in treatment of drug-refractory atrial fibrillation (AF).[1-4] Among different ablation techniques and tools, using irrigated single-tip ablation catheters and a three-dimensional (3D) mapping system, represents still the most frequent ablation approach.[5] After various technological advancements have been introduced over the years, rates of the first-pass PVI have improved substantially.[6] Several studies have hinted toward a role of the intervenous carina for persistent conduction between pulmonary veins (PV) and the left atrium (LA) due to an epicardial connection between the carina region and both

atria.[7-9] Therefore data referring to electrical and anatomical characteristics of the carina region have been published recently.[10-11] In our present study, we observed frequency and distribution of carina-related PV conduction after encircling of ipsilateral PVs during PVI. Furthermore, we hypothesized that carina width can be measured utilizing a fast anatomical mapping (FAM) of the LA and its conjunctive PV, which is generated routinely during PVI. Finally, we correlated values of carina width to the necessity of additional carina ablation to achieve PVI.

2 | METHODS

2.1 | Study population

Study data were drawn retrospectively from a cohort of 71 consecutive patients with drug-refractory AF who underwent their first-pass PVI between January 2020 and November 2020 at our institution. Catheter ablation was performed by a single experienced operator (DS). All patients provided informed consent for the ablation procedure, and the local institutional review board approved data collection management.

2.2 | Catheter ablation

Ablation procedures were performed under deep sedation with intravenous application of midazolam and propofol in a fasting state. Direct oral anticoagulation was withheld only for the morning of catheter ablation. Continuous and noninvasive monitoring of blood pressure and oxygen saturation was ensured. After femoral access, multielectrode diagnostic catheters were placed in the apex of the right ventricle and coronary sinus. Double transseptal puncture was performed by using fixed and long sheaths (LAMP45; Abbott) and a transseptal needle (BRK; Abbott) and guided by fluoroscopy and contrast without atrial pressure measurement or ultrasound guidance. Afterward a bolus of heparin was administered to achieve an activated clotting time of >300 seconds. Both sheaths were flushed with heparinized saline continuously. A circular mapping catheter (Lasso Nav; BiosenseWebster) and an irrigated ablation catheter (Thermocool ST; BiosenseWebster) were placed in the LA. FAM of the LA and conjunctive PVs was created by using a 3D mapping system (CARTO3; BiosenseWebster) using a resolution setting of 12. Mapping points were collected by the circular mapping catheter utilizing an automatic annotation system (Confidense Mapping©; BiosenseWebster). Antral encircling of ipsilateral PVs was performed by ablation in a power-controlled mode using 25 W at the posterior and 30 W at the anterior wall. Targeted ablation index (AI) was >400 at the posterior and >500 at the anterior wall. Ablation lesions were exclusively tagged by an automated tagging system (VisiTag©; BiosenseWebster) using a tag size of 3 mm, a stability maximum range of 2-3 mm, a stability minimum time of 8-10 seconds, and force overtime set at 30%-50%. Between ablation points, no interlesion distances of >6 mm were allowed. A contact force of 10-20 g was targeted at any ablation point and no dragging of the ablation catheter was allowed. After a single and continuous encircling of ipsilateral veins, PV isolation was assessed by placing the circular mapping catheter at the ostia of the superior and inferior PVs, respectively, thus allowing to verify a bidirectional block. In case of nonisolation, the complete ablation line was mapped with the ablation catheter carefully to localize an electrical gap on the encircling lesion. A detected gap on the line was closed by additional ablation. If the intervenous carina appeared to be the site of residual conduction, a continuous lesion on the carina was performed using 25 W and target AI of 350-400, and carina isolation was verified by loss of LA capture while pacing from the carina and disappearance of all carina potentials recorded from the mapping catheter. After a waiting time of 30 min, persistent isolation of PVs and carina was confirmed without adenosine administration. In case of acute reconnection, additional ablation was performed until complete isolation could be achieved. In patients with persistent AF, additional LA ablation for substrate modification (roofline, posterior box lesion, anterior mitral line) was performed at the discretion of the operator. The study and ablation protocol is depicted in Figure 1.

2.3 | Carina width measurement

Analysis of the anatomical mapping was performed offline and blinded to clinical parameters by a single investigator (DS). Carina width was assessed by measuring the shortest distance between ipsilateral superior and inferior PV ostia on the outside of the mapping shell. Using a sagittal clipping, plane intervenous carina width was also determined from the inside of the LA shell defining PV ostia as the point of maximum inflection between the PV and LA wall (Figure 2). A common PV ostium was defined as a merging of the superior and inferior PV ostia before entering the LA. Average carina width was calculated by averaging three different measurements.

