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ORIGINAL PAPER

Pulmonary vein reconnection and arrhythmia progression after antral linear catheter ablation of paroxysmal and persistent atrial fibrillation

Kristina Wasmer[1] · Dirk G. Dechering[1] · Julia Köbe[1] · Gerold Mönnig[1] · Christian Pott[1] · Gerrit Frommeyer[1] · Philipp S. Lange[1] · Simon Kochhäuser[1] · Lars Eckardt[1]

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Abstract
Background Assumption of different substrates is the basis for different ablation strategies in patients with paroxysmal and persistent atrial fibrillation (AF). We aimed to investigate pulmonary vein reconnection and influence on progression of initial paroxysmal (pAF) versus persistent atrial fibrillation (perAF).
Methods Between January 2010 and November 2012, 149 patients (117 men, mean age 59 ± 11 years, range 27–80 years) underwent at least one redo antral pulmonary vein isolation (PVI) using NavX-guided irrigated-tip radiofrequency catheter ablation. We analyzed whether and where reconnection of pulmonary veins was detected, and whether there were differences between patients with pAF and perAF.
Results Of the 149 patients who underwent a redo antral PVI, 80 patients had pAF and 69 had perAF. One, two and three redo PVIs were performed in 149, 26 and 6 patients, respectively. Reconnection of at least one PV was detected in all patients at the second PVI, in 19 of 26 patients (73 %) at the third PVI and 5 of 6 patients (83 %) at the fourth PVI. 20 (29 %) patients with perAF prior to the first PVI had pAF at the second PVI, whereas 15 (19 %) patients with initial pAF had persistent AF at the time of the first redo procedure. From the second to the third PVI, four patients had developed perAF after previous pAF and two with per AF now had pAF. PV reconnection was observed independent of underlying AF type. At the second redo procedure, of those with reconnected veins 12 had pAF and 13 perAF. At the third redo procedure, four patients had pAF and four perAF.
Conclusion Most patients with recurrent AF after PVI showed at least one reconnected vein during redo procedures. Reconnection was identified irrespective of the underlying AF type. Progression from pAF to perAF and vice versa was observed irrespective of the initial AF type.

Keywords Atrial fibrillation · Pulmonary vein isolation · Pulmonary vein reconnection · AF progression

Introduction

Pulmonary vein foci have been identified as the cause for paroxysmal atrial fibrillation (pAF) [1]. This observation is the basis for pulmonary vein isolation with different catheter technologies. End point for AF ablation is the electrical isolation of the pulmonary veins which has been shown to have a high success rate in pAF [2–4]. For patients with persistent AF, structural and electrophysiological changes of the left atrium and more complex mechanisms are proposed [4]. Thus, the ablation strategy for patients with persistent AF is less well defined. Initially, linear lesions have been proposed to prevent recurrence of AF [5]. In addition, ablation of complex fractionated electrograms [6, 7] as well as rotor ablation [8, 9] has been suggested. Linear lesions on the other hand have been shown to be proarrhythmic by increasing the risk for organized left atrial tachycardias [10]. In addition, the amount of left atrial ablation may increase the risk for complications. Very recently, the STAR AF II trial showed

✉ Kristina Wasmer
wasmerk@ukmuenster.de

[1] Abteilung für Rhythmologie, Department für Kardiologie und Angiologie, Universitätsklinikum Münster (UKM), Albert-Schweitzer-Campus 1, Gebäude A1, 48149 Münster, Germany

no advantage of extensive left atrial ablation compared with pulmonary vein isolation alone in patients with persistent atrial fibrillation [11].

Pulmonary vein reconnection as cause for AF recurrence is well accepted for paroxysmal AF, but not to the same extent for persistent AF. Based on the idea that the substrate is more complex in persistent AF, we hypothesized that there may be differences in pulmonary vein reconnection compared to paroxysmal AF. We therefore aimed to assess the pulmonary vein recovery during redo PVI procedures and to evaluate differences between patients with paroxysmal and persistent AF.

Methods

Study population

We analyzed data from our catheter ablation database and included all patients who had undergone at least one redo PVI procedure between January 2010 and March 2013. Patients with previous PVI at other institutions ($n = 26$) were not included. The study was approved by the Institutional Committee on Human Research at the University of Münster.

