Ablation for atrial fibrillation

Real-time assessment of pulmonary vein disconnection during cryoablation of atrial fibrillation: can it be ‘achieved’ in almost all cases?

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Aim
Real-time assessment of pulmonary vein (PV) disconnection is possible using an inner circular mapping catheter during cryoablation of atrial fibrillation (AF). However, it has been recently demonstrated that such continuous monitoring may only be possible in <50% of PVs. We hypothesized that a stepwise mapping approach, including pacing manoeuvres, could optimize monitoring of real-time PV disconnection during ablation.

Methods and results
Single-centre, prospective observational study (NCT01843465) including 34 consecutive eligible patients (128 PVs) undergoing a first procedure of cryoballoon ablation of AF using the Artic Front Advance® 28 mm catheter and a 20 mm diameter Achieve® catheter (AC) in all cases. Monitoring of real-time entrance block was possible, when AC was maintained in the standard position (distal to the tip of the Artic Front Advance® catheter) in 47 (36.7%) PVs. In an additional 63 cases (49.2%), such monitoring was possible after moving AC to a more proximal position and using different torqueing movements. Finally, using supplemental systematic pacing manoeuvres to test exit block, real-time assessment of PV disconnection was possible in 15 (11.7%) more PVs. Overall, real-time assessment of PV disconnection was possible in 97.7% of cases, after a mean duration of 48.6 ± 33.0 s.

Conclusion
Our results suggest that optimal use of the AC, with a systematic stepwise mapping approach, may dramatically improve the real-time monitoring of PV disconnection during AF cryoablation.

Keywords
Atrial fibrillation • Cryoablation • Achieve catheter • Entrance block • Exit block

Introduction
Cryoballoon ablation of atrial fibrillation (AF) has become available in recent years1 and preliminary results suggest it is a safe and effective alternative to radiofrequency catheter ablation.2–4

Bidirectional block at the left atrium–pulmonary vein (LA–PV) junction, defined as the absence of conduction into the PV from the LA (entrance block) and vice versa (exit block), has been an established endpoint of catheter ablation of AF since the original description of triggering of AF by PV ectopy.5

The Achieve® (AC) (Medtronic®) is an inner circular mapping catheter that has been made available to allow real-time documentation of LA–PV disconnection.6 The first two reports, recently published, have suggested that real-time assessment of PV entrance block during the delivery of cryoablation was only observed in <50% of patients.8,9

However, it has been demonstrated that the extent of atrial myocardial extension in PV sleeves is highly variable from vein to vein, even in the same patient.10 In addition, although the occurrence of exit block is known to be a good surrogate of PV–LA disconnection (since it almost always coexists with entrance block),11 information concerning the use of exit block as a means of real-time assessment of PV disconnection in the setting of cryoballoon ablation is currently sparse.

The aim of the present paper was therefore to provide a prospective evaluation of AC catheter with regards to the ability to allow
In this paper, we have demonstrated that real-time assessment of pulmonary vein disconnection during cryoballoon ablation of atrial fibrillation may be possible in up to 97.7% of veins using the Achieve™ catheter.

We have shown that real-time exit-block assessment can also be used for this purpose, providing additional 11.7% pulmonary veins, that would not be documented with the entrance block.

We present a new classification for pulmonary vein types, according to the method used for real-time assessment of disconnection.

real-time monitoring of PV disconnection with a systematic stepwise mapping approach: (i) using specific manipulation manoeuvres with the AC for maximizing the yield of documentation of entrance block; (ii) pacing through the AC during cryoenergy application for real-time exit-block assessment, when no clear PV potentials could be observed.

Methods

This was a prospective, non-randomized, single-centre, observational study (NCT01843465) evaluating the efficacy of the AC for the real-time documentation of LA–PV disconnection in the setting of AF catheter cryoballoon ablation.