Since no follow-up data can be provided, information about follow-up settings have been removed.

2.4 | Statistical analysis

Statistical analysis was performed using an online-based statistic software (Datatab). Continuous variables were reported as mean ± SD or as median where a normal distribution could not be assumed. Categorical variables were expressed as number and percentage. Differences between groups were tested using unpaired Student's *t* test, Mann-Whitney *U* test, χ^2 analysis, or Fisher test as appropriate. Statistical significance was considered when the two-sided *P*-value was <.05.

3 | RESULTS

3.1 | Baseline characteristics

A total of 71 patients (41 male, age 63 ± 9 years) and 142 encirclings were included for analysis. Paroxysmal AF was present in 51 (72%)

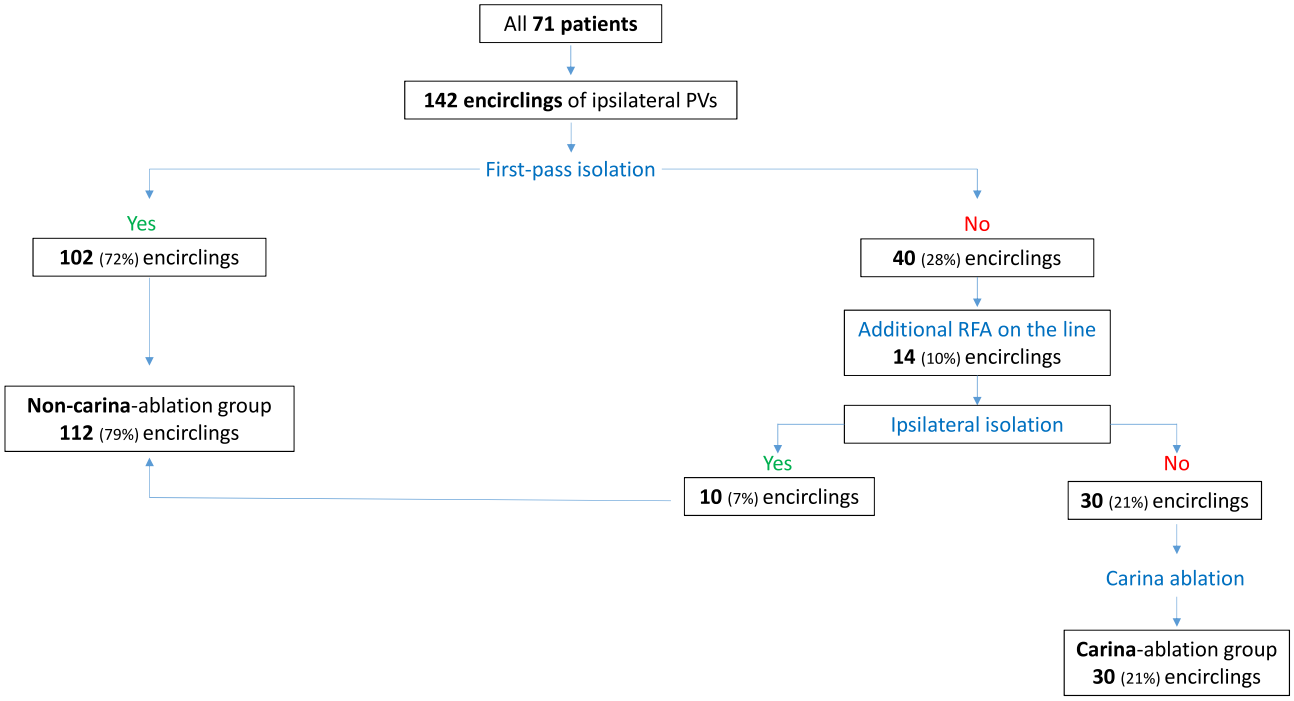

FIGURE 1 Study and ablation protocol. PV, pulmonary vein; RFA, radiofrequency ablation