149 patients had undergone their first PVI at our institution after failure of at least one antiarrhythmic drug to suppress symptomatic atrial fibrillation. We analyzed patient data including age, gender, type of AF (initially and after each procedure), duration of AF symptoms prior to the initial PVI procedure as well as class and number of failed antiarrhythmic drugs. Paroxysmal AF was defined as AF lasting less than 7 days and persistent AF lasting longer than 7 days. Patients with history of cardioversion prior to 7 day AF duration and otherwise paroxysmal AF were considered to have paroxysmal AF.

Pulmonary vein isolation procedure

All patients signed written informed consent prior to the procedure. A transesophageal echocardiogram was performed in all patients prior to the procedure. The ablation was done in the fasting state under sedation with midazolam and pain medication with piritramide as needed. Surface electrocardiograms and endocardial electrograms were continuously monitored and stored on a computer-based digital amplifier/recorder system (Siemens® Axiom Sensis XP™ or Prucka™, GE Medical®).

Our protocol of AF ablation has previously been published [12]. In brief, two six French sheaths were placed in the left groin. A decapolar steerable catheter (St. Jude Medical Inc., St. Paul, MN, USA or Inquiry™, IBI, Irvine Biomedical, Inc., Irvine, CA, USA) was placed in the coronary sinus (CS) via one of the sheaths.

Drugs including heparin and sedation were given via this access, while the other sheath was used to draw blood for activated clotting time measurements.

Two eight French sheaths were placed in the right groin, one being a SL1-sheath (Daig SL1®, St. Jude Medical Inc., St. Paul, MN, USA) for transseptal puncture. Transseptal puncture was performed with a transseptal needle (BRK™, St. Jude Medical Inc., St. Paul, MN, USA) and the sheath was then advanced into the left atrium. It was subsequently replaced by a steerable 8.5 French sheath (AGILIS NxT™, St. Jude Medical Inc., St. Paul, MN, USA). A second transseptal puncture was performed with the SL1 sheath and this again was advanced into the left atrium.

Both long sheaths were flushed continuously with heparinized solution (1000 U/1 l NaCl). 5000 IU of heparin was administered following the second transseptal puncture. Activated clotting time (ACT) was subsequently measured every 30 min and maintained above 250 s.

Two multi purpose catheters were advanced into the left atrium and placed into the ipsilateral pulmonary veins. Pulmonary vein angiograms were done by simultaneously flushing the catheters with 20 ml contrast medium.

The NaVX-Fusion System (St. Jude Medical Inc., St. Paul, MN, USA) was used for all procedures. The ablation catheter was a 4 mm externally irrigated-tip ablation catheter (IBI Therapy Coolpath Duo™ 7F, St. Jude Medical Inc.). A CT scan of the left atrium was used in all cases. Once the mapping/ablation catheter and a decapolar Lasso catheter (Inquiry Optima, St. Jude Medical Inc., St. Paul, MN, USA) had been advanced into the left atrium via the two transseptal sheaths, a NaVX Map was taken by moving the Lasso catheter around the left atrium and into the pulmonary veins and left atrial appendage (LAA). The anatomical map was fused with the CT scan of the left atrium. The resulting map was used for mapping of the PV and pulmonary vein re-isolation. The Lasso catheter was first placed in the right upper pulmonary vein. In case of PV potential recovery, antral linear ablation was performed under Lasso catheter guidance. Radiofrequency ablation was performed at a maximum power of 35 watt (posterior left atrial wall only 30 watt), a maximum flow rate of 30 ml/min and a maximum temperature of 50 °C.

Upon control or re-ablation of the septal upper PV, the Lasso catheter was placed in the inferior septal PV and ablation continued in a circular antral fashion until PV re-isolation was achieved. PV isolation was defined as loss of pulmonary vein potentials (PVP) within the PV. To prove left PV isolation, pacing in the coronary sinus or left atrial appendage was performed during ablation to distinguish between left atrial signals and PVP.

Follow-up

Patients were started on oral anticoagulation for at least 8 weeks and after that according to their risk factors as assessed by the CHA_2DS_2-VASc score. Patients and referring physicians were instructed to contact our institution if symptoms occurred during this interval. Patients were scheduled to be seen in our outpatient arrhythmia clinic 3 months after the ablation procedure. Until this visit, previously unsuccessful antiarrhythmic medications were continued. Re-ablation was scheduled as needed. All patients were contacted again by telephone at the time of manuscript preparation.