Study sample

All patients undergoing cryoballoon ablation of AF using the Artic Front Advance™ catheter together with the AC during a 3-month time interval (May–July 2013) were consecutively included in this observational study. History of symptomatic AF refractory to at least one anti-arrhythmic agent was an inclusion criterion for participating in the study. Patients with a previous AF ablation attempt or in persistent AF at the beginning of the procedure were not eligible. Development of AF during the procedure was not considered an exclusion criterion. Computed tomography documentation of LA–PV disconnection in the setting of AF catheter cryoballoon ablation.

Cryoballoon ablation procedure

All patients received general anaesthesia.

Using a transfemoral venous approach a quadripolar catheter was placed in the coronary sinus (Xtrem®, Sorin SPA®). A single transseptal puncture was performed under fluoroscopic guidance (with use of transoesophageal echocardiography only if no success was obtained with fluoroscopy). Upon completion of the transseptal puncture, patients received intravenous heparin to maintain an activated clotting time of > 300 s.

A steerable 12 Fr sheath (Flexcath®, Medtronic®) was placed in the LA and retrograde angiography of the PVs was performed. Before introducing the Artic Front Advance™ cryoballoon (Medtronic®) catheter in the sheath, a 20 mm diameter AC was inserted in the lumen of the cryoballoon. All patients were treated with the 28 mm diameter cryoballoon. Before delivering cryoballoon, the AC was positioned at the venous ostium to record baseline electrical activity. Then, it was advanced more distally similar to a guidewire to stabilize the deployed cryoballoon at the PV ostium. Occlusion was confirmed by angiography.

The ablation strategy consisted of two cryoenergy applications of at least 240 s in each PV always using the following sequence: left superior PV (LSPV), left inferior PV, right inferior PV (RIPV), and right superior PV (RSPV). In the presence of common ostia, the 28 mm balloon was first positioned across the superior and then across the inferior branches and the duration of both cryoenergy applications was extended to 300 s each.

Whenever a temperature drop was < −30°C at 30 s of cryoenergy application, or if a perfect occlusion of the PV was not possible, a ‘pull-down’ manoeuvre was performed as previously described by Chun et al.12

To avoid damage to the phrenic nerve while ablating the right PVs, pacing at high output (−12 mA and 1.0 ms duration) was performed with the quadriolar catheter at the level of the right atrium—superior vena cava junction and clinical monitoring of diaphragmatic stimulation was performed. When phrenic nerve capture ceased, we immediately discontinued the cryoenergy application and confirmed with the AC if the vein was completely isolated. If this occurred during the first application and phrenic nerve capture was fully recovered, we attempted to perform an additional freeze in a more antral position with less vigorous wedging of the balloon whenever it was possible, similar to the technique described by Casado-Arroyo et al.13

After cryoablation of all the PVs, we reintroduced the AC catheter into each PV to verify their complete electrical disconnection. The procedural endpoint was met when electrical isolation of the PV based on the elimination of all ostial PV potentials (entrance block) and exit conduction block were observed.

Definition of four different types of pulmonary vein according to left atrium–pulmonary vein conduction properties

In all PVs, after the cryoballoon inflation, and just before delivering cryoablation, mapping with the AC was performed to better distinguish the presence or absence of PV potentials, but also to assess the PV–LA conduction. These data, allowed us to classify each PV into one of the following types, using a systematic stepwise mapping approach:

