The challenging right inferior pulmonary vein A systematic approach for successful cryoballoon ablation

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The challenging right inferior pulmonary vein: A systematic approach for successful cryoballoon ablation

Abbreviated title: Right inferior pulmonary vein cryoballoon ablation

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Summary

Background. – Pulmonary vein isolation (PVI) using cryoballoon ablation is widely used for rhythm control in patients with paroxysmal atrial fibrillation. This technique has a steep learning curve, and PVI can be achieved quickly in most patients. However, the right inferior pulmonary vein (RIPV) is often challenging to occlude and isolate.

Aim. – We aimed to analyse the efficacy of RIPV ablation using a systematic approach.

Methods. – Consecutive patients referred for cryoballoon ablation of paroxysmal atrial fibrillation were enrolled prospectively. A systematic approach was used for RIPV cryoablation. The primary endpoint was acute RIPV isolation during initial freeze.

Results. – A total of 214 patients were included. RIPV isolation during initial freeze occurred in 179 patients (82.2%). Real-time PVI could be observed in 72 patients (33.6%), whereas cryoballoon stability required pushing the Achieve™ catheter inside the RIPVs in the remaining patients. The rate of unsuccessful or aborted first freeze as a result of insufficient minimal temperature was significantly higher in patients with real-time pulmonary vein potential recording (16.7% vs 6.3%; $P = 0.031$). To overcome this issue and obtain both stability and real-time PVI, a dedicated “whip technique” was developed. Twelve patients (5.6%) required a redo ablation; only two of these had a reconnected RIPV.

Conclusions. – A systematic approach to RIPV cryoablation can lead to a high rate of first freeze application. Operators should not struggle to visualize pulmonary vein potentials before ablation, as this may decrease cryoapplication efficacy. Thus, stability should be preferred over real-time PVI for RIPV ablation. Both stability and real-time PVI can be obtained using a “whip technique”.

KEYWORDS

Cryoablation;

Atrial fibrillation;

Right inferior pulmonary vein;

Pulmonary vein isolation

Abbreviations: CT, computed tomography; LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; PV, pulmonary vein; PVI, pulmonary vein isolation; PVP, pulmonary vein potential; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein.

Background

Pulmonary vein isolation (PVI) using cryoballoon ablation is a validated treatment for patients with symptomatic atrial fibrillation. Many studies and meta-analyses have demonstrated its efficacy and safety in providing acute and chronic PVI and sinus rhythm maintenance [1-4]. The learning curve for cryoballoon ablation is steeper than for radiofrequency ablation because catheter manipulation and positioning of a “single-shot” device is easier than performing a multipoint ablation [5, 6].

During cryoballoon ablation, however, acute and chronic PVI are dependent on a critical cryoballoon-tissue contact, warranting optimal and homogeneous freezing all around the pulmonary vein (PV) ostia and durable lesions. Reconnection gaps have been described in zones of suboptimal contact, i.e. the anterior segments of the superior PVs and the inferior segments of the inferior PVs [7]. This is particularly true for the right inferior pulmonary vein (RIPV), one of the preferential reconnection sites after cryoballoon ablation of atrial fibrillation [3, 7-9]. Indeed, vicinity of transseptal puncture, difficulty in occluding the ostium and particular PV anatomical considerations are some of the reasons explaining the trouble encountered by electrophysiologists when attempting to obtain RIPV occlusion and isolation [7]. As demonstrated recently, residual PV potentials (PVPs) can be found in up to 20% of RIPVs after cryoballoon ablation [10], demonstrating how challenging this PV can be to isolate.

Thus, in this manuscript, we prospectively investigated the effectiveness of a systematic stepwise approach to positioning the cryoballoon and obtaining acute RIPV isolation. The technique and procedural data are described in detail, and efficacy was analysed after mid-term follow-up.

Methods

Patients and design

Consecutive patients referred to our tertiary centre from 01 January 2015 to 30 June 2017 for cryoballoon ablation of paroxysmal atrial fibrillation were prospectively enrolled. Patients were excluded if RIPV cryoablation was not performed during the procedure because of the occurrence of a complication (e.g. persistent phrenic nerve palsy during right superior PV [RSPV] ablation) or if manifest PVI was proven before freezing application. Also, we do not generally perform cryoballoon ablation of atrial fibrillation for patients with a left common trunk, because the efficacy of ablation in this setting is controversial [11, 12]; consequently, such patients were not included.

This study was approved by the institutional ethics committee, and all patients provided informed consent.

Procedural characteristics

Before the procedure, transoesophageal echocardiography was performed to exclude the presence of a left atrial thrombus. Left atrial computed tomography (CT) was performed before cryoballoon ablation to analyse the PV anatomy. Vitamin K antagonists were continued (international normalized ratio of 2–3) if prescribed, while non-vitamin K antagonist oral anticoagulants were discontinued and replaced by intravenous heparin. Procedures were performed under conscious sedation using midazolam and fentanyl as necessary.

Venous access was obtained via the femoral vein. A 6F Xtrem® quadripolar catheter (Sorin SPA, Milan, Italy) was placed in the coronary sinus via the right femoral vein. A single transseptal puncture was performed under fluoroscopic and pressure guidance, without the use of periprocedural transoesophageal or intracardiac echocardiography. A “single big cryoballoon” approach, using a 28 mm balloon was performed, as described previously [13].

The cryoballoon catheter was introduced into the left atrium through a steerable 12F inner diameter FlexCath® sheath (Medtronic, Minneapolis, MN, USA), constantly flushed with heparinized saline. An Achieve™ mapping catheter (Medtronic) was advanced over the cryoballoon to the PV orifice and positioned inside the PV. The cryoballoon was inflated and advanced to the ostium of each PV. The quality of vascular occlusion was ascertained by the injection of diluted iodinated contrast agent into the PV using semiquantitative grading, as described previously [13, 14], from grade 4 (excellent with full retention of contrast medium) to grade 1 (very poor occlusion leading to rapid leakage from the PV). Ablation duration was dependent on the time-to-PVI (180 or 240 seconds if PVI was documented before or after 30 seconds of freezing, respectively). If the Achieve™ catheter was pushed into the PV to obtain better stability of the cryoballoon, leading to the inability to observe real-time PVI, a 240-second freezing application was performed.