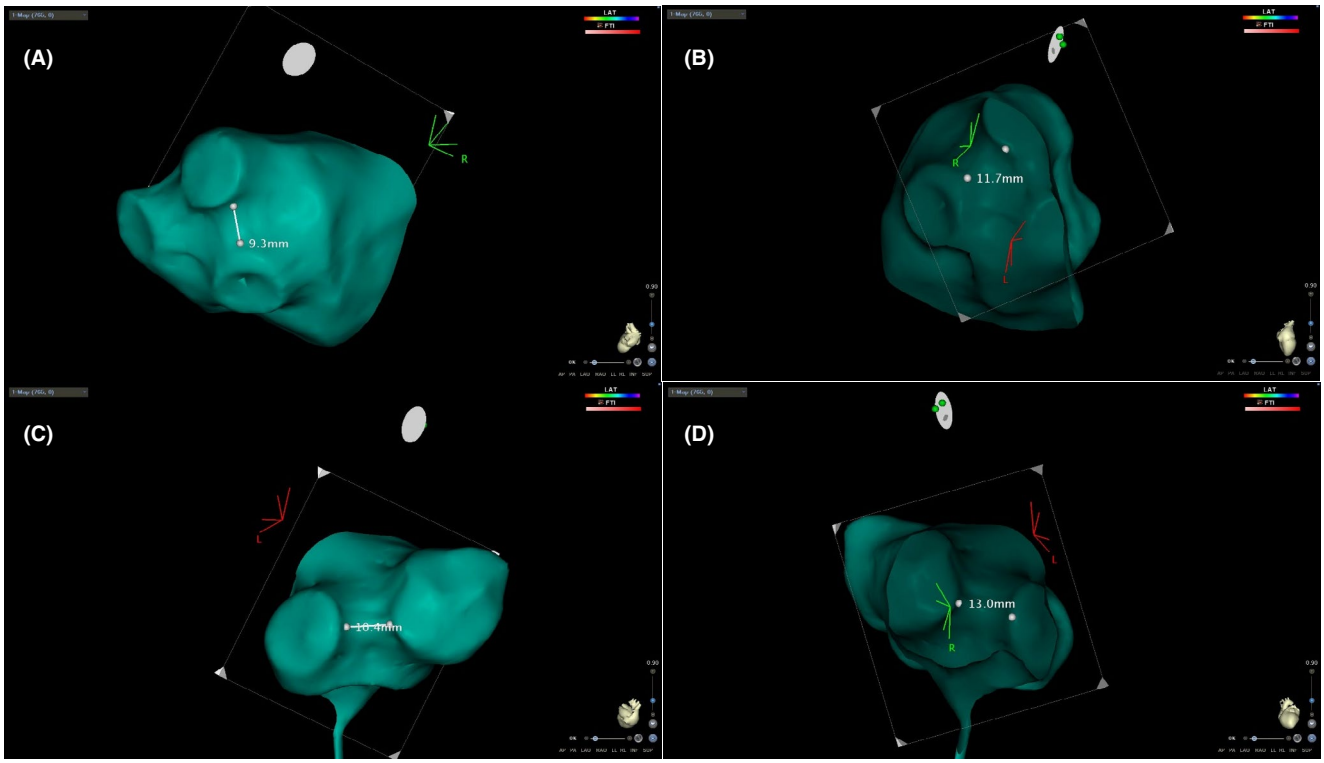

FIGURE 2 Left-sided carina width measurement on the outside (A) and inside (B) of the FAM. The same measurement of the right-sided carina from outside (C) and inside (D) of the shell. FAM, fast anatomical mapping

patients with a mean CHA_2DS_2-VASC score of 1.7 and a body mass index of 26.3 kg/m^2. Comorbidity of hypertension, diabetes, coronary artery disease, and heart failure was present in 32 (45%), 5 (7%), 5 (7%), and 4 (6%) patients. Mean procedure time, defined as time from the first femoral venous puncture to removing all catheters, was 119 ± 22 min and a mean radiofrequency (RF) application time of 38 ± 11 min could be observed. Fluoroscopy time was 6 ± 3 min resulting in a radiation dose of 320 ± 240 μGy × m^2. For FAM of the

LA and PV, 716 ± 115 mapping points were registered and localized in the LA–PV junction area mainly. The baseline characteristics are listed in Table 1.