- After balloon inflation, the AC was placed distal to the tip of the Artic front Advance™ catheter and PV potentials were sought (LabSystem PRO™, EP recording system, Bard Electrophysiology Division; Scale 16 ×). When potentials were detected in this standard position, the PV was defined as a Type 1 PV (Figure 1).
  - When no PV potentials were clearly detected, the AC was advanced and then partially withdrawn repeatedly, alongside with torqueing movements, to displace it backwards and more proximally into the proximity of the balloon (i.e. between the tip of the Artic Front Advance™ and the distal part of the balloon). After exclusion of far-field potentials by pacing manoeuvres (pacing from the distal coronary sinus, LA appendage, and right atrium or superior vena cava—see below for further explanations), when clear PV potentials were detected after this AC ‘backwards’ placement technique, the PV was considered as a Type 2 (Figures 2 and 3).
  - When no PV potentials were clearly detectable, pacing with the AC (all dipoles were sequentially assessed at high amplitude: 12 mA and 1.0 ms duration) was performed in the most proximal part of the PV and LA capture was sought. Whenever LA capture was observed
Finally, when neither PV potentials were detectable with the AC, nor catheter inside the superior vena cava or the right atrium. Potentials was routinely performed by pacing with the quadripolar catheter placed either in the coronary sinus or, preferentially, in the LA appendage (using the same transseptal puncture to place the catheter) for optimal pacing and clear separation of potentials. The exclusion of superior vena cava or right atrial far-field potentials was suspected, pacing sources (an external single-chamber temporary pacemaker—Model 5348, Medtronic—was used). While trying to assess the presence of entrance block, whenever the presence of LA appendage far-field potentials was suspected, pacing was performed using the quadripolar catheter placed either in the coronary sinus or, preferentially, in the LA appendage (using the same transseptal puncture to place the catheter) for optimal pacing and clear separation of potentials. The exclusion of superior vena cava or right atrial far-field potentials was routinely performed by pacing with the quadripolar catheter inside the superior vena cava or the right atrium.

For Type 3 right PVs, pacing was needed at the same time both for the monitoring of diaphragmatic stimulation and for real-time documentation of PV exit block; it was therefore necessary to use two external pacing sources (an external single-chamber temporary pacemaker—Model 5348, Medtronic—was used).

While trying to assess the presence of entrance block, whenever the presence of LA appendage far-field potentials was suspected, pacing was performed using the quadripolar catheter placed either in the coronary sinus or, preferentially, in the LA appendage (using the same transseptal puncture to place the catheter) for optimal pacing and clear separation of potentials. The exclusion of superior vena cava or right atrial far-field potentials was routinely performed by pacing with the quadripolar catheter inside the superior vena cava or the right atrium.

The absence of LA, superior vena cava, or LA appendage distant capture was assessed by cautiously pacing through many bipoles from the AC (especially those in posterior position for the LSPV and postero-inferior aspect for the RSPV), beginning from the proximal part and going in more distally inside the vein until capture was lost. Differential pacing inside the coronary sinus and the superior vena cava by the bipolar catheter placed inside the right atrium was also used to differentiate PV capture from atrial capture. Lastly, PV capture could be indirectly presumed in each Type 3 PV by loss of capture during the freezing cycle (the AC is in a completely fixed position while freezing), suggesting the occurrence of an exit block. In all cases, entrance block was then also confirmed by mapping the PV ostium after the cryoapplication.

**Statistical analysis**

Comparisons were performed between the different PVs. \( \chi^2 \) was used for nominal variables and one-way analysis of variance (ANOVA) was used for comparison of continuous variables, where appropriate; the Levene’s test was used to check the homogeneity of variance; equivalent non-parametric tests were used when Kolmogorov–Smirnov was in favour of the absence of normal distribution. Post hoc testing of ANOVA was performed using the least significant difference test. Results with \( P < 0.05 \) were regarded as significant.

PASW Statistics (SPSS Inc.) version 18.0 was used for descriptive and inferential statistical analysis.

**Results**

**Patients’ characteristics, details on procedure, and short-term follow-up**

During the pre-specified study inclusion period, 34 patients met eligibility criteria for participating in the study. Baseline characteristics of the study sample are shown in Table 1. There was a large predominance of paroxysmal AF (the rest were short-standing persistent AF) and patients had a low mean CHA2DS2-VASc score (1.3 ± 1.3). Only a minority of patients had structural heart disease: one patient with dilated cardiomyopathy and three patients with left ventricular hypertrophy resulting from hypertension.