Before ablation of the right-sided PV, the quadripolar catheter was relocated to the superior vena cava to constantly pace the right phrenic nerve at a 1500–2000 ms cycle length and a 10 mA/2 ms output during freezing. Pacing was started 30 seconds after the initiation of freezing, to avoid cryoballoon dislodgment caused by the intense right hemidiaphragmatic contractions. In case of

cessation or weakening of the contraction, freezing was discontinued immediately and the cryoballoon was deflated.

Ablation of the RIPV

A systematic stepwise approach was used for cryoablation of the RIPV (Fig. 1). First, the cryoballoon was retrieved inside the FlexCath® sheath, to allow full torque of the sheath towards the left PVs, while the Achieve™ catheter was pushed slightly outside the sheath to "protect" the atrium from potential harm from the tip of the FlexCath® (Fig. 1A). The sheath was rotated clockwise towards the right PVs (Fig. 1B, Fig. 1C, Movie A.1), and the Achieve™ catheter and cryoballoon were pushed inside the most inferior branch of the RIPV (Fig. 1D), to obtain a "hockey stick" approach [13]. The sheath was then advanced towards the left atrial roof with a slight counterclockwise rotation (Fig. 1E, Movie A.2), to allow balloon inflation outside the RIPV. The sheath was retrieved with a clockwise rotation while the balloon was inflated (Fig. 1F) to occlude the PV antra (Fig. 1G, Movie A.3). Occlusion was then ascertained by injecting diluted iodinated contrast agent (Fig. 1H, Movie A.4).

To obtain both stability and PVP recording, we developed a manoeuvre that we call the "whip technique". The shaft of the Achieve™ catheter is pushed toward the inferior branch of the RIPV, with the lasso deployed back towards the PV ostium. The stability of the cryoballoon is ensured by the shaft of the catheter ("stick of the whip"), while PV recording is warranted by the distal bipoles of the lasso located near the balloon tip ("lash of the whip"). A fluoroscopic image of the manoeuvre is depicted in Fig. 2.

The "pull-down" technique was only used in cases of improper PV occlusion (occlusion grade < 4) caused by a leak of contrast agent in the inferior segment of the RIPV. In those cases, after 60 seconds of freezing, both the sheath and the frozen cryoballoon were slightly pulled down to close the inferior gap, as described previously [13].

As described above, the duration of freezing was dependent on the time to PVI if PVPs were recorded (180 or 240 seconds if PVI was documented before or after 30 seconds of freezing, respectively). If PVPs were not recorded, a 240-second freezing application was performed. In all cases, freezing was stopped prematurely: (1) if the occlusion was considered suboptimal; (2) if the balloon temperature was considered not low enough (typically above –40 °C after 60–90 seconds of freezing) or excessively negative; (3) in the absence of PVI for those cases with real-time PVP

recording; and (4) in case of cessation or weakening of the hemidiaphragmatic contractions attesting the occurrence of a phrenic nerve palsy, as stated above.

A 20-minute waiting period was observed after ablating the RIPV to ensure persistent PVI.

Cardiac CT acquisition and analysis

All patients underwent a cardiac CT scan the day before ablation. Image acquisition was performed on a 64-row multidetector CT scanner (Discovery CT 750 HD, GE Healthcare, Milwaukee, WI, USA) during a single breath hold, without electrocardiogram gating. Typical acquisition parameters were: field of view 20–25 cm; tube voltage 100–120 kV; tube current 350 mAs, with a dose modulation protocol; slice thickness 0.625 mm; and pitch 0.984. Z-axis coverage was limited to cardiac volume, from the carina to the caudal part of the left atrium. A bolus of 60–100 mL of iobiditridol (Xenetix 350, Guerbet, Roissy, France) was injected at 4 mL/s, followed by a 40 mL saline chaser bolus. An automated bolus tracking system was used to synchronize the arrival of the contrast material with the initiation of the scan, with a threshold set at 150 Hounsfield units in the left atrium. Image analysis was performed by two observers in consensus (A. N. and M. L., with 3 and 10 years of experience in cardiac imaging, respectively) using PACS software, version 4.7 (Telemis SA, Louvain-la-Neuve, Belgium). The ostial diameters and spatial orientation of the RIPV were assessed on multiplanar reconstructed slices, as described previously [15]. Briefly, the maximal and minimal RIPV ostial diameters were measured on multiplanar reconstructed slices perpendicular to the RIPV centre line. The angle of the RIPV to the left-to-right axis was measured on axial transverse slices.

Follow-up

All antiarrhythmic drugs were stopped after the procedure. The patients underwent continuous in-hospital electrocardiogram monitoring for 48 hours after the procedure. The first outpatient clinic visit was 4–6 weeks after the procedure. Subsequent follow-up visits consisted of a clinical interview, electrocardiograms and 24-hour Holter monitoring at 3, 6 and 12 months. Recurrence was defined as any atrial arrhythmias lasting longer than 30 seconds, and a 3-month blanking period was applied. Procedural success was defined as freedom from any recurrence without administration of any antiarrhythmic drugs.

Endpoints

The primary endpoint was acute RIPV isolation during the first freezing application. Secondary endpoints were the rates of real-time PVI and RIPV reconnection if a redo procedure was performed.

Statistical analysis

Normally distributed variables are expressed as means ± standard deviations, and were compared using Student's *t* test. Non-normally distributed variables are expressed as medians (interquartile ranges), and were compared using the Mann-Whitney U test. Categorical variables are expressed as counts and percentages, and were compared using the χ^2 test (or Fisher's exact test, when needed). A *P* value < 0.05 was considered statistically significant. The analyses were performed with the SPSS statistical package, version 11.0 (SPSS Inc., Chicago, IL, USA).