3.2 | Carina width dimensions

Measurement of the carina width from inside and outside of the anatomical mapping shell showed a significant difference for both sides (right inside 10.8 ± 2.3 mm vs right outside 9.5 ± 2 mm, P <.001; left inside 10.2 ± 2.3 mm vs left outside 9 ± 2 mm, P =.003) observing the inside width being larger (Figure 3). Comparison of the right- and left-sided carina width showed no significant difference (inside right 10.8 ± 2.3 mm vs inside left 10.2 ± 2.3 mm, P =.16; outside right 9.5 ± 2 mm vs outside left 9 ± 2 mm, P =.212). Also, no significant difference of carina width could be found in patients with paroxysmal (Par) and persistent (Pers) AF (right $inside_{Par}$ 10.6 ± 1.7 mm vs right $inside_{Pers}$ 10.9 ± 2.4 mm, P =.61; left $inside_{Par}$ 9.8 ± 2.2 mm vs left $inside_{Pers}$ 10.1 ± 2.3 mm, P =.65).

3.3 | Carina width related to the necessity of carina ablation

Carina width was significantly larger in the carina ablation vs noncarina ablation group. In the case of carina ablation, mean carina width showed to be inside 11.5 ± 1.5 mm and outside 10.2 ± 1.3 mm vs 10.3 ± 2.4 mm (P =.002) and 9 ± 2.1 mm (P <.001), respectively. A comparable correlation could be observed in analyzing the right and left carina separately. In the carina ablation group, right-sided carina width showed to be broader (inside 11.9 ± 1.5 mm vs 8 ± 1.4 mm, P <.001; outside 10.4 ± 1.3 mm vs 7 ± 1.2 mm, P <.001) than in the noncarina ablation group. Same findings could be detected for the left-sided carina (inside 12.1 ± 1.3 mm vs 8.1 ± 1.1 mm, P <.001; outside 10.6 ± 1.2 mm vs 7.3 ± 1.3 mm, P <.001) (Figure 4).

3.4 | Distribution of carina and gap-related conduction after first encircling

In total, 142 ipsilateral encirclings were performed in 71 patients. First-pass isolation could be detected in 102 (72%) encirclings. Fourteen (10%) encirclings showed a remaining gap on the line during remapping, affording additional RF applications. After closing these gaps, 10 (7%) of 14 encirclings resulted in isolation of the ipsilateral PV, whereas in four encirclings, an additional electrical breakthrough originating from the carina could be observed. In 26 (18%) encirclings, no gaps on the line could be observed after the first-pass ablation, demonstrating persistent carina conduction. Thus, in total 30 (21%), encirclings showed the necessity of linear carina ablation resulting in the isolation of adjacent PV in all cases (Figure 1). Distribution analyses showed that remaining carina conduction after first-pass ablation was found more often at right-sided than left-sided encirclings with 22 (15%) vs 8 (6%) (P =.008). Also gaps on the line after first-pass ablation could be detected more often in the right-sided than in the left-sided encirclings with 10 (7%) vs 4 (3%) (P =.02) (Figure 5).

TABLE 1 Baseline, procedural characteristics, and complications

	N = 71
Clinical characteristics	
Age (y)	63 ± 9
Gender, male	41 (57.7%)
Paroxysmal AF	51 (71.8%)
Persistant AF	20 (28.2%)
EHRA IIb	7 (9.8%)
EHRA III	58 (81.7%)
EHRA IV	6 (8.5%)
CHA_2DS_2-VASC 0-1	36 (50.7%)
CHA_2DS_2-VASC 2-3	29 (40.8%)
CHA_2DS_2-VASC >3	6 (8.5%)
Body mass index, kg/m^2	26 ± 4
Hypertension	32 (45%)
Diabetes mellitus	5 (7%)
Sleep apnea	4 (5.6%)
Coronary artery disease	5 (7%)
Left ventricular ejection fraction >55%	67 (94.3%)
Procedural characteristics	
Procedure duration, min	119 ± 22
Fluoroscopy time, min	6 ± 3
Radiation dose, $\mu Gy \times m^2$	320 ± 240
RF time, min	38 ± 11
Fast anatomical mapping points, n	716 ± 315
Complications	
Vascular complication	1 (1.4%)
Pericardial tamponade	0
Phrenic paralysis	0
Transient ischemic attack	0
Stroke	0
Atrioesophageal fistulae	0
Death	0
Overall complication rate	1 (1.4%)

3.5 | Complications

The overall complication rate was 1.7%. One patient suffered from an aneurysma spurium at the puncture site, which developed 3 days after discharge and could be treated conservatively by manual compression (Table 1).