Overall, 128 PVs were assessed: 26 LSPVs, 26 left inferior PVs, 8 common left trunks, 34 RSPVs, and 34 RIPVs. Pulmonary vein disconnection was achieved in all veins using only cryotherapy. Higher temperatures (°C) were observed in the left inferior PV (left inferior PV vs. LSPV: \(-48.9 \pm 4.9 \) vs. \(-52.6 \pm 6.1\); \( P = 0.003 \); left inferior PV vs. common left trunk: \(-48.9 \pm 4.9 \) vs. \(-57.5 \pm 8.6\); \( P < 0.001 \); left inferior PV vs. RSPV: \(-48.9 \pm 4.9 \) vs. \(-54.9 \pm 5.0\); \( P < 0.001 \)). Duration of cryoenergy delivery was significantly longer in the common left trunk when compared with the RSPV (\( P = 0.003 \)), while a similar trend was found in comparison with the other veins [LSPV (\( P = 0.059 \)), left inferior PV (\( P = 0.062 \)), and RIPV (\( P = 0.055 \))].

Data on peri-procedural details including complications are provided in Table 2. No strokes, deaths, or major bleeds were observed. Transient phrenic nerve palsy occurred in seven patients (20.6%). However, in two of these, phrenic nerve palsy occurred during applications both in the RIPV and RSPV, accounting for nine PVs, where transient phrenic nerve palsy was observed during cryoenergy application. In only one case, phrenic nerve palsy lasted for > 24 h and was permanent in none.
Seven patients (20.6%) had recurrence (documented AF episodes lasting for \( \geq 30 \) s) during the 3-month blanking period after the procedure. One of these occurred in the first 24 h after the procedure.

**Real-time assessment of pulmonary vein disconnection during cryoablation**

Procedural information concerning the different anatomic types of PV is shown in Table 3. Overall, real-time assessment of PV isolation could be achieved during actual cryoballoon application in 125 (97.3%) veins. For the cases in which real-time assessment of the disconnection was impossible to obtain (2.3% of all PVs), verification of PV disconnection was done by moving the AC to the PV ostium after the freezing cycle and checking bidirectional block.

Monitoring of real-time entrance block was possible, when AC was maintained in the standard position (distal to the tip of the Artic Front Advance\textsuperscript{®} catheter, Type 1), in 47 (36.7%) PVs. In an additional 63 cases (49.2%), such monitoring was possible after moving AC to a more proximal position and using different torquing movements (Type 2). Finally, through the use of supplemental systematic pacing manoeuvres to assess exit block, real-time monitoring of PV disconnection was possible in an additional 15 (11.7%) PVs (Type 3). Overall, real-time assessment of PVs disconnection was possible in 97.7% of cases. The three PVs where no real-time documentation could be obtained (Type 4 PVs) were located at right (one inferior and two superior right PVs). A trend for a higher prevalence of Type 2 PVs was observed in the right PVs (\( \geq 55\%\) in both right PVs vs. 50% in the left inferior PV and \( \approx 25\%\) in the common left trunk and LSPV).

No significant differences regarding time to PV disconnection were observed either according to the PV anatomy (Table 3), or with the type of PV (Type 1 PV = 48.8 ± 29.0 s; Type 2 PV = 51.3 ± 38.2 s; Type 3 PV = 18.8 ± 5.2; overall \( P = 0.370\); subgroup comparisons: Type 1 vs. Type 2, \( P = 0.710\); Type 2 vs. Type 3, \( P = 0.160\); Type 1 vs. Type 3, \( P = 0.255\)). Real-time development of exit block was observed in all Type 3 PVs, which renders the possibility of far-field capture in these veins very unlikely.

