Cryoballoon Pulmonary Vein Isolation Guided by Transesophageal Echocardiography: Novel Aspects on an Emerging Ablation Technique

CLAUDIA HERRERA SIKLÓDY, M.D.,* JAN MINNERS, M.D., PH.D.,‡
MARTIN ALLGEIER, M.D.,† HANS-JÜRGEN ALLGEIER, M.D.,† NIKOLAUS JANDER, M.D.,†
REINHOLD WEBER, M.D.,* JOCHEN SCHIEBELING-RÖMER, M.D.,*
FRANZ-JOSEF NEUMANN, M.D.,‡ DIETRICH KALUSCHE, M.D.,*
and THOMAS ARENTZ, M.D.*

From the *Department of Electrophysiology, †Department of Echocardiography, and ‡Department of Cardiology, Herz-Zentrum, Bad Krozingen, Germany

TEE-Guided Cryoballoon PV Isolation. ***Background:*** **Pulmonary vein (PV) isolation using a balloon-mounted cryoablation system is a new technology for the percutaneous treatment of atrial fibrillation (AF). Transesophageal echocardiography (TEE) allows real-time visualization of cryoballoon positioning and successful vein occlusion via color Doppler. We hypothesized that PV mechanical occlusion monitored with TEE could predict effective electrical isolation.**

Methods: **We studied 124 PVs in 30 patients. Under continuous TEE assessment, a cryoballoon was placed in the antrum of each PV aiming for complete PV occlusion as documented by color Doppler. At the end of the procedure, PV electrical isolation was evaluated using a circumferential mapping catheter.**

Results: **Of the 124 PVs studied, 123 (99.2%) could be visualized by TEE: the antrum was completely visualized in 80 of them (64.5%), partially in 36 (29.0%), and only disappearance of proximal flow could be observed in the remaining 7 PVs (5.7%). Vein occlusion could be achieved in 111 of the 123 (90.2%) visualized PVs. Postinterventional mapping demonstrated electrical isolation in 109 of 111 occluded PVs (positive predictive value 98.2%) and only in 1 of 12 nonoccluded PVs (negative predictive value 91.7%, $P < 0.001$). After a mean follow-up of 7.4 ± 3.7 months, 73.3% of patients remained in sinus rhythm without antiarrhythmic drugs.**

Conclusion: **Color Doppler documented PV occlusion during cryoballoon ablation can predict effective electrical isolation.** *(J Cardiovasc Electrophysiol, Vol. pp. 1-6)*

atrial fibrillation, cryoablation, catheter ablation, transesophageal echocardiography, pulmonary vein

Introduction

Electrical pulmonary vein (PV) isolation is presently the cornerstone of atrial fibrillation (AF) ablation procedures.[1,2] Nevertheless, using standard ablation catheters, it remains a technically demanding and time-consuming technique, frequently requiring the use of a 3-dimensional (3D) mapping system. Moreover, radiofrequency ablation in the left atrium (LA) carries a higher complication rate than on the right side,[3,4] and can lead to thromboembolic events, PV stenosis,[5] or atrioesophageal fistulas.[6,7] To overcome these problems, new ablation devices and energies such as the cryoballoon have been recently introduced.[8,9]

With the cryoballoon, cryoenergy is applied using an occluding balloon system to create circumferential lesions around the PV. Correct positioning of the cryoballoon in the antrum of the PV plays an important role in the safety and efficacy of the procedure. In all previously published studies,[10,11] PV occlusion was verified using repetitive contrast fluid injections. However, this technique lacks precision in localizing a possible leak and does not give any further information on the surrounding anatomy.

Transesophageal echocardiography (TEE) allows real-time visualization of PV anatomy, as well as of all surrounding atrial structures. It therefore permits online monitoring of balloon positioning and PV occlusion via color Doppler, and might improve both safety and efficacy of the procedure. In this study, we hypothesized that TEE-guided documentation of mechanical occlusion of the PV during cryoballoon ablation procedures could predict effective electrical PV isolation.

Patients and Methods

We included the first 30 patients who were ablated in our center with a cryoballoon. All of them had highly symptomatic drug-refractory paroxysmal or persistent AF referred for a first AF catheter ablation procedure. Patients with long-persistent AF (>1 year)[2] that needed larger substrate modifications were excluded from the study. Informed consent was obtained from all patients before the procedure.