Results

Study population

From 01 January 2015 to 30 June 2017, 216 patients had cryoballoon ablation of paroxysmal atrial fibrillation. Two patients were excluded because RIPV ablation was not performed: one had persistent phrenic nerve palsy after RSPV ablation, which resolved after 3 months of follow-up; the other had overt RIPV isolation after RSPV ablation. Therefore, 214 patients were analysed in this study. Clinical characteristics are described in Table 1. Patients were mainly men, the mean age was 59.2 ± 10.5 years and co-morbidities were rare, as reflected by the low CHA_2DS_2-VASc score for the overall population (70.5% of patients with a score of 0 or 1). The left ventricular ejection fraction was 62.0 ± 6.9%, and patients mainly had non- or mildly-dilated atria (median 31.5 mL/m²).

RIPV ablation

Procedural characteristics are described in Table 2. The primary endpoint, RIPV isolation during the initial freeze, occurred in 179 patients (82.2%). The first freeze application was unsuccessful or aborted in 35 patients. Four main reasons led to these first failed attempts (Fig. 3 and Fig. 4): (1) temperature considered insufficient, leading to freezing cessation and repositioning of the cryoballoon

(*n* = 21); (2) loss of phrenic nerve capture because of dislodgment of the pacing catheter, requiring prophylactic immediate freezing interruption and balloon deflation (*n* = 8); (3) complete full freezing application with no PVPs recorded, and detection at the end of the application of a persistent atrio-PV connection (*n* = 5 after 240 seconds of freezing); and (4) temperature considered too negative and potentially harmful (*n* = 1; –61 °C after 107 seconds, and PVI not obtained despite this temperature).

A pull-down manoeuvre was only performed in those patients with imperfect PV occlusion as a result of stability issues (*n* = 17, 7.9%). At the end of these procedures, 100% of RIPVs were successfully ablated using the cryoballoon, and no focal cryothermal energy catheters needed to be used to obtain PVI.

Visualization of PVPs

Real-time PVI could be observed in 72 patients (33.6%), whereas cryoballoon stability required pushing the Achieve™ catheter inside the RIPV in the remaining 142 patients (66.4%). First-freeze PVI occurred in 77.8% of patients with real-time recording of PVPs during the initial freeze, whereas 86.6% of those with no PVPs recorded had a first efficient cryoapplication (*P* = 0.145). However, the proportion of aborted first freezes because of insufficient minimal temperature was significantly higher in patients with real-time recording of PVPs (16.7% vs 6.3%; *P* = 0.031).

If present, a median of 4.0 (3.0–6.0) PVPs per patient were observed. To overcome this issue, the dedicated manoeuvre called the “whip” technique (Fig. 2) was developed to allow PVP recording and cryoballoon stability.

A sensitivity analysis performed over the 3-year inclusion period did not show any learning curve effect on the rate of first-freeze PVI or PVP recording (*P* = 0.076 and *P* = 0.211, respectively).

Impact of RIPV anatomy on ablation outcomes

As shown in Table 3, left atrial volume index and RIPV ostial size were similar for patients reaching or not reaching the primary endpoint. However, RIPV posterior angulation analysed from the CT scan axial view was significantly higher for patients with a successful first freeze application (29.1 ± 12.4 vs 22.5 ± 16.1; *P* = 0.017). Examples of CT scans from patients with successful and unsuccessful first freeze applications are depicted in Fig. 5A/B and Fig. 5C/D, respectively.

Cryoablation of the other PVs

For the left superior PV (LSPV), left inferior PV (LIPV) and right superior PV (RSPV), PVPs could be recorded in 203 (94.9%), 182 (85.0%) and 182 (85.0%) patients, respectively, allowing the assessment of real-time PVI – significantly more than the 36.0% described previously for the RIPV ($P < 0.001$). However, the rate of successful first cryoapplication was not significantly different among PVs, as it occurred in 193 LSPVs (90.2%), 192 LIPVs (89.7%) and 187 RSPVs (87.4%), whereas the rate was 82.2% for RIPVs, as stated previously ($P = 0.103$).

Complications

Among the patients included, 23 patients (10.7%) had transient phrenic nerve palsy, including 18 during RSPV ablation and four during RIPV ablation, while one patient had reversible phrenic nerve palsy during both RSPV and RIPV cryoablations. Phrenic nerve palsy during RIPV ablation occurred at –47.3 ± 3.3 °C and after 179.0 ± 42.7 seconds of freezing, once PVI had occurred, in all four cases. All phrenic nerve palsies were transient, and resolved during the procedure after 1, 2, 14 and 18 minutes. None of the 214 patients analysed had persistent phrenic nerve palsy after cryoablation of the RIPV.

Follow-up

After 10.6 ± 6.0 months of follow-up, 14 patients had symptomatic recurrences of atrial fibrillation; 12 of these patients had a redo procedure. Reconnection gaps were predominantly localized in the RSPVs. Only two patients had a reconnected RIPV: in the posteroinferior segment for the first case; and in the posterior and the inferior segments for the second case. During the initial cryoablation, the first freeze was interrupted for both patients because of insufficient minimal temperature (at 90 seconds, temperature –32°C and five PVPs observed for the first case; and at 60 seconds, temperature –32 °C and four PVPs observed for the second case), and the RIPV was ablated at the third cryoapplication.

During the redo procedure, all conduction gaps were eventually ablated, resulting in complete PVI.

Discussion

Main results

The major findings of this study are that: (1) a systematic approach to RIPV ablation results in a high rate of PVI with a single freezing application; (2) PVP recording is possible in one third of patients because of stability issues, but is associated with more interrupted applications as a result of insufficient temperature drop; (3) a dedicated “whip technique” can be used to obtain both stability and PVP recording to assess real-time PVI; and (4) durable PVI was proven in most patients who required a redo ablation, during mid-term follow-up.