Regarding the number of cryoenergy applications for every PV type, no significant differences were found (Type 1 PV = 2.1 ± 0.4; Type 2 PV = 2.2 ± 0.6; Type 3 PV = 2.2 ± 0.6; Type 4 PV = 1.7 ± 0.6; overall \( P = 0.290\); subgroup comparisons: Type 1 vs. Type 2, \( P = 0.353\); Type 1 vs. Type 3, \( P = 0.671\); Type 1 vs. Type 4, \( P = 0.139\); Type 2 vs. Type 3, \( P = 0.846\); Type 2 vs. Type 4, \( P = 0.072\); Type 3 vs. Type 4, \( P = 0.111\)).
Of all assessed PVs, 93 belonged to patients with paroxysmal AF and 35 to patients with persistent AF. The distribution of PV type according to the type of AF was the following: Type 1 PV was found in 37.6% (n = 35) of paroxysmal vs. 34.3% (n = 12) of persistent AF PVs; Type 2 PV in 47.3% (n = 44) of paroxysmal vs. 54.3% (n = 19) of persistent AF PVs; Type 3 PV in 12.9% (n = 12) of paroxysmal vs. 8.6% (n = 3) of persistent AF PVs; Type 4 PV in 2.2% (n = 2) of paroxysmal vs. 2.9% (n = 1) of persistent AF (P = 0.852).

**Figure 3** Example of a left inferior PV, where PV potentials could be only shown with the AC catheter after the backward displacement of the AC catheter (type 2 PV), which allowed all poles to get behind the tip of the Artic Front Advance™ catheter tip, in closer proximity with the PV antrum. Pulmonary vein potentials are marked with the *.

**Discussion**

Our results demonstrate for the first time the feasibility of real-time documentation of LA–PV disconnection during cryoballoon ablation in >90% of patients using the AC catheter with our described technique. These results emphasize the extent to which careful systematic stepwise mapping, including pacing manoeuvres, can dramatically improve the capability of monitoring PV disconnection.

**Real-time assessment of pulmonary vein disconnection**

Real-time documentation of PV–LA disconnection during cryoballoon ablation by other groups was documented in only ~50% of PVs.7,8 However, these groups assessed only entrance block and according to the procedure description a backward displacement of the AC and pacing manoeuvres for assessing the exit block were not routinely performed. Surprisingly, we only observed about 36% of real-time documentation of PV–LA disconnection with the standard AC placement (Type 1 veins), which suggests that ‘backward’ positioning of the AC was instinctively done in some cases by the groups that published a 50% rate of real-time assessment. Nevertheless, our experience strongly suggests that the recording of PV potentials and, therefore, real-time documentation of LA–PV disconnection can be obtained in almost all the cases with easily reproducible manoeuvres which can be performed in a short time. Also, the use of the AC for real-time assessment of exit block seems to be an effective manoeuvre that has not yet been systematically assessed and seems to be particularly advantageous when PV potentials are either not detectable or poorly detectable. It has been described that the occurrence of unidirectional exit block is extremely rare (accounting for <0.6% of cases).11 Therefore, we think that systematically assessing exit block during cryoballoon ablation may be an effective alternative to confirm PV isolation in real time.

In a very recent investigation by Andrade et al.14 assessing the time course of exit and entrance block in PV isolation during cryoballoon ablation, real-time PV recordings were obtainable in 45 out of 58 PVs (77.6%). However, these authors assessed only the left PVs, which in our population showed a non-significant trend to display PV potentials more frequently in the standard AC position (Type 1 PV). Despite assessing real-time exit block, the study focused mainly on its temporal relationship with entrance block, finding that it develops earlier [median (interquartile range) of 5 (3–12) s]. However, no cases of only unidirectional exit block without entrance block were observed, reinforcing the point that assessment of exit block alone may be adequate. Finally, these authors did not provide information concerning the possibility of real-time assessment of exit block when PV potentials are not discernible (Type 3 PVs) and did not provide a clinical application for real-time assessment of exit block, proposing the exclusive use of entrance block as the endpoint of cryoablation of AF. Pathophysiologically, AF may develop with PV ectopy conducting into the atrium,11 but not otherwise, which makes achieving the exit block during cryoballoon ablation an essential endpoint of this procedure, providing a very strong rationale for its use.