Dr. Arentz reports research support and lecture fees from Cryocath®.

Address for correspondence: Dr. Claudia Herrera Siklódy, M.D., Herz-Zentrum, Department of Electrophysiology, D 79189 Bad Krozingen, Germany. Fax: +49-7633-402-2429; E-mail: claudia.h.siklody@gmail.com

Manuscript received 11 March 2009; Revised manuscript received 28 April 2009; Accepted for publication 29 April 2009.

doi: 10.1111/j.1540-8167.2009.01524.x

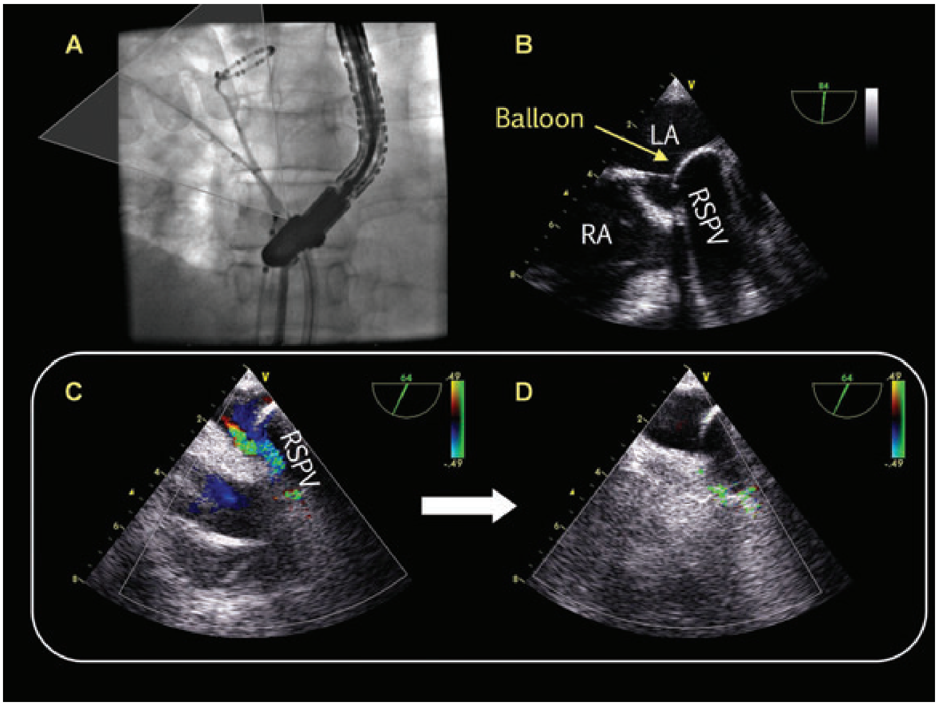

Figure 1. *TEE-guided cryoballoon PV isolation. (A) Anteroposterior fluoroscopic view of the chest showing the cryoballoon already inflated and placed in front of the right superior PV. The TEE probe has already been turned to the right side to allow an optimal visualization of the PV's antrum (shadow). Note that a circular mapping catheter has been placed in the superior vena cava in order to allow phrenic nerve pacing during the application. (B) Echocardiographic view of the right superior PV antrum, displaying the whole left atrial antrum and the PV itself, as well as the balloon that has been placed in front of it. (C) Color Doppler showing the presence of residual flow in the inferior aspect of the right superior PV. (D) A slight withdrawal of the balloon allows then to seal this gap, as shown by the disappearance of flow inside of the PV. LA = left atrium; PV = pulmonary vein; RA = right atrium; RSPV = right superior PV; TEE = transesophageal echocardiography.*

Ablation Procedure

All patients were anticoagulated at least 1 month prior to the procedure. Two days before ablation, anticoagulation was stopped aiming for an international normalized ratio between 1.8 and 2.0. The presence of intracardiac thrombi was ruled out with TEE. All patients underwent a computed tomography scan, and 3D anatomical models of the LA were reconstructed. The ostial diameter of each PV was measured in 2 different axes in order to adapt the choice of the balloon's size to each patient's anatomy: if all PVs presented a diameter <18 mm, the PV isolation was performed using a 23-mm diameter cryoballoon. If any PV was >18 mm, we chose a 28-mm balloon (Arctic front®, Cryocath, Montreal, Quebec, Canada, shaft size 11 Fr) in order to create wider lesions including part of the LA surrounding the PV. One single balloon size was used for every patient.

