Catheter ablation of peri-nodal and pulmonary veno-atrial substrates: should it be cool?

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Catheter cryoablation (CRYO) is an alternative approach to radiofrequency (RF) ablation in the treatment of cardiac arrhythmias. The favourable lesion characteristics of CRYO and its unique properties of cryomapping and cryoadhesion make this newer approach especially suitable for the treatment of peri-nodal substrates, such as atrioventricular nodal re-entrant tachycardia and septal accessory pathway, and pulmonary veno-atrial substrate in atrial fibrillation. This review aims to present and discuss the data on the use of catheter CRYO for these substrates with special emphasis on its efficacy and safety compared with RF ablation.

Keywords
Catheter cryoablation • Cryoballoon • Atrioventricular nodal re-entrant tachycardia • Septal accessory pathways • Atrial fibrillation

Introduction
Catheter cryoablation (CRYO) is a new approach in the treatment of cardiac arrhythmias by using an alternative energy source instead of the conventional radiofrequency (RF) energy. Compared with RF, the lesion created by CRYO is characterized favourably by being well circumscribed, intact endothelium with minimal thrombus and preservation of extracellular matrix. Together with the unique properties of cryoadhesion with adhesion of catheter tip to cardiac tissue during ablation and cryomapping, which is the ability to produce a reversible lesion at a modestly low temperature, a more precise lesion can be made with less collateral damage. Cryoablation has been applied and tested in the treatment of different arrhythmias, including atrioventricular nodal re-entrant tachycardia (AVNRT), accessory pathway (AP)-mediated atrioventricular reentry, right atrial isthmus-dependent atrial flutter, atrial fibrillation (AF), and ventricular arrhythmias. However, the Achilles tendon of CRYO remains to be the higher recurrence rate compared with RF ablation. With its better safety profile, this newer energy source has been shown to be especially suitable for the ablation of peri-nodal substrates, namely in AVNRT and septal pathway-mediated atrioventricular reentry. The recently available balloon-based cryocatheter has also established its application as a tool for pulmonary vein isolation (PVI) for AF. This paper aims to review the data on the use of CRYO for peri-nodal and pulmonary veno-atrial substrates with special emphasis on its efficacy and safety compared with RF ablation.

Atroventricular nodal re-entrant tachycardia

Inadvertent atrioventricular block complicating radiofrequency catheter ablation

Although RF ablation for AVNRT is both effective and safe, inadvertent atrioventricular block (AVB) with the need for permanent pacemaker implantation remains a potential complication. The reported incidence of this complication varies quite widely in the literature. In the seminal work by Jackman et al., 80 patients with AVNRT underwent RF ablation and one (1.3%) patient developed complete heart block and required pacemaker implantation. Similarly, in an early larger prospective multicentre trial performed by Calkins et al., 5 (1.3%) of 373 patients with AVNRT were complicated by complete heart block after RF ablation. The risk of inadvertent AVB observed in more recent contemporary studies appears much lower. In a large prospective registry involving 3160 patients undergoing RF ablation for AVNRT, eight (0.3%) of them developed complete heart block and required pacemaker implantation. In a non-randomized comparative study between RF ablation and CRYO, Opel et al. reported a 0.7% incidence of complete heart block in the RF arm involving 149 patients. Deisenhofer et al. reported 0.4% incidence of complete heart block in the RF arm in a randomized comparative study between RF ablation and CRYO.

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What's new?

- No inadvertent atrioventricular block complicating catheter CRYO for AVNRT has been reported. The risk for this complication is significantly lower in CRYO when compared with RF ablation as shown by two recently published meta-analysis studies. However, there has not been any adequately powered prospective randomized study to confirm this observation.
- A low recurrence rate of catheter ablation for septal accessory pathway can be achieved by targeting a short 'time-to-effect' of <10 s or a short 'time-to-success' of <25 s.
- Phrenic nerve injury complicating cryoballoon pulmonary vein isolation can be prevented by monitoring the amplitude of diaphragmatic compound motor action potential.
- Left atrial-oesophageal fistula may be prevented by monitoring the luminal oesophageal temperature.