**Is real-time assessment of pulmonary vein disconnection of clinical value?**

Real-time documentation of LA–PV disconnection has been associated with shorter procedure and fluoroscopy times.15 Also, documentation of an early disconnection of the PV has been shown to lead to a higher procedural success rate, with shorter PV isolation times predicting a sustained disconnection.16,17 which reinforces the importance of our findings. Indeed, the feasibility of real-time assessment of PV disconnection in a vast majority of cases would help better tailor the procedure (the number and duration of cryoapplications) for each patient.

Furthermore, since no ideal cryoablation protocol (the number of applications and application duration) has been yet developed or tested,18 the documentation of the exact time of LA–PV disconnection will provide useful data to allow development of a standardized
Figure 4  Example of a PV, where PV potentials cannot be clearly identified with the AC catheter. However, PV exit block could be documented in real-time during cryoablation (Type 3 PV). Notice the change in P-wave morphology in panel (A) demonstrating LA capture (black arrow) before and in the beginning of cryoablation. (B) Loss of LA capture (dotted arrow) during cryoablation, indirectly suggesting the occurrence of an exit block. (C) Left atrial appendage far-field (‡), also visible in panel (A), before cryoenergy application. Pacing in the LA appendage performed to exclude far-field (image not shown).
The number of applications may be needed). Also, from the safety point
before 30 s—probably a shorter application time and a lower
protocol in the future (e.g. if PV disconnection occurs very early—
before 30 s—probably a shorter application time and a lower
number of applications may be needed). Also, from the safety point
of view, there may be advantages in real-time documentation of PV
disconnection: if a very early right PV disconnection was obtained
(i.e. before 60 s) and a phrenic nerve palsy was observed later during
the course of the application (e.g. at 150 s), the operator may choose
not to perform a second application after phrenic nerve recovery. In
addition, shorter procedure duration and less applications may also
lead to a lower incidence of complications, in general, with oesophageal
injury and phrenic nerve palsy being particularly relevant. In our inves-
tigation, the observed incidence of temporary phrenic nerve palsy was
similar to what has been described by Casado-Arroyo et al. using
the newer generation cryoballoon (19.5%).

Some investigations have suggested that AF-free survival after
cryoablation of AF might be worse in patients with common left pul-
monary trunk. This could be potentially explained by the position-
ing of the cryoballoon, which is supposed to be more distal, thus
making the registration of PV potentials more difficult, which could
be a limitation for treating these patients. Accordingly, in our sample
of eight patients with left common PV, only 25.0% had Type
PVs. This reinforces the importance of routinely searching for
Types 2 and 3 PVs, which in our sample allowed the documentation
of the cryoballoon, which is supposed to be more distal, thus
making the registration of PV potentials more difficult, which could
be a limitation for treating these patients. Accordingly, in our sample
of eight patients with left common PV, only 25.0% had Type
PVs. This reinforces the importance of routinely searching for
Types 2 and 3 PVs, which in our sample allowed the documentation
of the freezing artefacts, which additionally did not involve all
the cases, PV disconnection occurred well before the occur-
dence of the freezing artefacts, which additionally did not involve all
dipole of the AC. Lastly, the occurrence of AF during cryoablation
may partially

Limitations

Although to the best of our knowledge, we have provided the first
experience of a systematic approach for optimization of the real-time
monitoring of PV disconnection during cryoablation of AF, this single-
centre study has some limitations besides its small sample.

First, since we only used the 28 mm balloon together with the
20 mm AC, we do not know if our results can be extrapolated
when different sizes are used. Since the 28 mm balloon is likely to
be more antral in position, this could have been partly responsible
for the higher rate of documentation of PV disconnection in our
sample.

Secondly, a potential concern of positioning the AC very proxim-
ally (near the distal part of the balloon), is poor stability and artefacts
due to the cooling. However, at least with the 20 mm AC there was
good stability even in a proximal position. Furthermore, in our study,
in all the cases, PV disconnection occurred well before the occur-
rence of the freezing artefacts, which additionally did not involve all
dipole of the AC.