The ablation procedure was performed under general anesthesia and continuous TEE assessment.

TEE was performed by an experienced echocardiographist using a device with a multiplane 8-MHz transducer (Vivid®, General Electrics, GE Vingmed, Horten, Norway). PVs were displayed in a longitudinal plane, starting at an angle of 70 degrees for the septal and 110 degrees for the lateral veins. The plane was then gradually adjusted to optimize Doppler alignment for each single PV and to locate maximum flow.[12] Every effort was made to visualize the whole antrum. If this was not possible, proximal PV branches were searched to assess proximal flow. Visualization of the PVs was classified into excellent (including the whole antrum), moderate (only parts of the antrum), or low (only proximal flow). For orientation purposes, the antrum was divided into 4 quadrants in terms of anterior/posterior and superior/inferior.

Vascular access was obtained through the right femoral vein, and a quadripolar catheter (Xtreme®, Sorin, Milan, Italy) was positioned in the coronary sinus. One single transseptal puncture was performed under TEE guidance and a steerable sheath (Flexcath®, Cryocath, Montreal, Canada, outer diameter 15 Fr, inner diameter 12 Fr) was placed in the LA. Heparin was then infused to maintain an activated clotting time (ACT) >300 during the whole procedure. The deflated double-coated cryoballoon was then advanced over an extra-rigid 0.032-mm guidewire placed inside of each PV (GuideRight® Superstiff, St. Jude Medical, St. Paul, MN, USA) and inflated in front of the vein. In order to avoid any mechanical damage, special care was taken to inflate the balloon outside of the PV. After inflation, the balloon was advanced aiming for PV flow disappearance as documented by color Doppler (Fig. 1). If PV occlusion was not achieved by simply pushing the balloon into the PV, the device was turned clockwise and counterclockwise or even slightly withdrawn until PV flow disappeared. If leakage persisted, its localization was then documented. Each PV was frozen twice over 5 minutes, trying to select 2 different branches with the guidewire at every freeze. Cryoablation was repeated a third time if occlusion was only documented at the second position. During the ablation of right-sided PVs, we performed phrenic nerve pacing from a catheter located in the superior vena cava in order to promptly detect phrenic nerve injury.

After cryoablation, patients presenting with AF were cardioverted and every PV was mapped during sinus rhythm using a variable diameter 20-pole circular mapping catheter (Optima®, St. Jude Medical). If remnant ostial potentials were still recorded, differential pacing of the atrium near the vein was performed to prove entrance block in the PV.[13,14] If conduction persisted, the location of the electrical gap was documented and electrical isolation was segmentally completed using a 8-mm cryoablation catheter (Freezor Max®, Cryocath). The endpoint of the procedure was complete electrical PV isolation, documented at least 30 minutes after the last application.

Postablation Care

After the procedure, warfarin was restarted and intravenous heparin was administered until the international normalized ratio was ≥2. Warfarin was continued for at least 3 months. On the first postprocedural day, all patients underwent surface electrocardiogram (ECG), transthoracic echocardiography, and 24-hour Holter monitoring.

All antiarrhythmic drugs were withdrawn 3 months after the procedure. At 6 months, a routine visit was performed at our clinic, including imaging of the PVs to exclude stenosis and a 24-hour Holter monitoring. During follow-up, patients were advised to contact us at any time in case of palpitations and were provided with an event recorder if no arrhythmia had been documented. Any atrial arrhythmia lasting >30 seconds was considered a recurrence. All patients were contacted at the end of the study.

Statistical Analysis

Continuous variables are expressed as mean ± SD and are compared by the Student *t*-test or a paired *t*-test if necessary. Categorical variables are compared by χ^2 analysis or with the Fisher exact test. Statistical significance is reached at a P level ≤ 0.05.

Results

We analyzed 124 PVs in 30 patients (57.7 ± 9.3 years old, 84% males, 73.3% with paroxysmal AF). They had an atrial fibrillation history of 5.6 ± 3.8 years and had tried 3 ± 1 antiarrhythmic drugs. Twelve of them (40%) had a history of structural heart disease. The mean diameter of the left atrium was 41 ± 4 mm.