Technical challenges during cryoballoon ablation

Cryoballoon ablation has demonstrated its efficacy and safety in providing acute [4] and chronic [2, 3] PVI and sinus rhythm maintenance, with a rate of freedom from any atrial tachyarrhythmias of 78.1% after 12 months of follow-up [16]. Still, there is a non-negligible rate of recurrences, mainly explained by PV reconnections, subsequent to part of the atria being incompletely ablated, allowing PV ectopic beats to invade the left atrium and initiate atrial fibrillation. After second-generation cryoballoon ablation, the rate of durable PVI has been shown to range from 66.0% to 91.0% [2, 3, 7-9, 17, 18]. The most reconnected PVs have been identified as the RSPV [2], the RIPV [3, 7-9] or both right PVs equally [17]. The vicinity of the transseptal puncture and perturbations induced by phrenic nerve pacing may hamper optimal positioning of the cryoballoon in the PV ostia, causing inadequate balloon-tissue contact, PV reconnection and, eventually, atrial fibrillation recurrence [7]. This is particularly true for the RIPV, which is considered to be one of the most difficult PVs to isolate when using cryoballoon ablation [10, 14]. Chun et al. described three approaches to obtaining RIPV occlusion before freezing application: (1) the “direct approach”, with direct alignment of cryoballoon and PV ostia; (2) the “hockey stick technique”, used in patients with an early branching inferior PV; and (3) the “big loop technique”, when neither of the previous techniques is feasible [13].

Contact between the cryoballoon and the PV ostium remains the main issue for RIPV ablation, particularly in its inferior segment, where reconnection gaps are usually localized, as observed during redo procedures [7, 19]. The “pull-down” technique has been described to overcome this difficulty. The

cryoballoon is placed in contact with the superior aspect of the RIPV ostia, and freezing is started regardless of a remaining inferior leakage [13]. Once the cryoballoon is considered to be frozen and attached to the superior PV edge, a pull-down movement is performed to close the inferior gap and create a circumferential lesion. However, it remains controversial whether the resulting lesion would be similar and long-lasting if ice formation develops directly inside antral tissue, when perfect contact is obtained, or if a previously frozen cryoballoon is advanced towards the tissue and ice placed in contact with the PV secondarily. Thus, in this study, a “pull-down” technique was only performed for those patients with suboptimal RIPV occlusion (8.1%), and a “hockey stick technique” was always preferred and attempted first.

Efficacy of a systematic approach to RIPV ablation

Using a stepwise approach to cryoballoon positioning, the rate of first-freeze RIPV isolation was 82.2%, roughly similar to the 87.4–90.2% observed for the other PVs. However, real-time PVI could be observed in only one third of RIPVs, whereas it was observed in most LSPVs, LIPVs and RSPVs. Visualization of PVPs decreased cryoapplication efficacy, as we showed that the proportion of aborted first freezes because of insufficient minimal temperature was significantly higher in those patients with real-time recording of PVPs. Indeed, a common thought, often observed in clinical practice, is that desperately struggling to obtain PVPs may destabilize and dislodge the cryoballoon. Thus, stability may be preferred over real-time PVI. Furthermore, we describe here a specific positioning of the Achieve™ catheter, aiming to obtain both stability and PVP recording, which we have called the “whip technique”: the shaft of the Achieve™ catheter represents the “whip stick”, pushed far towards RIPV branching and ensuring stability, and the lasso represents the “whip lash”, coming back towards the PV ostium to record PVPs on the distal electrodes.

Anatomical considerations

To date, few studies have analysed the impact of PV anatomy on cryoballoon ablation efficacy. Controversial results about the efficacy of cryoballoon ablation for patients with left common trunks were published recently [12, 20, 21], whereas its efficacy on other atypical PV anatomies has not been reported thus far. Additionally, some PV characteristics have been described to influence PV occlusion

and/or freezing efficacy, such as ovality index [22, 23] or orientation of PV ostia [23]. Indeed, a relationship between the PV coronal angle and the degree of occlusion was described by Sorgente et al. [23]. Regarding the RIPV, better occlusions were observed for more horizontal veins, while those with more inferior angles tended to be more difficult to occlude [23]. Conversely, we aim to target the more inferior branch of the RIPV, to obtain a “hockey stick” configuration, guaranteeing optimal occlusion and contact with the PV ostia. It is worth noting that a more posterior axial angle was observed for PVs with a first efficient freeze, probably explained by a larger distance and, thus, an easier approach from the transseptal puncture.

Study limitations

We acknowledge some limitations in our study. First, it was a single-centre study, and the efficacy of the stepwise technique described to obtain RIPV occlusion and cryoballoon isolation should be validated in larger studies.

The persistence of PVI could only be assessed in patients with recurrences of arrhythmias referred for a redo ablation, and one may argue that it could differ in asymptomatic or symptomatic patients not referred for a second procedure. However, it was recently demonstrated that the incidence and characteristics of PV reconnections were similar, regardless of clinical recurrences [9].

Of note, the incremental benefit added by the “whip technique” was not specifically tested in this study, and will require further dedicated studies.

Conclusions

A systematic approach to RIPV cryoablation can lead to a high rate of first freeze application. Our results suggest that operators should probably not struggle to visualize PVPs before ablation, especially when stability is compromised, as it may decrease the efficacy of cryoapplication. Thus, one should prefer stability over real-time PVI for RIPV ablation. The dedicated “whip technique” described in this study can be used to obtain both stability and real-time PVI.

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Disclosure of interest

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Figure legends

Figure 1. Systematic approach to right inferior pulmonary vein ablation; see text for details. CCW: counterclockwise; CW; clockwise.

Figure 2. The "whip" technique for right inferior pulmonary vein (RIPV) isolation. A, B. The shaft of the Achieve™ catheter is pushed toward the inferior branch of the RIPV with the lasso deployed back towards the pulmonary vein (PV) ostium (panels A and B, with and without injection of diluted contrast agent, respectively). A, C. The stability of the cryoballoon is ensured by the shaft of the catheter ("stick of the whip"), while PV recording is warranted by the distal bipoles (Lasso 1–2 and Lasso 2–3, panels A and C, arrows) of the lasso located near the balloon tip ("lash of the whip"). C. Real-time PV isolation (indicated by crosses) can be observed; arrows indicate PVPs.

Figure 3. Flowchart of study population and outcomes of right inferior pulmonary vein (RIPV) ablation. PN: phrenic nerve; PVI: pulmonary vein isolation; PVP: pulmonary vein potentials; RSPV: right superior pulmonary vein.