Thirdly, we cannot completely rule out loss of capture during
cryoablation due to AC dislodgement in the initial phase of cryoa-
aplication. Lastly, the occurrence of AF during cryoablation may partially
interfere with the strategy outlined in this study as atrial pacing for
Type 3 PVs would not be possible. However, we did not encounter
this problem in the present study, since the nine PVs with AF during
cryoablation were either Type 1 or 2.

Table 1 Baseline sample data

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Sample (n = 34)</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>59.5 ± 12.5</td>
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<tr>
<td>Female Gender</td>
<td>38.2% (13)</td>
</tr>
<tr>
<td>Body Mass Index (Kg/m²)</td>
<td>27.4 ± 4.3</td>
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<tr>
<td>Clinical data</td>
<td></td>
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<tr>
<td>Paroxysmal AF (%)</td>
<td>76.5% (26)</td>
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<tr>
<td>AF duration (years)</td>
<td>4.8 ± 5.0</td>
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<td>Previous cavo-tricuspid isthmus ablation</td>
<td>17.6% (6)</td>
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<td>CHADS₂ score</td>
<td>0.5 ± 0.9</td>
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<tr>
<td>CHA₂DS₂-VASc</td>
<td>1.3 ± 1.3</td>
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<td>Congestive heart failure</td>
<td>2.9% (1)</td>
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<td>Hypertension (%)</td>
<td>23.5% (8)</td>
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<tr>
<td>Diabetes mellitus</td>
<td>2.9% (1)</td>
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<tr>
<td>Previous stroke or TIA</td>
<td>8.8% (3)</td>
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<td>Vascular disease</td>
<td>5.9% (2)</td>
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<td>Dyslipidaemia (%)</td>
<td>14.7% (5)</td>
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<tr>
<td>Thyroid disease (%)</td>
<td>17.6% (6)</td>
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<td>Anti-arrhythmic treatment</td>
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<tr>
<td>Class I (%)</td>
<td>26.5% (9)</td>
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<tr>
<td>Beta-blocker (%)</td>
<td>2.9% (1)</td>
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<tr>
<td>Class III (%)</td>
<td>17.6% (6)</td>
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<td>Association without amiodarone</td>
<td>26.5% (9)</td>
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<tr>
<td>Association with amiodarone</td>
<td>26.5% (9)</td>
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<tr>
<td>Imaging data</td>
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<td>Underlying heart disease</td>
<td>11.8% (4)</td>
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<tr>
<td>Indexed LA volume (mL/m²)</td>
<td>42.9 ± 16.8</td>
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<tr>
<td>Indexed LA area (cm²/m²)</td>
<td>12.2 ± 2.8</td>
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<td>LV ejection fraction (%)</td>
<td>63.7 ± 7.0</td>
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Table 2 Peri-procedural aspects and complications

<table>
<thead>
<tr>
<th>Peri-procedural aspects</th>
<th>(n = 34)</th>
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<tbody>
<tr>
<td>Total procedure time (min)</td>
<td>135.0 ± 34.9</td>
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<tr>
<td>Fluoroscopy time (min)</td>
<td>27.1 ± 10.3</td>
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<tr>
<td>Radiation dosage (cGy cm²)</td>
<td>7471.3 ± 5002.0</td>
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<tr>
<td>Use of the Artic Front Advance® 28 mm cryoballoon</td>
<td>100% (34)</td>
</tr>
<tr>
<td>Use of the Achieve® 20 mm mm circular mapping catheter</td>
<td>100% (34)</td>
</tr>
<tr>
<td>Peri-procedural complications</td>
<td>4.9% (2)</td>
</tr>
<tr>
<td>Phrenic nerve palsy lasting &gt; 24 h</td>
<td>2.9% (1)</td>
</tr>
<tr>
<td>Left atrial flutter relapse &lt; 24 h</td>
<td>2.9% (1)</td>
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Table 3  Assessment of peri-procedural aspects according to each of the treated PVs

