Collateral Damage from Catheter Ablation of Atrial Fibrillation:
Lessons Learnt in the Past Decade

Wanwarang Wongcharoen, MD,[1] Li-Wei Lo, MD,[2] and Shih-Ann Chen, MD[2]

[1]Department of Internal Medicine, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand, [2]Division of Cardiology, Department of Medicine, Taipei Veterans General Hospital, Taipei, Taiwan; and the Institute of Clinical Medicine and Cardiovascular Research, National Yang-Ming University, Taipei, Taiwan.

Abstract

Catheter ablation for atrial fibrillation (AF) has been increasingly performed over the past decade. Regardless of technological advances and technique improvement, catheter ablation for AF remains a highly complex procedure and the risk of procedural complications is not negligible. This article discusses the management and the approach to avoid the serious complications of catheter AF ablation including pulmonary vein stenosis, atrioesophageal fistula, cardiac tamponade, stroke and collateral nervous damage. The management of periprocedural anticoagulation and the complications associated with epicardial AF ablation are also described.

Introduction

Atrial fibrillation (AF) is the most common sustained arrhythmia, contributing to a significant morbidity and mortality. Catheter ablation of the pulmonary veins (PVs) and left atrium (LA) has been shown to be an effective strategy for the treatment of symptomatic AF. Regardless of technological advances and technique improvement, catheter ablation for AF remains a highly complex procedure and the risk of procedural complications is not negligible. The major complications have been reported to occur in up to 5.2% of procedures.[1-3] A systematic investigation among 32,569 patients undergoing catheter ablation for AF has demonstrated that mortality is around 0.1%.[4] Nevertheless, the true prevalence of complications is possibly underestimated in retrospective surveys because of recollec-

tion bias and other factors. This article will focus on the management of serious complications of catheter AF ablation and the approaches to avoid those complications.

PV Stenosis

The PVs have been demonstrated to be an important source of the initiation of AF5,[6] and also to have a role in the maintenance of AF.[7] Isolating all accessible PVs has become the primary goal of most ablation approaches. At the early stage of AF ablation as the clinical experience with ablation had just grown, radiofrequency lesions were applied within the PVs or at the venoatrial junction to isolate PVs. As a result, PV stenosis had emerged as a major concern after PV ablation. Early reports demonstrated the incidence of PV

Corresponding Address : Shih-Ann Chen, M.D., Division of Cardiology, Taipei Veterans General Hospital, 201 Sec. 2, Shih-Pai Road, Taipei, Taiwan, R.O.C.

stenosis as high as 8 to 15%.[8-10] The predictive factors for the development of PV stenosis were the application of energy inside the veins and inappropriate energy delivery.[9, 10] The mechanism by which PV stenosis may develop after ablation is unclear. It could be attributable to the response to thermal injury within the PVs which included the intimal proliferation with organizing thrombus, necrotic myocardium in various stages of collagen replacement, endovascular contraction, and proliferation of elastic lamina.[11]

Most patients with severe PV stenosis presented with dyspnea on exertion. Other symptoms included dyspnea at rest, recurrent cough, pleuritic chest pain, flu-like symptoms and hemoptysis.[12] Due to the non-specific symptoms, the patients with PV stenosis had frequently been misdiagnosed as bronchitis and delaying establishment of PV stenosis.[13] Awareness of this condition is fundamental for proper and prompt management. Computed tomography (CT) evaluation was the most helpful way in identifying the location and extent of the stenosis. Lung perfusion scan was also beneficial in determining the pathophysiology of the stenosis and its progression. Previous study showed that the patients with PV stenosis did not develop symptoms unless the perfusion of the affected lobe falls below 20% or the perfusion of the entire lung on the affected side falls below 25%.[14]

The preferred therapy for patients with symptomatic severe PV stenosis is PV angioplasty. However, the incidence of restenosis was high as 70% with angioplasty alone but was lower with PV stenting with an incidence of 33%.[9, 15] In the patients with asymptomatic severe PV stenosis, the decision to proceed intervention is challenging. The risk of PV intervention including stroke (0.7%), tamponade (0.5%) and groin complications (0.5%) should be weighed carefully with the potential benefits of the procedure.[9] Routine CT scanning at 3 months postablation can be used as a screening tool to identify patients with PV stenosis following ablation based on the evidence that no patient had progression of PV stenosis after normal CT scan at 3 months after AF ablation.[9]

How to Avoid PV Stenosis?