Figure 4. Minimal temperature and freezing duration of the 214 first freeze applications. Successful first freeze applications are depicted in black (180- or 240-second applications) and red (interrupted prematurely because of the occurrence of phrenic nerve [PN] palsy). Unsuccessful first freeze applications are represented in green (premature interruption of freezing because of suboptimal temperature and no pulmonary vein isolation [PVI] observed), yellow (dislodgement of the PN pacing catheter requiring freezing interruption and balloon deflation), blue (full freezing application performed without visualization of any pulmonary vein potentials, and persistence of pulmonary vein potentials after mapping the pulmonary vein ostia) and purple (minimal temperature considered as harmful, leading to freezing interruption).

Figure 5. A–D. Axial angulation of the right inferior pulmonary vein in two patients with unsuccessful (panels A and B) and successful (panels C and D) first freeze applications.

Table 1 Patient characteristics at baseline (n = 214).

Age (years)	59.2 ± 10.5
Men	157 (73.4)
Hypertension	58 (27.1)
Diabetes mellitus	7 (3.3)
Current smoker	13 (6.1)
Dyslipidaemia	33 (15.4)
History of stroke	17 (7.9)
Body mass index (kg/m²)	26.5 ± 4.7
CHA_2DS_2-VASc score	
0	95 (44.4)
1	56 (26.1)
2	40 (18.7)
3	16 (7.5)
4	4 (1.9)
5	3 (1.4)
6–9	0 (0)
Episode duration	
< 12 hours	135 (63.1)
12–24 hours	34 (15.9)
24–48 hours	24 (11.2)
> 48 hours	21 (9.8)
Number of antiarrhythmic drugs tested before ablation	1.9 ± 1.0
Left ventricular ejection fraction (%)	62.0 ± 6.9
Left atrial volume index (mL/m²)	32.1 (25.1–38.9)

Data are expressed as number (%) for categorical variables, mean ± standard deviation for normally distributed variables and median (interquartile range) for non-normally distributed variables. CHA_2DS_2-VASc: Congestive heart failure, Hypertension, Age ≥ 75 years (Doubled), Diabetes, Stroke/transient ischaemic attack/thromboembolism (Doubled) – Vascular disease, Age 65–74 years and Sex category

(Female)

Table 2 Procedural data from right inferior pulmonary vein ablation (*n* = 214).

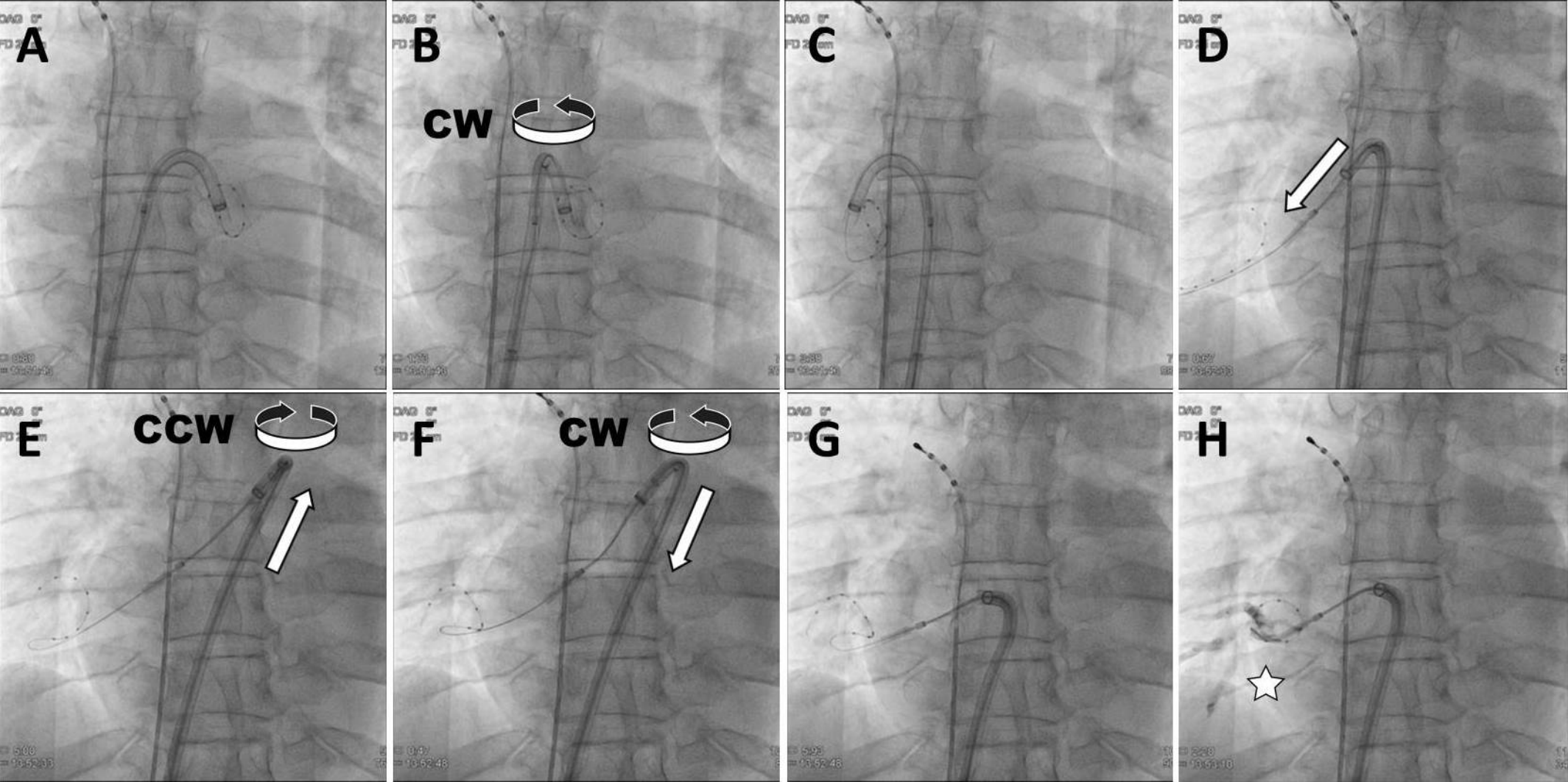
Occlusion	
Perfect (4/4)	197 (92.1)
Good (3/4)	17 (7.9)
Number of PVPs recorded	
0/8	142 (66.4)
1/8	0 (0)
2/8	9 (4.2)
3/8	16 (7.5)
4/8	12 (5.6)
5/8	9 (4.2)
6/8	14 (6.5)
7/8	4 (1.9)
8/8	8 (3.7)
Minimal temperature achieved (° C)	–47.2 ± 8.7
Variables in case of real-time PVI during first freeze (*n* = 72)	
Time to PVI (seconds)	36.2 ± 18.2
Temperature at PVI (° C)	–29.1 ± 14.8
Procedure duration (minutes)	80.0 (70.0–90.0)
Fluoroscopy time (minutes)	17.3 (13.2–22.4)