Statistical analysis

Continuous data are given as mean ± SD (range in brackets). Comparison between groups was carried out using the Mann–Whitney *U* test and Fisher's exact test, where applicable. A two-tailed p value < 0.05 was considered to be significant.

Results

Patient characteristics

The clinical characteristics of the patients are summarized in Table 1. The data of 149 patients (117 men, 70 %, mean age 59 ± 11 years, range 27–80 years) were included in the analysis. 80 patients (54 %) had underlying paroxysmal atrial fibrillation and 69 (46 %) had underlying persistent atrial fibrillation. The mean AF duration was 9 ± 7 years, 10 ± 8.5 years in pAF and 8 ± 7.7 years in perAF ($p = 0.18$). Patients had failed a mean of 1.3 ± 0.5 antiarrhythmic drugs, class I in 103 (69 % of patients, amiodarone in 56 (38 %) patients and dronedarone in 26 (17 %) patients. The majority of patients had failed one (95 patients, 64 %), 42 patients (28 %) two and five patients (3 %) three antiarrhythmic drugs, and seven patients (5 %) had undergone primary PVI without prior antiarrhythmic trial.

Table 1 Patient characteristics

Number of patients	149
Age (years)	59 ± 11
Male/female (%)	117/32
Duration of AF (mean in years)	9.4 ± 7.3
Paroxysmal/persistent AF (%)	54/46
Number of failed AA drugs	1.3 ± 0.5
History of Class I (flecainide, propafenone)	60.1 %
History of Class III (amiodarone/sotalol)	33.7 %
Dronedarone	16.0 %

Type of atrial fibrillation

The number of redo procedures in relation to AF type is shown in Fig. 1. 26 patients underwent two and six patients underwent three redo PVI procedures. At the first redo procedure 15 patients (19 %) with initial paroxysmal AF had persistent AF and 20 patients (29 %) with initial persistent AF had paroxysmal AF at the time of the redo procedure (Table 2).

Pulmonary vein recovery

Data on pulmonary vein recovery are summarized in Fig. 2 and Table 3. The time interval between the first and second PVI was 7.8 ± 6.8 months (range 1–35 months), between second and third PVI 10.9 ± 8.4 months (range 1–28 months) and between the third and fourth PVI 21.4 ± 20.2 months.

At the first redo procedure, at least one PV was reconnected in all 149 patients. At the second redo procedure, 21 of 25 patients (84 %) had at least one reconnected PV and at the third redo procedure 4 of 5 patients (80 %). There was no difference in any PV reconnection and number of reconnected veins between paroxysmal and persistent AF ($p = 0.78$). At the third pulmonary vein isolation, only four patients (16 %) had isolated veins, and in the majority of patients two (nine patients) or three (five patients) veins were reconnected. In four patients, all veins were conducting despite two previous pulmonary vein isolations. At the fourth PVI, three patients still had two reconnected pulmonary veins.

At the time of the third PVI, in seven patients the same veins were found to be reconnected as during the previous PVI, while in the remaining patients fewer veins were reconnected compared to the previous PVI. In no case a

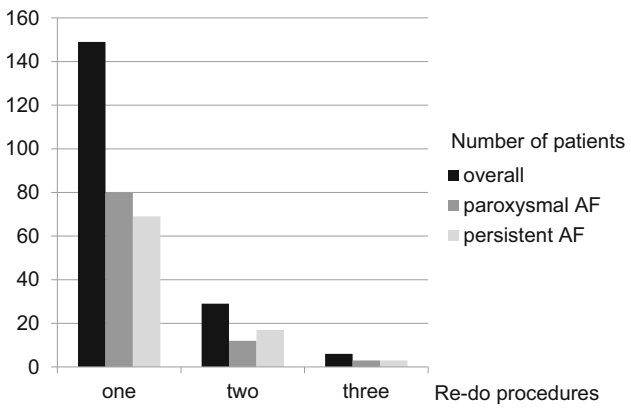

Fig. 1 Number of redo procedures in relation to AF type

Table 2 Changes in AF type

	Overall	From paroxysmal to persistent	From persistent to paroxysmal
At first redo (%)	35/149 (23 %)	15/35 (43 %)	20/35 (57 %)
At second redo	5	4	1
At third redo	1	1	0