The incidence of inadvertent AVB complicating RF ablation for AVNRT is likely to be strongly related to operator experience and the methodology of data collection. The risk may be significantly under-estimated in retrospective studies. For experienced operators, the expected risk of this complication would be <1% and varies between 0.3 and 0.7% while the risk would be close to that reported in early studies, i.e. around 1.3%, for less experienced operators.

Procedural techniques and advantages of using catheter cryoablation for atrioventricular nodal re-entrant tachycardia

Cryoablation has the unique advantage of creating a more accurate lesion with the properties of cryoadhesion and cryomapping. Slow pathway modification or ablation can be performed with 4, 6, or 8 mm-tip cryocatheters (Freezor, Medtronic, Inc.). The function of cryomapping is available only in 4 and 6 mm-tip catheters (Figure 1). Similar to RF ablation, the target sites for ablating AVNRT with CRYO are in the triangle of Koch. A combination of electrogram and anatomical approaches adopted from the experience in RF ablation is also applicable to CRYO with modifications. The most optimal amplitude ratio of the atrial and ventricular signals at the target site has not been studied for CRYO. In general, a ratio of 0.25–0.5 is recommended and the successful sites are usually slightly more anterior in CRYO than that in RF ablation. Cryomapping can be performed by lowering the temperature of the catheter tip to −30°C. Transient electrophysiological effect will occur and full recovery of electrophysiological function is expected with rewarming within 60 s. At any potential ablation site, the temperature of the catheter tip is lowered to −30°C for a maximal duration of 60 s to test the electrophysiological effect by using programmed electrical stimulation which has reproducibly demonstrated dual atrioventricular nodal physiology or induced AVNRT. If cryomapping at a potential site results in no desirable electrophysiological effect or AVB, cryomapping can be stopped and repeated at another target site. Slow pathway elimination is a preferred endpoint for cryomapping in AVNRT. After successful cryomapping, the catheter tip temperature can be lowered to −70 to −80°C for CRYO. A 4-min cycle is commonly used. Double freezing with two cycles may be used at the same or nearly the same site to increase lesion size and depth. In contrast to RF ablation, junctional rhythm does not occur during CRYO in the triangle of Koch. The use of a linear lesion approach by sequential ablation of sites with different amplitude ratios of the atrial and ventricular electrograms in the triangle of Koch has also been described and may reduce the recurrence rate. After initial success with CRYO, repeat testing for early recurrence after 30 min is highly recommended.

The acute procedural success rate is similar between CRYO and RF ablation in the treatment of AVNRT (Table 1). The major advantage of CRYO is the absence of inadvertent AVB which is well-known by two recently published meta-analysis studies. Hanninen et al. performed a meta-analysis and systematic review on 14 comparative trials, involving 5619 patients who underwent CRYO or RF ablation for AVNRT. There was no permanent inadvertent AVB in the CRYO group while there was 0.75% incidence rate of permanent inadvertent AVB in the RF group (P = 0.05). Santangeli et al. performed a similar meta-analysis and appropriately excluded a registry involving 3518 patients in the RF group and 65 patients in the CRYO group. In this meta-analysis, with 1078 patients in the CRYO group and 1262 patients in the RF group, there was no permanent inadvertent AVB in the CRYO group and an incidence rate of 0.87% in the RF group (P = 0.035). As another advantage, Chan et al. has shown that both patient pain perception and operator stress were significantly reduced in CRYO compared with RF ablation in AVNRT.