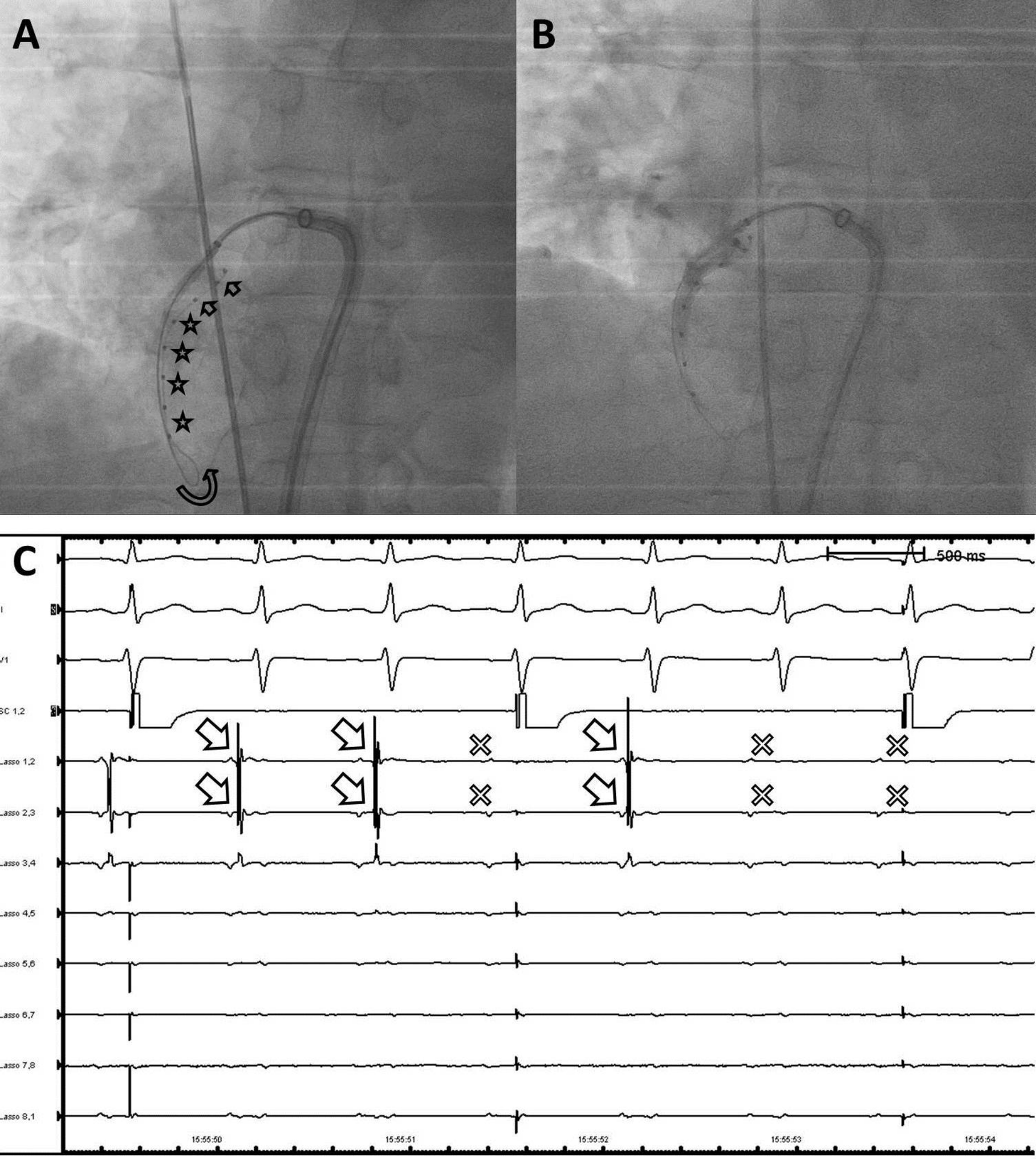
Data are expressed as number (%) for categorical variables, mean ± standard deviation for normally distributed variables or median (interquartile range) for non-normally distributed variables. PVI: pulmonary vein isolation; PVP: pulmonary vein potential.