PV Anatomy

Four of the 30 patients had accessory right-sided PVs, and 3 of them presented a left common ostium. The mean diameter of these 3 common ostia was 30 mm. Therefore, both available balloon sizes were too small to attempt its isolation, and the 2 main branches were separately isolated and also independently analyzed.

Cryoballoon ablation was therefore performed in a total of 124 PVs, using 9 × 23 mm (30%) and 21 × 28 mm (70%) cryoballoons. Figure 2 provides an overview of the ablation results. Table 1 provides a summary of the data concerning PV size and time of cryoablation.

TEE-Guided PV Occlusion

Of the 124 PVs, 123 could be visualized by TEE. In 64.5% of them (80 of 124) visualization was excellent, in 29.0% of them (36 of 124) it was considered as moderate, and in 5.7% of the veins (7 of 124) only proximal flow could be registered. One PV (0.8%) identified on the CT scan could not be visualized by TEE.

From the visualized PVs, 90.2% (111 of 123) could be successfully occluded by the cryoballoon. Successful occlusion was more frequent in superior PVs than in inferior ones (98.4% vs 81.0%, P = 0.005).

PV Electrical Isolation

Successful PV isolation was documented in 109 of the 111 occluded PVs, compared to only 1 of the 12 nonoccluded

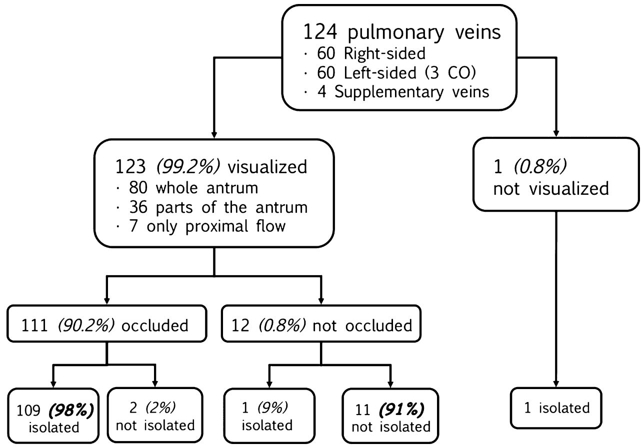

Figure 2. *Flowchart summarizing all pulmonary vein (PV) visualization and isolation.*

veins. Mechanical PV occlusion as assessed by flow disappearance inside of the vein was therefore a strong predictor of PV electrical isolation (positive predictive value 98.2%, negative predictive value 91.7%). Moreover, visualization of the whole PV antrum does not seem to be necessary to predict isolation: the positive predictive value was 98.6% in patients where the PV antrum was completely visualized and 97.1% in patients with a moderate or low visualization. In 10 of 13 nonisolated PVs, the quadrant where a flow leakage had been documented matched the localization of the electrical gap.

Finally, 111 of 124 attempted PVs (89.5%) could be successfully isolated after exclusive cryoballoon ablation. The use of TEE allowed us to effectively isolate all 4 supplementary PVs: 2 of these veins were close enough to the main branch to be covered by the balloon during its ablation. The 2 other ones, though, had to be separately targeted. This maneuver led to the disappearance of flow inside of the small vein, leaving during this single "freeze" a considerable leakage in the nearest main one (Fig. 3).

In 2 PVs, we noted late flow reappearance during cryoenergy application (after >100 seconds). A supplementary cryoballoon ablation was then performed in these 2 veins in order to ensure its effective ablation. TEE also avoided inflating the balloon across the interatrial septum while attempting to isolate a right inferior PV.

Further ablation was necessary in 13 of 124 veins. This occurred in 11 of 30 patients (36.7%), as conduction persisted mainly in only 1 vein per patient. After 2.8 ± 1.3 focal

TABLE 1

PV Size and Time of Cryoablation

	Mean Diameter (mm)	Mean Time of Cryoablation (Minutes)
Global (per patient)	18.3 ± 3.3*	41.9 ± 7.2
Left superior	19.9 ± 2.6	11.2 ± 2.5
Left inferior	17.5 ± 2.4	11.0 ± 2.0
Right superior	19.4 ± 3.3	9.9 ± 3.5
Right inferior	16.0 ± 3.4	9.4 ± 2.6
Right-sided supplementary	9.6 ± 1.5	5.0 ± 0.0

*Global mean PV diameter excludes the 3 common left ostia and the 4 right-sided supplementary veins, which are detailed in the text.