Strategies to reduce the recurrence rate of cryoablation for atrioventricular nodal re-entrant tachycardia

The major disadvantage of using CRYO to treat AVNRT is the consistently higher recurrence rate compared with RF ablation (Table 1). The recurrence rate varies from 3 to 20% when 4 mm-tip cryocatheters were used. A larger 6 mm-tip cryocatheter was tested in subsequent studies. Disappointingly, despite higher uniformity, the recurrence rate was 9–10% and was still significantly higher than that of RF ablation. There are a few strategies which can be used to reduce the recurrence rate of CRYO in AVNRT. First, a more robust endpoint can be used. Gupta et al. observed in a retrospective series of 71 patients that the recurrence rate after CRYO for AVNRT was significantly higher if an AV nodal echo beat was still inducible after ablation than if slow pathway elimination was achieved. Sandilands et al. reported that a lower recurrence rate after CRYO for AVNRT could be achieved if a 6 mm instead of 4 mm-tip cryocatheter was used, and slow pathway elimination was confirmed after ablation. Similarly, Eckhardt et al. achieved a low recurrence rate of 4% after CRYO for AVNRT in 75 patients by using an ablation endpoint of elimination of tachycardia plus AH jump with one AV nodal echo beat.
Figure 1  The function of cryomapping in AVNRT and AP. (A) Loss of slow pathway conduction with programmed electrical stimulation during cryomapping. (B) Baseline surface electrocardiography and intracardiac electrograms in a patient with pre-excitation pattern due to para-Hisian AP conduction. (C) During cryomapping, para-Hisian AP conduction was blocked with surface electrocardiography showing a change in pre-excitation pattern due to a second right free wall AP.

Table 1  Comparison of acute procedural success and recurrence rate between CRYO and RF ablation in the treatment of AVNRT

<table>
<thead>
<tr>
<th>Authors</th>
<th>Study design</th>
<th>Number of patients</th>
<th>Acute procedural success rate (Follow-up duration (months))</th>
<th>Recurrence rate</th>
<th>Cryocatheter size (mm)</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>RF(%)</td>
<td>CRYO(%)</td>
<td>P-Value</td>
</tr>
<tr>
<td>Kimman et al.21</td>
<td>RCT</td>
<td>33</td>
<td>30</td>
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<td>RCT</td>
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<td>100</td>
<td>7.4</td>
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<td>Collins et al.23</td>
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<td>57</td>
<td>12</td>
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<td>2.2</td>
<td>97</td>
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<td>Avari et al.24</td>
<td>Prospective cohort</td>
<td>43</td>
<td>37</td>
<td>9.6</td>
<td>95</td>
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<td>Chan et al.27</td>
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<td>80</td>
<td>13.6</td>
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<td>Opel et al.18</td>
<td>Prospective cohort</td>
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<td>123</td>
<td>3</td>
<td>95</td>
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<td>251</td>
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<tr>
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<td>131</td>
<td>143</td>
<td>51.6</td>
<td>96</td>
</tr>
</tbody>
</table>

RF, radiofrequency; CRYO, cryoablation; RCT, randomized controlled trial; NS, non-significant.
Increasing the lesion size of CRYO is another strategy to reduce the recurrence rate after AVNRT treatment. Under favourable catheter orientation, contact pressure, and local blood flow, the lesion created by an 8 mm-tip cryocatheter may be even larger than that created by a 3.5 mm-tip saline-irrigated catheter. Silver et al. achieved an acute procedural success of 91% and only 2.8% recurrence rate in 77 paediatric patients with AVNRT treated by an 8 mm-tip cryocatheter. There was no complication of inadvertent AVB. Chan et al. performed a retrospective case-controlled study in which 20 patients with AVNRT treated with an 8 mm-tip cryocatheter were compared with 20 patients treated with RF ablation. There was no significant difference between the two treatment groups in terms of acute procedural success (CRYO 90% vs. RF 95%; P = 0.098) and recurrence rate (CRYO 5.9% vs. RF 0%; P = 0.304). There was no permanent inadvertent AVB in both groups. A large-scale randomized study comparing CRYO with an 8 mm-tip catheter and RF ablation in patients with AVNRT is currently ongoing [Comparative Study between Cryoablation and Radiofrequency Ablation in the Treatment of Supraventricular Tachycardia (CRYOABLATE)].

Figure 2 shows the catheter position and corresponding atrial and ventricular electrograms in a patient who underwent AVNRT ablation with an 8 mm-tip cryocatheter.