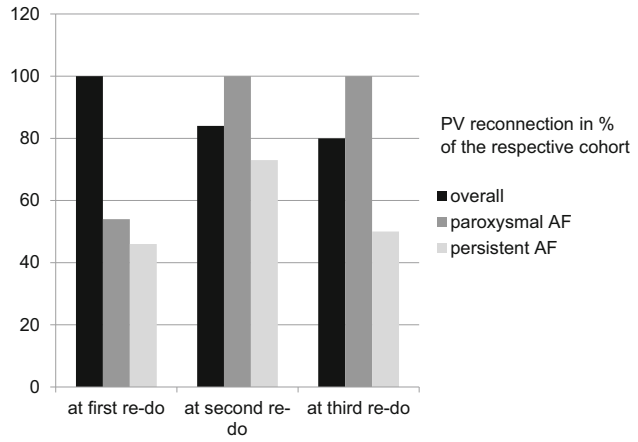

Fig. 2 Any pulmonary vein reconnection (AF type at the time of the procedure)

pulmonary vein was conducting that had been isolated during the preceding PVI. The same was observed in patients who had undergone a fourth PVI.

Follow-up

Follow-up was complete in 127 of 149 patients (85 %), and 22 patients were lost to follow-up (13 with perAF and 9 with pAF). The mean follow-up of the remaining patients since the last PVI was 47 ± 16 months (range 4–87 months). Four patients had died. 73 patients (57 %) were free from symptomatic AF recurrence, 61 % with initially paroxysmal AF and 54 % of those with initially persistent AF. Of the 73 asymptomatic patients, 46 (63 %) [27 with paroxysmal AF (38 %) and 19 with persistent AF (34 %)] were free of symptoms from AF off antiarrhythmic drugs, whereas 24 patients (14 with paroxysmal and 10 with persistent AF) (33 %) were on antiarrhythmic drugs. Nine patients (7 %) ($n = 4$ with paroxysmal AF) developed left atrial tachycardia and underwent ablation. Eight patients (6 %) had undergone AV-node ablation.

Discussion

PV reconnection after linear ostial PVI is frequent and not related to AF type. In patients with persistent AF, PVI may lead to reversal of AF progression, namely change from persistent to paroxysmal AF in about 10 % of patients who initially presented with persistent AF.

PV reconnection

Recovery of PV conduction has been identified as the leading cause of AF recurrence in paroxysmal AF [4]. The recently published Gap-AF-AFNET 1 trial [13] revealed that complete acute electric isolation of the PV veins resulted in less AF recurrence and was superior to incomplete PV isolation. Three months after the index procedure, PV reconnection was observed in 70 % of the patients with previously isolated PVs. Use of contact force is not associated with lower AF recurrence rate [14, 15]. Repeat PVI results in increment in efficacy [16, 17] in patients with paroxysmal AF. Regarding patients with "nonparoxysmal AF", the ideal ablation strategy remains to be defined [18, 19]. There is a wide spectrum of different ablation approaches ranging from pure PVI isolation to linear lesions and substrate ablation [6, 20–23]. To increase the durability of AF ablation, ablation of autonomic ganglia and rotor ablation have recently been added to the choices of AF ablation strategies [8, 9, 24, 25]. The STAR AF II trial [11] suggests that linear lesions and ablation of complex fractionated electrograms in addition to pulmonary vein isolation are not associated with reduction of AF recurrence rate.