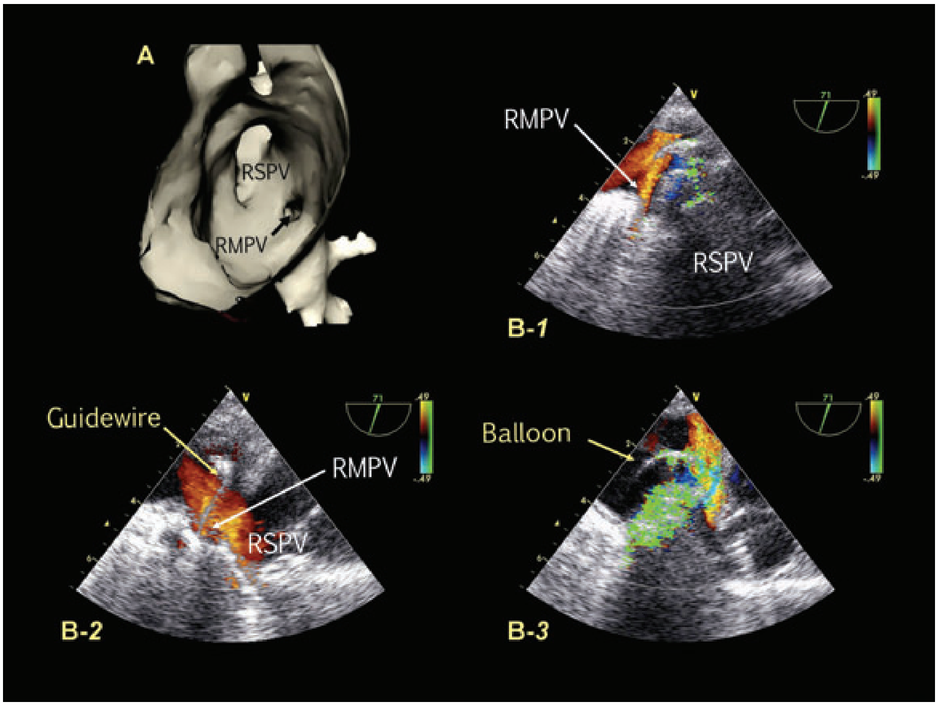

Figure 3. *Separate cryoballoon ablation of a supplementary intermediate right-sided pulmonary vein (PV). (A) Interior view from a 3-dimensional reconstruction of the left atrium, showing a clear independent entrance of this intermediate PV in the left atrium. (B-1) Echocardiographic view of the right superior PV antrum, with the cryoballoon already placed in front of the main vein. The main PV is already effectively occluded, as shown by the absence of color Doppler flow. Nevertheless, flow (red) persists in the small intermediate PV (arrow). (B-2) After the ablation of the main PV, the guidewire is selectively introduced inside this intermediate PV. (B-3) The balloon is then inflated in front of this intermediate PV. Note the absence of flow inside of the small vein, but the presence of a big leakage in the superior aspect of the main one (blue star). RMPV = supplementary right intermediate PV; RSPV = right superior PV.*

cryoablation applications per vein, all 13 remaining nonisolated PVs could be successfully isolated (1 left superior, 2 left inferior, 1 right superior, and 9 right inferior PVs).

Total time procedure from groin access to sheath removal was 180 ± 36 minutes and total fluoroscopy time 40.9 ± 12.7 minutes.

Complications

Transient phrenic nerve paralysis was observed in 4 patients (13.3%) during right upper PV cryoablation, all of them using a 23-mm balloon. The freeze was then immediately interrupted, and the phrenic nerve recovered during the following 2 hours in all 4 patients.

One patient developed a groin hematoma after the procedure and had to be surgically revised. One patient presented a femoral pseudoaneurysm 1 week after the procedure that could be successfully managed with local thrombin injection.

No cardiac tamponade, embolic events, or atrioesophageal fistula were observed. No pulmonary stenosis was documented at the 6-month follow-up visit.