**Septal accessory pathway-mediated atrioventricular re-entry**

**Performance of RF catheter ablation for septal accessory pathways**

Although in general, RF ablation of APs enjoys a high acute procedural success rate, low complication, and recurrence rates, the performance is in fact dependent on the location of the AP (Table 2). The acute procedural success rate is lower and recurrence rate higher in RF ablation for septal AP compared with left free wall AP. More importantly, inadvertent permanent AVB occurred in around 3% of patients. Uncommonly, posteroseptal AP may be located epicardially and ablation inside the coronary sinus (CS) is necessary. However, RF ablation inside the CS is associated with extra risks including adherence of catheter tip to CS wall, CS thrombosis, and collateral damage to coronary artery.

**Performance of cryoablation for septal accessory pathways**

With the special feature of cryomapping and cryoadhesion, the risk of permanent inadvertent AVB complicating catheter ablation for...
septal APs can be eliminated by using CRYO (Table 3).50–56 The acute procedural success rate of around 84% is comparable with that of RF ablation. However, similar to the case in AVNRT, a high recurrence rate of around 29% was observed.

Apart from the advantage of avoiding permanent inadvertent AVB, CRYO may also be a safer approach for ablation inside the CS. Collins et al.57 described 21 paediatric patients with left-sided APs and CRYO inside the CS. They achieved an acute procedural success rate of 71% and a recurrence rate of 40%. Most importantly, there was no evidence of coronary artery damage after the procedure.

### Strategies to reduce the recurrence rate of cryoablation for septal accessory pathways

Two strategies, namely ‘time-to-effect’ and ‘time-to-success’, may be used to reduce the recurrence rate of using CRYO to treat septal AP (Figure 3). Drago et al.58 studied 30 children who underwent successful CRYO for right-sided APs, there was a 20% recurrence rate with a mean follow-up of 20 months. The authors showed that ‘time-to-effect’, which was defined by the time interval from onset of cryomapping at −30°C to loss of AP conduction, predicted recurrence. A ‘time-to-effect’ of ≥10 s predicts recurrence with area under curve of 0.77, sensitivity of 83%, and specificity of 67%. Kaltman et al.59 performed a retrospective study on 25 children who underwent CRYO for right-sided APs including free wall and septal pathways. Direct CRYO to −80°C without cryomapping was performed and the time interval from onset of CRYO to interruption of AP conduction was defined as ‘time-to-success’. If the ‘time-to-success’ was within 25 s, a full cycle of 4 min was given. Otherwise, ablation would be stopped and another target site was attempted. With this approach, the authors achieved an acute procedural success rate of 96% and a low recurrence rate of 4%.

### Pulmonary vein isolation for atrial fibrillation

**Substrates ablated by cryoballoon**

Cryoballoon (CB) (Arctic Front Advance, Medtronic, Inc.) is a recently available tool for PVI in patients with AF. With the favourable lesion characteristics and the balloon-based design, CB PVI may reduce the complications of pulmonary vein stenosis (PVS),60 thromboembolism,61 and left atrial-oesophageal fistula (AOF). On the other hand, procedural complexity may also be reduced compared with the conventional approach of RF ablation. Depending on the size and geometry of the CB and pulmonary veins.
In a recent study performed by Kenigsberg et al., the area of ablation in the posterior left atrium (LA) in 43 patients who underwent PVI by second-generation CB was calculated by using pre- and post-procedural three-dimensional (3D) electroanatomical maps overlaid with the pre-procedural CT of the LA. The ablation area included the PV antrum and occupied 73% of the LA posterior wall. On the other hand, transient vagal reaction with bradycardia and hypotension is commonly seen, especially on thawing, after CB ablation of left-sided PVs. This may indicate modulation of the ganglionated plexi situated at the PV antrum. Yorgun et al. reported their observation in 145 patients with drug-refractory AF undergoing PVI with CB. Intra-procedural vagal reaction was observed in 41% of patients. With a median follow-up of 17 months, the recurrence rate was 18%. Non-paroxysmal AF, large LA size, and early recurrence predict higher risk of AF recurrence. Notably, the need for atropine administration or temporary pacing predicts low risk of AF recurrence.