Our data confirm the widely accepted role of pulmonary vein reconnection for AF recurrences. It has to be acknowledged, though, that patients without a redo procedure (e.g., asymptomatic patients) would show reconnected veins in a high percentage as well. This was shown in the GAP-AF-AFNET 1 trial. We did not investigate these patients and therefore cannot present data regarding PV reconnection in an overall cohort with previous PV

Table 3 Number of reconnected veins (AF type at the time of the procedure)

No. of reconnected veins	Overall	Paroxysmal	Persistent	*p*
At first redo	2.94 ± 0.91	2.92 ± 0.89	2.95 ± 0.94	0.78
At second redo	2.05 ± 1.05	2.30 ± 1.22	1.71 ± 1.19	0.21
At third redo	1.60 ± 1.09	1.68 ± 1.21	1.33 ± 0.98	0.40

isolation. As would be expected from a mechanistic standpoint, there is no difference between PV reconnection in relation to AF type. In addition, the number of reconnected veins was no different between patients with paroxysmal and persistent AF. Of note, PVI led to reversal of persistent AF to paroxysmal AF in 13 % of patients. The mean duration of persistent AF in these patients was comparable to those who stayed with persistent AF after the first PVI. 15 patients (10 %) progressed from paroxysmal to persistent AF.

Outcome

Based on current scientific data, AF ablation is a symptomatic treatment and aims at eliminating symptoms. We therefore deemed the procedure successful if patients were free of symptoms. Certainly, not all patients are truly free from AF as studies have shown that catheter ablation not only reduces AF burden, but also reduces symptoms from AF [26, 27]. The overall success rate was 60 % and thereby lower compared to other reports on PVI [28, 29]. This may be due to the higher percentage of patients with persistent AF and the relatively long AF history in the majority of patients, both reflecting a rather "real-world" AF population referred for catheter ablation. As expected, the success rate of PVI was higher in paroxysmal versus persistent AF.

Limitations

This is a retrospective analysis and only patients with repeat ablation procedures were included. Ablation was performed without contact force, which was not available at the time. This may have influenced the amount of PV reconnection.

Conclusion

Most patients with recurrent AF after PVI showed at least one reconnected vein during redo procedures. Reconnection was identified irrespective of the underlying AF type. A substantial number of patients (13 %) improved from persistent to paroxysmal AF by their first PVI. Our observations support the concept of circumferential PVI as the initial procedure in all AF patients and postpone more extensive ablation strategies for patients with AF recurrences despite persisting PV isolation.

Compliance with ethical standards

Conflict of interest All authors declare that there is no conflict of interest.

References

1. Haïssaguerre M, Jais P, Shah DC, Takahashi A, Hocini M, Quiniou G et al (1998) Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med 339:659–666