<table>
<thead>
<tr>
<th></th>
<th>Overall (128 PV)</th>
<th>LSPV (n = 26)</th>
<th>LIPV (n = 26)</th>
<th>CLT (n = 8)</th>
<th>RIPV (n = 34)</th>
<th>RSPV (n = 34)</th>
<th>P (ANOVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of applications</td>
<td>8.2 ± 1.1</td>
<td>2.1 ± 0.4</td>
<td>2.1 ± 0.4</td>
<td>2.0 ± 0</td>
<td>2.3 ± 0.5</td>
<td>2.2 ± 0.7</td>
<td>0.383</td>
</tr>
<tr>
<td>Time of cryoenergy (s)</td>
<td>1917.4 ± 285.1</td>
<td>518.6 ± 99.0</td>
<td>519.4 ± 105.0</td>
<td>615.0 ± 1232</td>
<td>519.6 ± 150.1</td>
<td>467.4 ± 127.8</td>
<td>0.047</td>
</tr>
<tr>
<td>Time to PV disconnection (s)</td>
<td>48.6 ± 33.0</td>
<td>54.8 ± 32.8</td>
<td>52.3 ± 35.5</td>
<td>45.0 ± 29.9</td>
<td>50.4 ± 35.0</td>
<td>39.3 ± 29.8</td>
<td>0.496</td>
</tr>
<tr>
<td>Average temperature (°C)</td>
<td>–52.6 ± 5.8</td>
<td>–53.6 ± 6.1</td>
<td>–48.9 ± 4.9</td>
<td>–57.5 ± 8.6</td>
<td>–51.3 ± 4.4</td>
<td>–54.9 ± 5.0</td>
<td>0.001</td>
</tr>
<tr>
<td>Temporary phrenic nerve paralysis</td>
<td>7.0% (9)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>11.8% (4)</td>
<td>14.7% (5)</td>
<td>0.067</td>
</tr>
<tr>
<td>Real-time assessment of PV disconnection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard AC technique/Type 1 PV</td>
<td>36.7% (47)</td>
<td>57.7% (15)</td>
<td>38.5% (10)</td>
<td>25.0% (2)</td>
<td>32.4% (11)</td>
<td>26.5% (9)</td>
<td>0.339</td>
</tr>
<tr>
<td>Need for AC manoeuvre/Type 2 PV</td>
<td>49.2% (63)</td>
<td>26.9% (7)</td>
<td>50.0% (13)</td>
<td>25.0% (4)</td>
<td>55.9% (19)</td>
<td>58.8% (20)</td>
<td></td>
</tr>
<tr>
<td>Real-time exit block/Type 3 PV</td>
<td>11.7% (15)</td>
<td>15.4% (4)</td>
<td>11.5% (3)</td>
<td>25.0% (2)</td>
<td>8.8% (3)</td>
<td>8.8% (3)</td>
<td></td>
</tr>
<tr>
<td>No documentation/Type 4 PV</td>
<td>2.3% (3)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>2.9% (1)</td>
<td>5.9% (2)</td>
<td></td>
</tr>
</tbody>
</table>

Type 1 PV—PV potentials detectable in the standard AC position; Type 2 PV—PV potentials only detectable after the backward displacement of the AC; Type 3 PV—real-time documentation of PV disconnection only possible through AC pacing—exit block; Type 4 PV—real-time assessment of PV disconnection not possible.

AC, Achieve; LSPV, left superior pulmonary vein; LIPV, left inferior pulmonary vein; CLT, common left trunk; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein.

Conclusion

These results suggest that through the use of specific, easy to perform, and reproducible it is possible to document real-time disconnection in > 90% of PVs during balloon cryoablation of AF. This has important clinical implications for better standardization of the procedure and potentially for a better understanding of the disease and its recurrences.

Conflict of interest

S.B. is a consultant for Boston Scientific and Medtronic. J.-P.A. is a consultant for SJM and Biosense Webster. No conflicts of interest for other co-authors.

References