**How to achieve permanent pulmonary vein isolation with cryoballoon?**

The key to permanent PVI with CB ablation is to achieve good circumferential contact of the CB with the PV ostium or antrum. This will require excellent occlusion of the PV by CB. A semi-quantitative PV occlusion score is usually used. Grade 1 denotes very poor occlusion with immediate rapid outflow of contrast medium from the PV during contrast injection through the inner lumen of CB catheter. Grade 4 denotes excellent occlusion with full retention of contrast medium without visible outflow. Grades 2 and 3 represent fair and good occlusion, respectively. Grade 4 occlusion should always be targeted. Apart from contrast injection, different imaging tools have been used with success to facilitate PV occlusion with CB, namely intracardiac echocardiography and 3D transoesophageal echocardiography. Pulmonary vein occlusion could also be guided by monitoring the change in pressure waveform recorded at the tip of the CB catheter. With excellent occlusion, the pressure waveform will change from that of LA to pulmonary artery.

Although the temperature recorded by a thermocouple situated at the proximal part of the CB underestimates the true temperature at the balloon–tissue interface, it does predict acute PVI. It has been shown that a minimal temperature $< -51^\circ C$ was invariably associated with PVI. On the other hand, if the temperature was $\geq -36^\circ C$ in superior veins and $\geq -33^\circ C$ in inferior veins after 2 min of CRYO, failed PVI could be predicted with specificity of 97% for superior veins and 95% for inferior veins. The positive predictive value was 82% for superior veins and 80% for inferior veins.

Recently, a 4 F circular 8-pole mapping catheter has become available and can be placed in the inner lumen of the CB catheter. It provides real-time monitoring of the PV potentials and the time to PVI. It has been shown in a non-randomized study that both the procedural duration and fluoroscopic exposure could be reduced by using this catheter during CB PVI procedures.

The optimal dose for CB ablation remains an unanswered question. In a non-randomized comparative study, 51 patients with paroxysmal AF underwent PVI procedures with the first-generation CB. There was no difference in the clinical success rate but a higher incidence of phrenic nerve injury (PNI) by using a dose of three cryoapplications compared with two cryoapplications each of 5 min in duration for each PV. In another non-randomized comparative study, 52 patients with paroxysmal or early persistent AF underwent PVI procedures with the second-generation CB. Comparing two cryoapplications with a single cryoapplication each of 3 min in duration for each PV, there was no significant difference in AF-free survival at 6 months.
action potential (CMAP). A 30% reduction in amplitude has been
PNI is to monitor the amplitude of diaphragmatic compound motor
nerve during ablation. High-output pacing of the phrenic nerve through the superior vena cava is mandatory during CB ablation. Keeping the CB more antral in position and monitoring the phrenic nerve function during ablation can prevent PNI. Most of the patients with PNI complicating CB ablation recovered within 1 year. Prevention of PNI can be achieved by deferring the ablation until the right atrial appendage is deflated, or by pressing the stop button consecutively for two times, i.e. the ‘double-stop’ technique.

How to Prevent complications from cryoballoon ablation?

Phrenic nerve injury is a potential complication of catheter ablation for AF. It is more specific to balloon-based technology compared to conventional RF ablation. A meta-analysis of the right atrial appendage has been shown to herald clinical PNI. A 30% reduction in amplitude of the phrenic nerve can be performed by manual palpation and fluoroscopic monitoring. Partrain et al. has shown that in anteroposterior fluoroscopic view, if no part of the CB was lateral to the tip of the phrenic nerve, there would be a 20% reduction in amplitude. With conventional operators, CB ablation is unlikely. In the fluoroscopic view, if no part of the CB was lateral to the tip of the phrenic nerve, PNI would be very unlikely. In a recent study, the incidence of PNI during CB ablation varied from 2 to 11% and is very likely to be dependent on operator experience and the strategies used to prevent this complication. Most of the patients with PNI complicating CB ablation recovered within 1 year. Prevention of PNI can be achieved by deferring the ablation until the right atrial appendage is deflated, or by pressing the stop button consecutively for two times, i.e. the ‘double-stop’ technique.