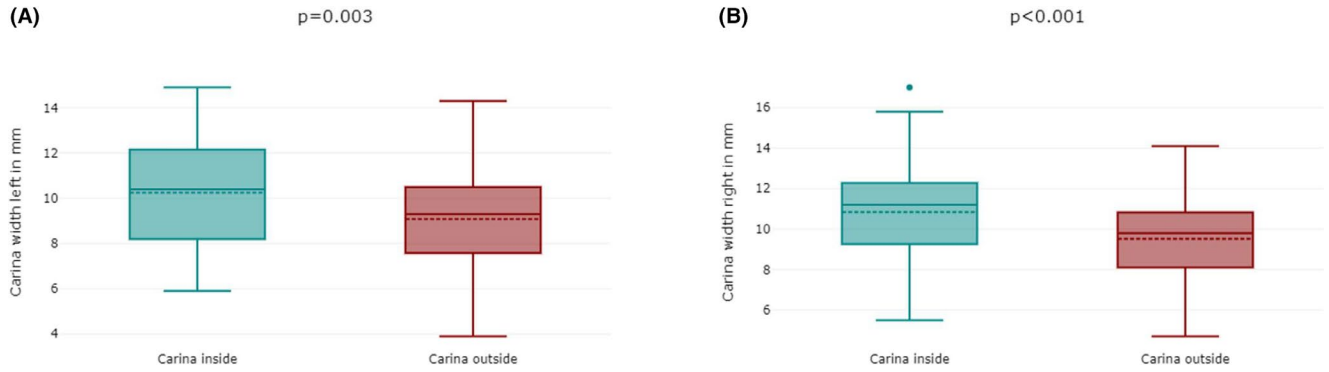

FIGURE 3 Measurement of the carina width from inside and outside of the left (A) and right (B) anatomical shell

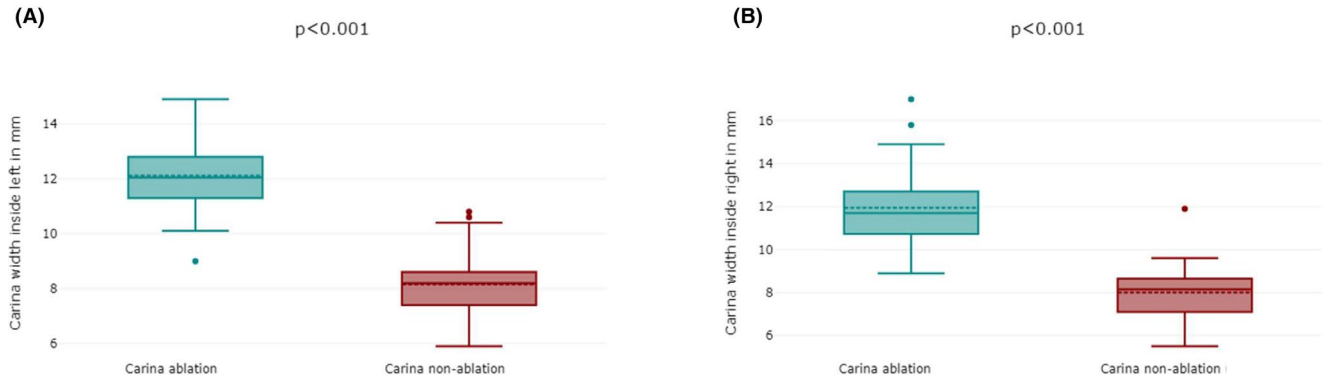

FIGURE 4 Left (A) and right (B) carina width related to carina ablation or non-carina-ablation group showing values for measurement from inside of the anatomical shell