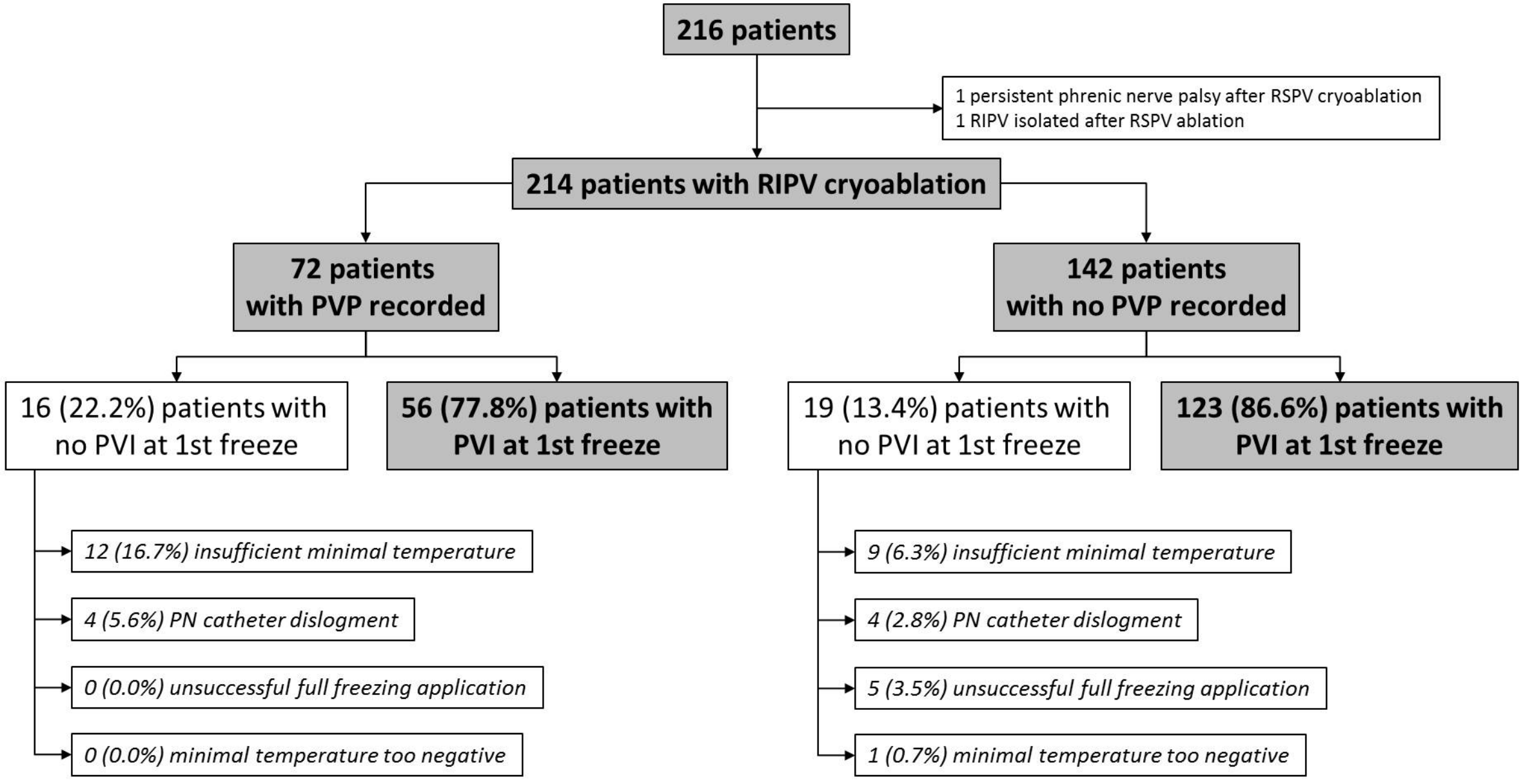
Table 3 Anatomical data in patients with successful and unsuccessful first freeze applications.

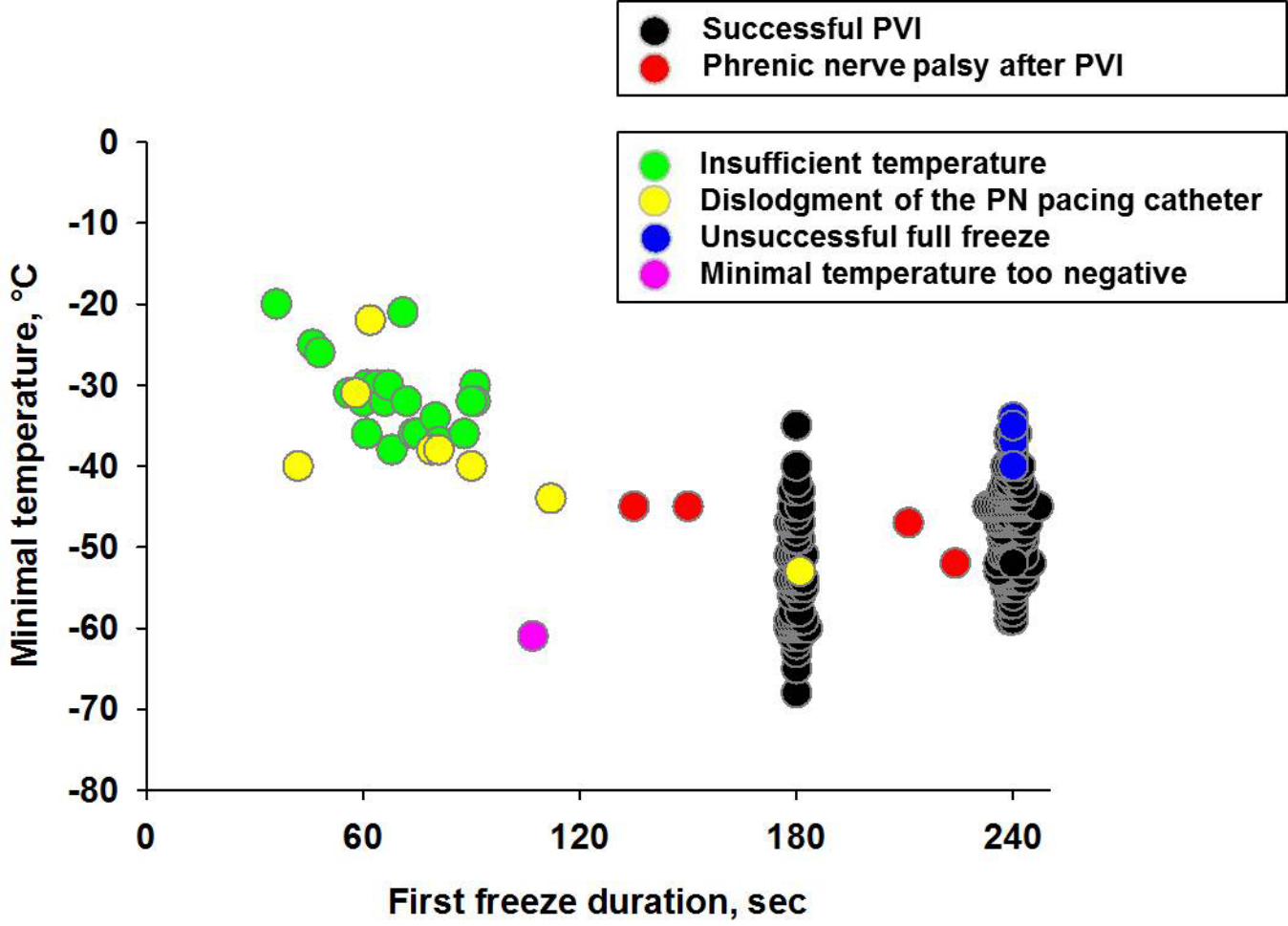
	Efficient first freeze	Inefficient first freeze	*P*
Left atrial volume index (mL/m²)	32.2 (25.2–40.1)	30.5 (23.7–36.1)	0.361
RIPV size (mm)			
Long diameter	17.6 (15.9–19.3)	18.0 (16.5–20.1)	0.440
Short diameter	15.0 (13.2–17.0)	15.3 (13.6–17.6)	0.641
RIPV angulation (°)			
Axial angle	29.1 ± 12.4	22.5 ± 16.1	0.017
Sagittal angle	17.8 ± 1.2	13.0 ± 3.2	0.228