A number of studies have been performed to compare CB with conventional RF ablation in the treatment of AF (Table 4). The acute procedural success and chronic freedom from AF recurrence are in general similar between the two ablation approaches. In most of the studies, CB ablation, in a recently published meta-analysis involving 14 studies, 469 patients undergoing CB ablation and 635 patients undergoing CB ablation, the acute procedural success rate was 99%. For paroxysmal AF, the acute procedural success rate was 97%. For paroxysmal CB PVI, the acute procedural success rate was 77%. For chronic AF, the acute procedural success rate was 72%. For chronic CB PVI, the acute procedural success rate was 72%. For chronic AF, the acute procedural success rate was 72%.

Table 4 Studies comparing CB with RF ablation in the treatment of atrial fibrillation

<table>
<thead>
<tr>
<th>Authors</th>
<th>Study design</th>
<th>Number of patients</th>
<th>RF approach</th>
<th>Follow-up (months)</th>
<th>APS (%)</th>
<th>Freedom from AF recurrence (%)</th>
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<tr>
<td>Linhart et al.</td>
<td>Case-control</td>
<td>20</td>
<td>CB1</td>
<td>Irrigated</td>
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<td>CB RF P-Value</td>
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<td>Kogovc et al.</td>
<td>Prospective cohort</td>
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<td>CB1</td>
<td>Irrigated</td>
<td>12</td>
<td>CB RF P-Value</td>
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<td>Prospective cohort</td>
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<td>CB1</td>
<td>Irrigated</td>
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<td>Herron et al.</td>
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<td>30</td>
<td>CB1</td>
<td>Irrigated</td>
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<td>CB RF P-Value</td>
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<td>Prospective cohort</td>
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<td>CB1</td>
<td>Irrigated</td>
<td>23</td>
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<td>CB1</td>
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<td>27</td>
<td>CB RF P-Value</td>
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<td>Irrigated</td>
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<tr>
<td>Wasserlauff et al.</td>
<td>Case-control</td>
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<td>CB1/2</td>
<td>Irrigated</td>
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<td>Jourda et al.</td>
<td>Case-control</td>
<td>75</td>
<td>CB2</td>
<td>Irrigated + Contact-force</td>
<td>12</td>
<td>CB RF P-Value</td>
</tr>
</tbody>
</table>

CB, cryoballoon; CB1, first-generation cryoballoon; CB2, second-generation cryoballoon; RF, radiofrequency; AF, atrial fibrillation; APS, acute procedural success; Ns, not available; PVI, pulmonary vein isolation; CPVI, circumferential pulmonary vein isolation; 3D, three-dimensional mapping; CFAE, complex fractionated atrial electrograms; GP, ganglionated plexi; RCT, randomized controlled study.

Radiofrequency strategies were according to the choice of individual operators and included CPVI, linear, CFAE, and GP ablation with fluoroscopy or 3D.
has been shown to be safe and may reduce the risk of persistent PNI.91,92

Pulmonary vein stenosis
Pulmonary vein stenosis is a known complication of RF ablation for AF, especially when segmental ostial ablation is performed. With the adoption of circumferential antral RF ablation of PV guided by 3D mapping system, the incidence of PVS is markedly reduced to 1.3%.93 Segmental PVI performed with focal CRYO has been shown to be free of the complication of PVS.60 Neumann et al.7 reported the first experience of using CB ablation to treat AF in 346 patients and no PVS was observed. However, in the STOP-AF trial, 7 of the 228 patients treated with CB ablation (3.1%) developed PVS.5 Five patients were asymptomatic, one patient underwent PV stenting, and one patient became asymptomatic at 12-month follow-up. The inconsistency in the incidence of PVS is likely due to the frequent use of the 23 mm CB and the relatively low volume of procedures leading to learning curve effect in the study centres of STOP-AF trial.