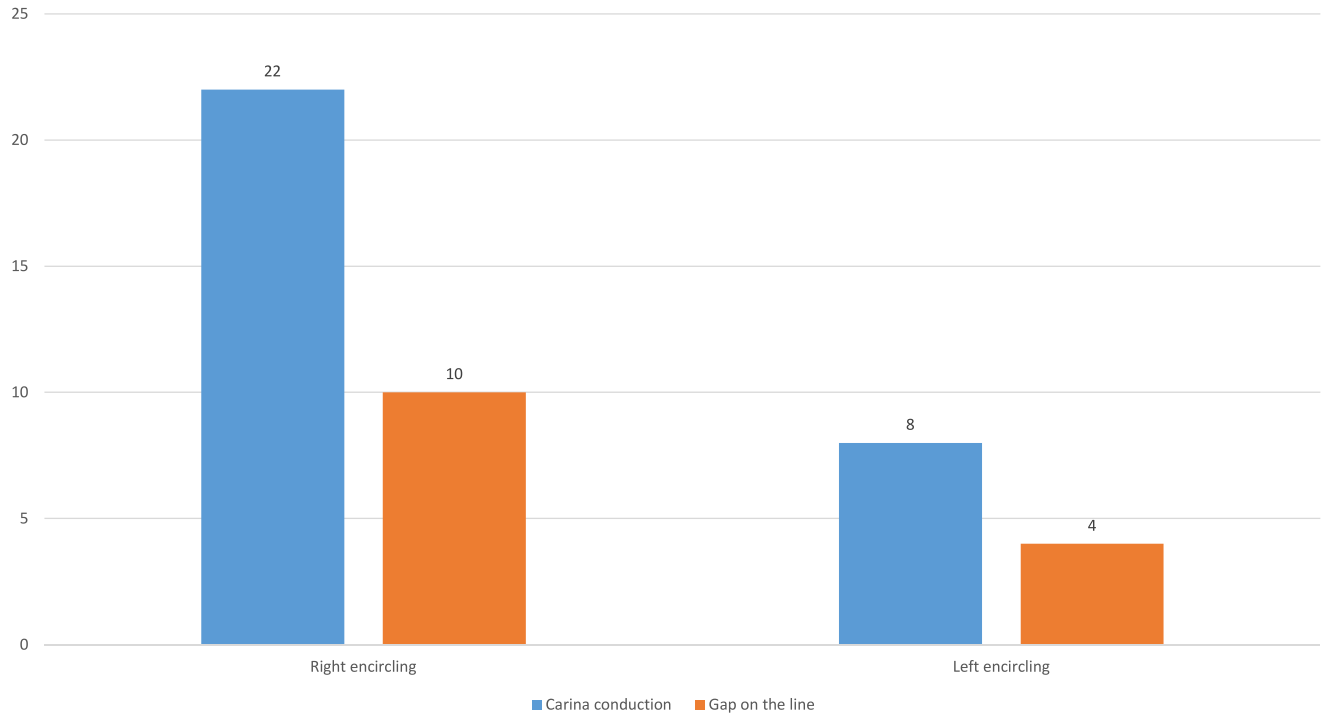

FIGURE 5 Distribution of carina-related and gap-related conduction after single encircling

4 | DISCUSSION

4.1 | Main findings

After AI-guided ipsilateral encircling, providing an interlesion distance of <6 mm, the intervenous carina seems to be the most common site of persistent conduction between PV and LA. Persistent conduction could be detected more often on the right-sided carina. Our data suggest that the necessity for carina ablation is related to a larger carina width, which can be determined by routine anatomical mapping during ablation procedure.

4.2 | Carina-related persistent conduction

The carina has been extensively observed as a potential electrical connection site between LA and PV caused by muscular connections due to crossing myocardial strands and bridges at the interpulmonary isthmus, which can run also toward an epicardial direction and set an epicardial connection of the encircled area to the LA.[12] Therefore Yoshida et al demonstrated that PVI could not be achieved without carina ablation in 20% of treated patients due to epicardial connections between the right-sided carina and right atrium.[13] In accordance with these published data, we also found the carina being a critical breakthrough site in 21% of analyzed encirclings linked to the necessity of carina ablation to achieve PVI. The intervenous carina has to be recognized as a primary site of remaining PV-LA conduction during PVI, whereas gaps on the encircling line have become more uncommon due to improvement of lesion transmurality and contiguity using ablation variables such as AI and interlesion distance. In accordance, we observed a gap on the circumferential ablation line only in 7% of studied encirclings. The incidence of carina-related PV–LA conduction has also been studied in relationship to the distance between the encircling line and the PV ostia. Lin et al[14] showed that a lesion distance <8 mm to the PV ostia resulted in a lower incidence of carina-related conduction and a less common necessity for carina ablation. Furthermore, more ostial ablation circles in a "figure of eight" manner at the PV carina had been demonstrated to be more effective referring to first-pass isolation rates. In conclusion, the intervenous carina has to be considered as a frequent ablation target in PVI.