Clinical Follow-Up

After a mean follow-up of 7.4 ± 3.7 months, 73.3% of patients were arrhythmia free without antiarrhythmic drugs: 78.9% in the group exclusively isolated with the cryoballoon and 63.6% among those who needed supplementary focal applications ($P = 0.36$). Among the 8 remaining patients, 7 presented short episodes of recurrent paroxysmal atrial fibrillation and 1 with a persistent one. Three of them underwent a second procedure where a conduction gap in the previous ablation circumference was documented and closed.

Discussion

TEE-guided assessment of PV occlusion during cryoballoon ablation is able to predict effective PV electrical isolation with a positive predictive value of 98%. The transesophageal echocardiographical approach is simple and feasible: 99.2% PVs could be identified, 64.5% of them with a visualization of the whole antrum.

Can We Abandon Postablation Electrical Mapping?

According to our data, cryoballoon PV ablation guided with sole color Doppler documented disappearance of proximal flow ensures electrical isolation of 98% of the PV. Using conventional radiofrequency techniques, PV isolation ratios reported by leading centers usually range between 80% and 98%,[15-17] rarely reaching 100%.[18] Observational data even pointed isolation ratios as low as 60%,[19] possibly derived from the technical complexity of standard PV isolation techniques. Considering a 98% isolation ratio, postablation electrical mapping may thus be superfluous in patients in whom occlusion was achieved and documented during ablation of all 4 PVs (63.3% in our cohort). However, further correlation with clinical success needs confirmation in larger trials before electrical mapping can safely be dropped. In addition, electrical mapping remains necessary in those PVs where occlusion cannot be documented in order to complete the circumferential lesion, and in those patients were non-PV foci are also targeted for ablation.

The Advantages of Intraprocedural Echocardiography

Beyond sole monitorization of mechanical occlusion, transesophageal echocardiography provides many extra safety bonuses that render it particularly attractive compared to the use of intravenous contrast. It first allows ruling out the presence of intracardiac thrombi. It permits guiding transseptal puncture, as well as a safe and precise positioning of the guidewire in the LA, minimizing the risk of left atrial appendage damage. It enables continuous monitoring of the precise localization of the balloon, preventing its inflation inside of a PV and therefore a possible PV rupture.

Once the balloon has been inflated, the use of TEE gives meaningful detailed anatomic information, and provides instantaneous feedback on the effect of every maneuver performed to try to occlude the PV. This helped us achieve in our very first experience with the device an isolation ratio[10] and clinical results[20] comparable to other published studies. It makes the use of contrast fluid during the procedure unnecessary. Finally, the achievement of complete PV occlusion, which allows avoidance of the warming effects of surrounding circulating blood, helps to reach low ablation temperatures, and may be correlated to long-term PV isolation.

We also noted that TEE allowed us to observe some undescribed phenomenon, as well as to resolve them during the procedure. Whenever PV occlusion cannot be achieved, particularly by complex anatomies such as extremely oval PV or supplementary right-sided PVs, echocardiography precisely localizes the site of leakage and permits the development of alternative strategies. In the last cases of our series, oval PVs were successfully ablated by freezing the balloon at the cranial part of the PV antrum, and then pulling it gently back after approximately 45 seconds under attentive TEE supervision, aiming to close the gap by slightly pulling the frozen PV balloon toward the caudal aspect of the antrum. This maneuver can only be echocardiographically documented, as contrast fluid cannot be injected through the balloon once the temperature falls under 0°C. Whenever this last "pull-back" strategy was not feasible, the PV antrum was ablated in 2 stages, aiming sequentially aiming at the cranial and the caudal aspects of the PV antrum. Supplementary right-sided PVs were specifically targeted by selecting them with the guidewire: this approach permits the creation of more complete overlapping lesions around septal PVs as it includes LA tissue located between the superior and the inferior septal PV.

Safety and Feasibility

Compared to our previously published data,[21] procedure times with the cryoballoon were shorter (including both ablation time and also mapping time after ablation), similar to previously published cryoballoon data.[11] Fluoroscopy times were not longer and tended to be shorter at the end of the study, as we had advanced in our learning curve.

Although the study had not been powered for safety, the use of cryoenergy in the left atrium proved to be very safe. The main observed complication was a transient phrenic nerve paralysis. In our cohort, definite nerve damage could always be avoided by the use of pacing during the applications in the right upper PV, allowing its early recognition. The ratio between the size of the vein and the size of the balloon seems to play a crucial role in the appearance of this complication.[11,22] Therefore, special care should be taken in evaluating the size of right-sided PVs before choosing the size of the balloon, and a large balloon could be preferable.