Left atrial-oesophageal fistula
Atrial-oesophageal fistula is a rare but highly fatal complication of RF ablation for AF.94 The use of CB, unfortunately, is not immune from this complication and with increasing experience worldwide, cases of AOIF have been reported.95,96 Because of the rarity of this complication, no predictor has been identified. Furnkranz et al.97 has recently shown that the use of luminal oesophageal temperature monitoring (Figure 5) reduced the incidence of thermal oesophageal lesions, which may be a precursor of AOF. In the control group of 32 patients who underwent PVI with the second-generation CB, the incidence of oesophageal lesions was 18.8%. In 66 patients who had the procedures guided by luminal oesophageal temperature and ablation stopped whenever the latter reached 15°C, the incidence of oesophageal lesions was significantly reduced to 1.5%. Luminal
oesophageal temperature monitoring may thus be a potential strategy to prevent the complication of AOF during CB ablation.

**Summary: should it be cool for atrioventricular nodal re-entrant tachycardia, septal accessory pathway, and atrial fibrillation catheter ablation?**

Inadvertent permanent AVB is nowadays an uncommon complication of RF ablation of AVNRT, and the incidence is estimated to be 0.3–0.7% for experienced operators and 1.3% for less experienced operators. Cryoablation of AVNRT enjoys a minimal, if not zero, risk of inadvertent permanent AVB. The major disadvantage is the consistently shown higher recurrence rate with 4 and 6 mm-tip cryocatheters. By adopting a more robust ablation endpoint of slow pathway elimination and using 8 mm-tip cryocatheter, the recurrence rate may be significantly reduced to a level comparable with RF ablation. In the author’s opinion, the risk of inadvertent permanent AVB should be vigorously prevented and CRYO should be the first choice for the treatment of AVNRT in paediatric patients. In adult patients, they should be well-informed of the pros and cons of CRYO and RF ablation and actively involved in the choice of energy source.

Septal AP is a challenging substrate for catheter ablation. The acute procedural success rate is lower and the recurrence rate is higher for both CRYO and RF ablation. There is on average a 3% risk of inadvertent permanent AVB in using RF ablation for septal AP. In contrast, there has been no case of inadvertent permanent AVB ever reported in the literature for CRYO. A short ‘time-to-effect’, defined as onset of cryomapping at −30°C to loss of AP conduction, of <10 s or a short ‘time-to-success’, defined as onset of CRYO to loss of AP conduction, of <25 s, predicts a low recurrence rate. In the author’s opinion, by using the above ablation strategies to reduce the recurrence rate, CRYO should be considered as the first choice in the treatment of septal AP.

Cryoballoon is a recently available tool for PVI in patients with AF. Depending on the relative size and geometry of the PV and CB, either ostial or antral level of PVI can be achieved. It has also been shown that modulation of ganglionated plexi situated in the neighbourhood of PV antrum may also be achieved by CB ablation. Most of the comparative studies showed that the acute procedural success and chronic success of freedom from AF recurrence were similar between RF and CRYO. The procedural and fluoroscopic duration has been shown to be shorter with CRYO compared with RF ablation. Phrenic nerve injury is a specific complication of balloon-based technology for PVI and occurs predominantly during ablation of right-sided PVS. High-output phrenic nerve pacing through the superior vena cava is mandatory during CB ablation of right-sided PVS. The incidence of PNI complicating CB PVI varies from 2 to 11% and can be largely prevented by monitoring of phrenic nerve function with manual palpitation, intracardiac echocardiography, and most importantly diaphragmatic CMAP recording. Atrial-oesophageal fistula is a rare but fatal complication of both RF ablation and CRYO. Luminal oesophageal temperature monitoring may be a promising strategy to prevent this complication from CB PVI. In the author’s opinion, with the currently available data, the choice between CB and RF ablation depends on the preference and experience of the operator for patients with paroxysmal AF. When ablation strategies in addition to PVI are anticipated, e.g. in patients with persistent AF, RF ablation should still be considered as the first choice.

**Conflict of interest:** none declared.

**References**