Interestingly, first-pass isolation rates during PVI seem to differ by location side. We found first-pass isolation in 91% of left-sided and 78% of right-sided PV after single ipsilateral encircling. These results correspond to recently published data by Mulder et al[15] finding a left- and right-sided first-pass isolation rate of 59% and 44%, respectively. Further published data demonstrate first-pass isolation rates between 43% and 98%,[14,16,17] showing a lower rate for the right-sided encircling accordingly. We also observed a critical breakthrough at the right-sided carina in 22 (73%) of 30 encirclings in which carina ablation had to be performed. As we could not provide a difference of right- and left-sided carina width in our study, we support the hypothesis of Yoshida et al[13] that this might be related to increased epicardial connections of the right-sided pulmonary venous carina to the right atrium by small myocardial fibers.[18]

We hypothesized that intervenous carina dimensions can be depicted and measured by using a distance measurement tool integrated into the employed 3D mapping system. We found a correlation between larger carina width and the necessity of carina ablation, which is in line with published data, where carina dimensions have been determined by computer tomography (CT) scans.[15] Although we cannot compare our values of carina width to published CT data directly, due to the lack of own CT scans, it can be presumed that larger carina dimensions are associated with both a higher number and greater variation of myocardial sleeves oriented between the LA and epicardial connection sites.

Increased connection possibilities may well be resulting in more frequent carina conduction as a critical part of PVI. Thus carina width analyses using 3D mapping systems and its routinely provided anatomical mapping data of the LA-PV region can allude to the necessity of additional carina ablation to achieve PVI.

4.3 | Role of carina conduction in other ablation techniques

The role of residual carina conduction after cryothermal PVI has been observed by Tadafumi et al[19] in a group of 96 patients. Although PVI could be achieved in 85 (89%) patients, postablation bipolar voltage mapping showed different ablation patterns with either antral PVI including scarring of the carina region or ostial PVI with residual local signals ≥0.1 mV at the carina region. The rate of 1-year freedom from arrhythmia was significantly different with 84% and 57%, respectively, pointing out the importance of the carina region for clinical success after cryothermal PVI. While the carina region is ablated twice by treating the superior and inferior PV (crosstalk), the remaining electrical LA–PV connection associated with the carina region can be observed less often in ablation techniques using balloon catheters. Recently, Bologna et al[20] published a very low incidence of carina-related electrical gaps after PVI using an endoscopic ablation system, finding only 18 (5%) of 373 patients with a carina-related reconnection site. Interestingly, utilization of high power-short duration (HPSD) energy settings seems to be associated with a higher rate of remaining carina conduction. Klein et al[21] reported different reconnection patterns with HPSD (50 W) and force-time integral guided low-power long duration (LPDL, 25-35 W) strategies. Although both groups showed similar freedom of arrhythmia at 1 year (79% vs 73%; P =.339), a higher propensity for reconnection at the right PV carina was found in the HPSD group compared with the LPLD group (46.7% vs 20.6%). Furthermore, patients undergoing HPSD ablation required more applications at the right carina to achieve PVI and had a significantly higher rate of right carinal reconnections at redo procedures.

4.4 | Limitations

First, this is a single-center and retrospective study with a rather small number of patients. Moreover, values of carina width using

a 3D mapping system were measured by only one observer, thus no data of interobserver variability can be given. Since no CT scans have been performed, validation of measured values in relation to carina width cannot be reported. We intended to illustrate a relationship between carina width size and electrical conduction abilities in a proportioned manner independently from its absolute value. Furthermore, we did not measure the area size of the encirclings, thus a possible relationship between carina conduction and encircling size cannot be evaluated by this study. Since no follow-up data are presented, no clinical effects of carina ablation on clinical outcomes can be provided. The aim of this study was to study the impact of carina conduction on acute PVI during antral ablation. According to published data by Mulder et al carina-related persistent conduction after antral encircling did not impact AF recurrence clinically in contradiction to gap-related persistent conduction.[15]

5 | CONCLUSION

The remaining carina conduction after a single PV encircling is a common finding during PVI. This was observed at the right-sided carina more frequently and required additional carina ablation for PVI. Carina width can be depicted and analyzed from the anatomical mapping provided by the 3D mapping system.

CONFLICT OF INTEREST

The authors declare no conflict of interests for this article.

AUTHOR CONTRIBUTION

Concept/design: Dong-In Shin, Christian Blockhaus; Data analysis / interpretation: Dong-In Shin, Christian Blockhaus, Marc Horlitz; Critical revision of article: Buelent Koektuerk, Hans Peter Waibler, Alexander Bufe, Melchior Seyfarth; Data collection: Dong-In Shin, Stephan List.

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