2. Jaïs P, Cauchemez B, Macle L, Daoud E, Khairy P, Subbiah R, Hocini M, Extramiana F, Sacher F, Bordachar P, Klein G, Weerasooriya R, Clémenty J, Haïssaguerre M (2008) Catheter ablation versus antiarrhythmic drugs for atrial fibrillation: the A4 study. Circulation 118:2498–2505
3. Wazni OM, Marrouche NF, Martin DO, Verma A, Bhargava M, Saliba W, Bash D, Schweikert R, Brachmann J, Gunther J, Gutleben K, Pisano E, Potenza D, Fanelli R, Raviele A, Themistoclakis S, Rossillo A, Bonso A, Natale A (2005) Radiofrequency ablation vs antiarrhythmic drugs as first-line treatment of symptomatic atrial fibrillation: a randomized trial. JAMA 293:2634–2640
4. Calkins H, Kuck KH, Cappato R, Brugada J, Camm AJ, Chen SA, Crijns HJ, Damiano RJ Jr, Davies DW, DiMarco J, Edgerton J, Ellenbogen K, Ezekowitz MD, Haines DE, Haissaguerre M, Hindricks G, Iesaka Y, Jackman W, Jalife J, Jais P, Kalman J, Keane D, Kim YH, Kirchhof P, Klein G, Kottkamp H, Kumagai K, Lindsay BD, Mansour M, Marchlinski FE, McCarthy PM, Mont JL, Morady F, Nademanee K, Nakagawa H, Natale A, Nattel S, Packer DL, Pappone C, Prystowsky E, Raviele A, Reddy V, Ruskin JN, Shemin RJ, Tsao HM, Wilber D (2012) 2012 HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design. Europace 14:528–606
5. Knecht S, Hocini M, Wright M, Lellouche N, O'Neill MD, Matsuo S, Nault I, Chauhan VS, Makati KJ, Bevilacqua M, Lim KT, Sacher F, Deplagne A, Derval N, Bordachar P, Jaïs P, Clémenty J, Haïssaguerre M (2008) Left atrial linear lesions are required for successful treatment of persistent atrial fibrillation. Eur Heart J 29:2359–2366
6. Nademanee K, McKenzie J, Kosar E, Schwab M, Sunsaneewitayakul B, Vasavakul T, Khunnawat C, Ngarmukos T (2004) A new approach for catheter ablation of atrial fibrillation: mapping of the electrophysiologic substrate. J Am Coll Cardiol 43:2044–2053
7. Oral H, Chugh A, Yoshida K, Sarrazin JF, Kuhne M, Crawford T, Chalfoun N, Wells D, Boonyapisit W, Veerareddy S, Billakanty S, Wong WS, Good E, Jongnarangsin K, Pelosi F Jr, Bogun F, Morady F (2009) A randomized assessment of the incremental role of ablation of complex fractionated atrial electrograms after antral pulmonary vein isolation for long-lasting persistent atrial fibrillation. J Am Coll Cardiol 53:782–789
8. Haissaguerre M, Hocini M, Denis A, Shah AJ, Komatsu Y, Yamashita S, Daly M, Amraoui S, Zellerhoff S, Picat MQ, Quotb A, Jesel L, Lim H, Ploux S, Bordachar P, Attuel G, Meillet V, Ritter P, Derval N, Sacher F, Bernus O, Cochet H, Jais P, Dubois R (2014) Driver domains in persistent atrial fibrillation. Circulation 130:530–538
9. Narayan SM, Krummen DE, Clopton P, Shivkumar K, Miller JM (2013) Direct or coincidental elimination of stable rotors or focal sources may explain successful atrial fibrillation ablation: on-treatment analysis of the CONFIRM trial (conventional ablation for AF with or without focal impulse and rotor modulation). J Am Coll Cardiol 62:138–147
10. Sawhney N, Anousheh R, Chen W, Feld GK (2010) Circumferential pulmonary vein ablation with additional linear ablation results in an increased incidence of left atrial flutter compared