A majority of the nonisolated veins were right inferior PVs, most probably due to its posterior position and its proximity to the transseptal access, which still constitute a technical challenge with current balloon-mounted devices.

This report shows our very first experience with this new device: the combined use of the cryoballoon and the echocardiography guidance appeared hence to be very secure and led to good clinical success rates. Part of the procedure's safety might be attributable to the intraoperative use of TEE itself.

Study Limitations

As the aim of our study was among others saving contrast-associated toxicity, we did not compare the use of TEE with the use of contrast fluid assessing PV effective occlusion. No control group was used.

Although at higher costs, similar results could probably also be obtained using intracardiac echography, avoiding the need for general anesthesia.

Clinical follow-up did not include 7-day-Holter or daily transtelephonic monitoring, so that asymptomatic AF recurrences might have been underrated.

Conclusion

TEE-guided assessment of PV mechanical occlusion during cryoballoon PV isolation is feasible and effective. Compared to contrast fluid injection, it provides relevant supplementary anatomical information on surrounding structures and predicts effective electrical isolation with a positive predictive value of 98.2%.

References

1. Natale A, Raviele A, Arentz T, Calkins H, Chen SA, Haissaguerre M, Hindricks G, Ho Y, Kuck KH, Marchlinski F, Napolitano C, Packer D, Pappone C, Prystowsky EN, Schilling R, Shah D, Themistoclakis S, Verma A: Venice chart international consensus document on atrial fibrillation ablation. J Cardiovasc Electrophysiol 2007;18:560-580.
2. Calkins H, Brugada J, Packer DL, Cappato R, Chen SA, Crijns HJ, Damiano RJ Jr, Davies DW, Haines DE, Haissaguerre M, Iesaka Y, Jackman W, Jais P, Kottkamp H, Kuck KH, Lindsay BD, Marchlinski FE, McCarthy PM, Mont JL, Morady F, Nademanee K, Natale A, Pappone C, Prystowsky E, Raviele A, Ruskin JN, Shemin RJ: HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: Recommendations for personnel, policy, procedures and follow-up. A report of the Heart Rhythm Society (HRS) Task Force on catheter and surgical ablation of atrial fibrillation. Heart Rhythm 2007;4:816-861.
3. Spragg DD, Dalal D, Cheema A, Scherr D, Chilukuri K, Cheng A, Henrikson CA, Marine JE, Berger RD, Dong J, Calkins H: Complications of catheter ablation for atrial fibrillation: Incidence and predictors. J Cardiovasc Electrophysiol 2008;19:627-631.
4. Bertaglia E, Zoppo F, Tondo C, Colella A, Mantovan R, Senatore G, Bottoni N, Carreras G, Coro L, Turco P, Mantica M, Stabile G: Early complications of pulmonary vein catheter ablation for atrial fibrillation: A multicenter prospective registry on procedural safety. Heart Rhythm 2007;4:1265-1271.
5. Robbins IM, Colvin EV, Doyle TP, Kemp WE, Loyd JE, McMahon WS, Kay GN: Pulmonary vein stenosis after catheter ablation of atrial fibrillation. Circulation 1998;98:1769-1775.
6. Pappone C, Oral H, Santinelli V, Vicedomini G, Lang CC, Manguso F, Torracca L, Benussi S, Alfieri O, Hong R, Lau W, Hirata K, Shikuma N, Hall B, Morady F: Atrio-esophageal fistula as a complication of percutaneous transcatheter ablation of atrial fibrillation. Circulation 2004;109:2724-2726.
7. Scanavacca MI, D'Avila A, Parga J, Sosa E: Left atrial-esophageal fistula following radiofrequency catheter ablation of atrial fibrillation. J Cardiovasc Electrophysiol 2004;15:960-962.
8. Sarabanda AV, Bunch TJ, Johnson SB, Mahapatra S, Milton MA, Leite LR, Bruce GK, Packer DL: Efficacy and safety of circumferential pulmonary vein isolation using a novel cryothermal balloon ablation system. J Am Coll Cardiol 2005;46:1902-1912.
9. Avitall B, Urboniene D, Rozmus G, Lafontaine D, Helms R, Urbonas A: New cryotechnology for electrical isolation of the pulmonary veins. J Cardiovasc Electrophysiol 2003;14:281-286.
10. Van Belle Y, Janse P, Rivero-Ayerza MJ, Thornton AS, Jessurun ER, Theuns D, Jordaens L: Pulmonary vein isolation using an occluding