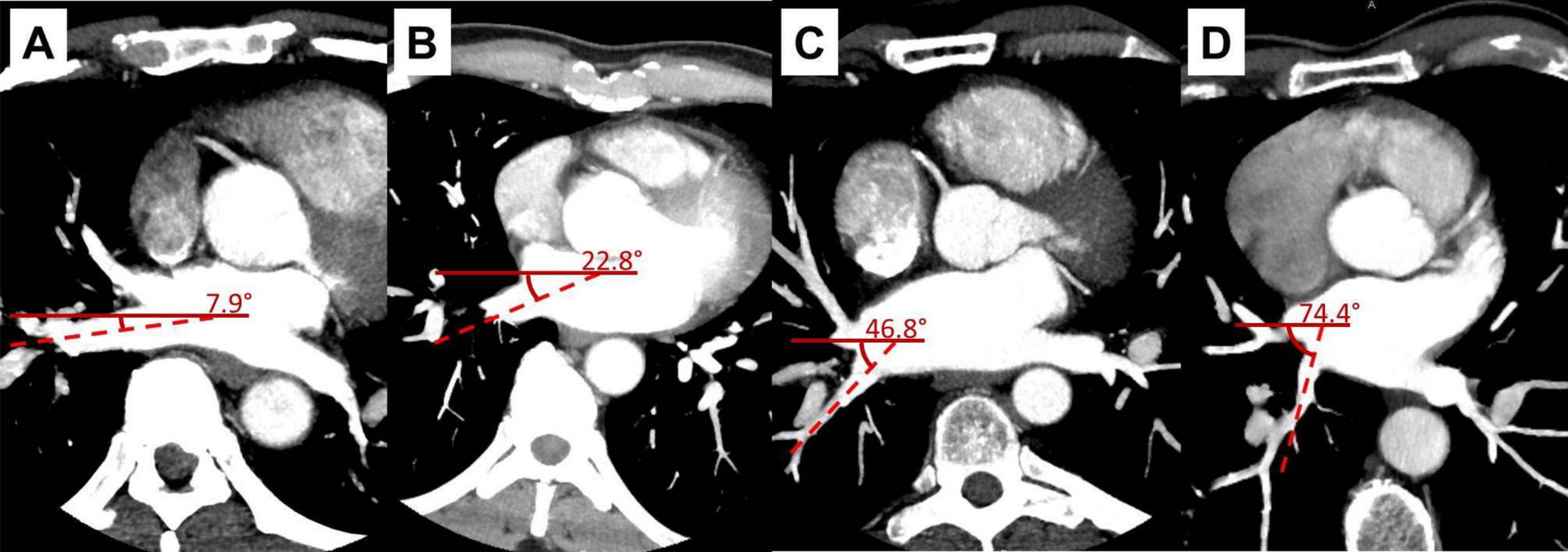
Data are expressed as median (interquartile range) for non-normally distributed variables and mean ± standard deviation for normally distributed variables. RIPV: right inferior pulmonary vein.


A
B
cw
C
D
E
ccw
F
cw
G
H


A
B
C
500 ms
I
V1
SC 1,2
Lasso 1,2
Lasso 2,3
Lasso 3,4
Lasso 4,5
Lasso 5,6
Lasso 6,7
Lasso 7,8
Lasso 8,1
15:55:50
15:55:51
15:55:52
15:55:53
15:55:54


216 patients
1 persistent phrenic nerve palsy after RSPV cryoablation
1 RIPV isolated after RSPV ablation
214 patients with RIPV cryoablation
72 patients with PVP recorded
142 patients with no PVP recorded
16 (22.2%) patients with no PVI at 1st freeze
56 (77.8%) patients with PVI at 1st freeze
19 (13.4%) patients with no PVI at 1st freeze
123 (86.6%) patients with PVI at 1st freeze
12 (16.7%) insufficient minimal temperature
4 (5.6%) PN catheter dislogment
0 (0.0%) unsuccessful full freezing application
0 (0.0%) minimal temperature too negative
9 (6.3%) insufficient minimal temperature
4 (2.8%) PN catheter dislogment
5 (3.5%) unsuccessful full freezing application
1 (0.7%) minimal temperature too negative


Successful PVI
Phrenic nerve palsy after PVI
Insufficient temperature
Dislodgment of the PN pacing catheter
Unsuccessful full freeze
Minimal temperature too negative
Minimal temperature, °C
0
-10
-20
-30
-40
-50
-60
-70
-80
0
60
120
180
240
First freeze duration, sec


A
7.9°
B
22.8°
C
46.8°
D
74.4°