with segmental pulmonary vein isolation as an initial approach to ablation of paroxysmal atrial fibrillation. Circ Arrhythm Electrophysiol 3:243–248
11. Verma A, Jiang CY, Betts TR, Chen J, Deisenhofer I, Mantovan R, Macle L, Morillo CA, Haverkamp W, Weerasooriya R, Albenque JP, Nardi S, Menardi E, Novak P, Sanders P, STAR AF II Investigators (2015) Approaches to catheter ablation for persistent atrial fibrillation. N Engl J Med 372:1812–1822
12. Bittner A, Mönnig G, Zellerhoff S, Pott C, Köbe J, Dechering D, Milberg P, Wasmer K, Eckardt L (2011) Randomized study comparing duty-cycled bipolar and unipolar radiofrequency with point-by-point ablation in pulmonary vein isolation. Heart Rhythm 8:1383–1390
13. Kuck KH, Hoffmann BA, Ernst S, Wegscheider K, Treszl A, Metzner A, Eckardt L, Lewalter T, Breithardt G, Willems S, Gap-AF–AFNET 1 Investigators (2016) Impact of complete versus incomplete circumferential lines around the pulmonary veins during catheter ablation of paroxysmal atrial fibrillation: results from the Gap-Atrial Fibrillation-German Atrial Fibrillation Competence Network 1 Trial. Circ Arrhythm Electrophysiol 9(1):e003337. doi:10.1161/CIRCEP.115.003337
14. Makimoto H, Heeger CH, Lin T, Rillig A, Metzner A, Wissner E, Mathew S, Deiss S, Rausch P, Lemeš C, Kuck KH, Ouyang F, Tilz RR (2015) Comparison of contact force-guided procedure with non-contact force-guided procedure during left atrial mapping and pulmonary vein isolation: impact of contact force on recurrence of atrial fibrillation. Clin Res Cardiol 104:861–870
15. Wakili R, Clauss S, Schmidt V, Ulbrich M, Hahnefeld A, Schüssler F, Siebermair J, Kääb S, Estner HL (2014) Impact of real-time contact force and impedance measurement in pulmonary vein isolation procedures for treatment of atrial fibrillation. Clin Res Cardiol 103:97–106
16. Ouyang F, Bänsch D, Ernst S, Schaumann A, Hachiya H, Chen M et al (2004) Complete isolation of the left atrium surrounding the pulmonary veins: new insights from the double lasso technique in paroxysmal atrial fibrillation. Circulation 110:2090–2096
17. Ouyang F, Antz M, Ernst S, Hachiya H, Mavrakis H, Deger FT et al (2005) Recovered pulmonary vein conduction as a dominant factor for recurrent atrial tachyarrhythmias after complete circular isolation of the pulmonary veins: lessons from double lasso technique. Circulation 111:127–135
18. Wang XH, Liu X, Sun YM, Gu JN, Shi HF, Zhou L, Hu W (2007) Early identification and treatment of PV re-connections: role of the observation time and impact on clinical results of atrial fibrillation ablation. Europace 9:481–486
19. Calkins H (2012) Catheter ablation to maintain sinus rhythm. Circulation 125:1439–1445
20. Brooks AG, Stiles MK, Laborderie J, Lau DH, Kuklik P, Shipp NJ, Hsu LF, Sanders P (2010) Outcomes of long-standing persistent atrial fibrillation ablation: a systematic review. Heart Rhythm 7:835–846
21. Nademanee K, Schwab MC, Kosar EM, Karwecki M, Moran MD, Visessook N, Michael AD, Ngarmukos T (2008) Clinical outcomes of catheter substrate ablation for high-risk patients with atrial fibrillation. J Am Coll Cardiol 51:843–849
22. Haïssaguerre M, Hocini M, Sanders P, Sacher F, Rotter M, Takahashi Y, Rostock T, Hsu LF, Bordachar P, Reuter S, Roudaut R, Clémenty J, Jaïs P (2005) Catheter ablation of long-lasting persistent atrial fibrillation: clinical outcome and mechanisms of subsequent arrhythmias. J Cardiovasc Electrophysiol 16:1138–1147
23. Haïssaguerre M, Sanders P, Hocini M, Takahashi Y, Rotter M, Sacher F, Rostock T, Hsu LF, Bordachar P, Reuter S, Roudaut R, Clémenty J, Jaïs P (2005) Catheter ablation of long-lasting persistent atrial fibrillation: critical structures for termination. J Cardiovasc Electrophysiol 16:1125–1137
24. Katritsis DG, Giazitzoglou E, Zografos T, Pokushalov E, Po SS, Camm AJ (2011) Rapid pulmonary vein isolation combined with autonomic ganglia modification: a randomized study. Heart Rhythm 8:762–768
25. Katritsis D, Pokushalov E, Romanov A, Giatzoglou E, Siontis G, Po S, Camm AJ, Ionnidis J (2013) Autonomic denervation added to pulmonary vein isolation for paroxysmal atrial fibrillation: a randomized clinical trial. J Am Coll Cardiol 62:2318–2325
26. Hindricks G, Piorkowski C, Tanner H, Kobza R, Gerds-Li JH, Carbucicchio C, Kottkamp H (2005) Perception of atrial fibrillation before and after radiofrequency catheter ablation: relevance of asymptomatic arrhythmia recurrence. Circulation 112:307–313
27. Verma A, Champagne J, Sapp J, Essebag V, Novak P, Skanes A, Morillo CA, Khaykin Y, Birnie D (2013) Discerning the incidence of symptomatic and asymptomatic episodes of atrial fibrillation before and after catheter ablation (DISCERN AF): a prospective, multicenter study. JAMA Intern Med 173:149–156
28. Ouyang F, Tilz R, Chun J, Schmidt B, Wissner E, Zerm T, Neven K, Köktürk B, Konstantinidou M, Metzner A, Fuernkranz A, Kuck KH (2010) Long-term results of catheter ablation in paroxysmal atrial fibrillation: lessons from a 5-year follow-up. Circulation 122:2368–2377
29. Bhargava M, Di Biase L, Mohanty P, Prasad S, Martin DO, Williams-Andrews M, Wazni OM, Burkhardt JD, Cummings JE, Khaykin Y, Verma A, Hao S, Beheiry S, Hongo R, Rossillo A, Raviele A, Bonso A, Themistoclakis S, Stewart K, Saliba WI, Schweikert RA, Natale A (2009) Impact of type of atrial fibrillation and repeat catheter ablation on long-term freedom from atrial fibrillation: results from a multicenter study. Heart Rhythm 6:1403–1412