cryoballoon for circumferential ablation: Feasibility, complications, and short-term outcome. Eur Heart J 2007;28:2231-2237.
11. Neumann T, Vogt J, Schumacher B, Dorszewski A, Kuniss M, Neuser H, Kurzidim K, Berkowitsch A, Koller M, Heintze J, Scholz U, Wetzel U, Schneider MA, Horstkotte D, Hamm CW, Pitschner HF: Circumferential pulmonary vein isolation with the cryoballoon technique results from a prospective 3-center study. J Am Coll Cardiol 2008;52:273-278.
12. Jander N, Minners J, Arentz T, Gornandt L, Furmaier R, Kalusche D, Neumann FJ: Transesophageal echocardiography in comparison with magnetic resonance imaging in the diagnosis of pulmonary vein stenosis after radiofrequency ablation therapy. J Am Soc Echocardiogr 2005;18:654-659.
13. Shah D, Haissaguerre M, Jais P, Hocini M, Yamane T, Macle L, Choi KJ, Clementy J: Left atrial appendage activity masquerading as pulmonary vein potentials. Circulation 2002;105:2821-2825.
14. Shah D, Burri H, Sunthorn H, Gentil-Baron P: Identifying far-field superior vena cava potentials within the right superior pulmonary vein. Heart Rhythm 2006;3:898-902.
15. Bertaglia E, Zerbo F, Zoppo F, Trivellato M, Favaro A, Pascotto P: Pulmonary vein isolation predicts freedom from arrhythmia after circumferential antral ablation for paroxysmal atrial fibrillation. J Cardiovasc Med (Hagerstown) 2007;8:896-903.
16. Kumagai K, Muraoka S, Mitsutake C, Takashima H, Nakashima H: A new approach for complete isolation of the posterior left atrium including pulmonary veins for atrial fibrillation. J Cardiovasc Electrophysiol 2007;18:1047-1052.
17. Dixit S, Gerstenfeld EP, Ratcliffe SJ, Cooper JM, Russo AM, Kimmel SE, Callans DJ, Lin D, Verdino RJ, Patel VV, Zado E, Marchlinski FE: Single procedure efficacy of isolating all versus arrhythmogenic pulmonary veins on long-term control of atrial fibrillation: A prospective randomized study. Heart Rhythm 2008;5:174-181.
18. Kanj MH, Wazni O, Fahmy T, Thal S, Patel D, Elay C, Di Biase L, Arruda M, Saliba W, Schweikert RA, Cummings JE, Burkhardt JD, Martin DO, Pelargonio G, Dello Russo A, Casella M, Santarelli P, Potenza D, Fanelli R, Massaro R, Forleo G, Natale A: Pulmonary vein antral isolation using an open irrigation ablation catheter for the treatment of atrial fibrillation: A randomized pilot study. J Am Coll Cardiol 2007;49:1634-1641.
19. Cappato R, Calkins H, Chen SA, Davies W, Iesaka Y, Kalman J, Kim YH, Klein G, Packer D, Skanes A: Worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. Circulation 2005;111:1100-1105.
20. Van Belle Y, Janse P, Theuns D, Szili-Torok T, Jordaens L: One year follow-up after cryoballoon isolation of the pulmonary veins in patients with paroxysmal atrial fibrillation. Europace 2008;10:1271-1276.
21. Arentz T, Weber R, Burkle G, Herrera C, Blum T, Stockinger J, Minners J, Neumann FJ, Kalusche D: Small or large isolation areas around the pulmonary veins for the treatment of atrial fibrillation? Results from a prospective randomized study. Circulation 2007;115:3057-3063.
22. Chun KR, Schmidt B, Metzner A, Tilz R, Zerm T, Koster I, Furnkranz A, Koektuerk B, Konstantinidou M, Antz M, Ouyang F, Kuck KH: The ‘single big cryoballoon’ technique for acute pulmonary vein isolation in patients with paroxysmal atrial fibrillation: A prospective observational single centre study. Eur Heart J 2009;30:699-709.