Currently, the incidence of ablation-related PV

stenosis has been decreasing. Recent reports have shown the incidence of PV stenosis after AF ablation ranging from 0.3 to 1.5%.[3, 16, 17] One of the reasons is the innovation of the AF ablation technique and strategy, which avoids energy applications within the vein and limits the ablation outside the orifice of the PV. Theoretically, electrical isolation of the PVs from the LA by radiofrequency energy delivery outside the PV ostia should reduce the risk of developing significant PV stenosis. However, the development of PV stenosis remains possible due to the fact that this approach requires applying lesion close to anterior part of left PV ostia along the LA appendage (LAA) ridge. In addition, the inadvertent ablation of tissue distal to the PV ostium can be caused by the shifts in the electroanatomic map, respiratory motion, and poor catheter stability.

Apart from the acquired PV stenosis, we reported the incidence of preexisting stenosis of PVs before AF ablation of 2.8%.[18] This condition may be a consequence of congenital focal stenosis or external compression by adjacent structures. Detection of this condition by imaging modalities before the catheter ablation can provide information for planning the ablation strategy and prevent a misdiagnosis of ablation-related PV stenosis.

Atrioesophageal Fistula

Atrioesophageal fistula is a rare complication after AF ablation with an incidence reported less than 0.1%.[19] However, it is associated with very high morbidity and mortality. Atrioesophageal fistula typically presents 1 to 5 weeks post AF ablation. Presenting manifestations include septic shock, neurological deficits from air emboli and gastrointestinal bleeding. Thoracic CT scan is the recommended first line investigation. With a very high mortality rate exceeding 50%, prompt diagnosis necessitates emergent cardiac and esophageal surgery to prevent rapid deterioration and death. Temporary esophageal stenting to stabilize the esophagus at the injury site has been reported as the alternative approach.[20]

The energy applications within LA near the esophageal course can cause thermal injury of the esophagus. As a result, this thermal injury may lead to inflammation and potential fistula formation. Other predisposing factors that have been suggested

include the close anatomic relationship between the esophagus and the LA, a thin posterior LA wall in slim patients, reduced soft tissue between the esophagus and the LA, the distribution of the fat pad at the posterior LA wall,[21] and mechanical trauma induced by echocardiographic probes.[22]

How to Avoid Atrioesophageal Fistula?

To prevent esophageal damage, several methods have been suggested. The simple approach is to reduce power or temperature settings during ablation and to avoid applications of energy over the esophagus. The esophagus in more than 90% of the patients was located on the left posterior LA wall.[21] Previous study showed that additional LA lines performed increase the risk of developing esophageal ulcerations.[23] Therefore, the drawing of additional LA lines should only be performed if there is sufficient evidence for an arrhythmic substrate outside the PVs. If so, recommendations have been made to move lesions from the mid posterior wall to the anterior roof, where LA tends to be thicker and is not adjacent to esophagus. Because the esophagus is a mobile structure and it can migrate during the AF ablation, static images might have limited values. In our laboratory, we routinely ask the patient to swallow a thick barium paste which facilitates visualization of the esophagus on fluoroscopy. This approach is also effective to monitor for esophageal migration during the procedure which has been recognized to occur in up to 50% of the patients.[24]

Continuous monitoring of the esophagus temperature has been proposed as a method to monitor for esophageal injury.[25] The limitation of this approach is the difficulty of achieving good tissue contact with the temperature probe and the need to position the probe in the direct proximity of the ablation catheter. Nevertheless, one case of atrioesophageal fistula has been reported despite <1°C rise recorded from an esophageal temperature probe.[19] Furthermore, esophageal cooling balloon has been reported to reduce the esophageal temperature, but this approach may be limited by the fact that the inflated balloon would press on the esophageal wall against the LA and increase the contact force with the ablation catheter.[26] Other approaches include the placement of balloons

in the oblique sinus to separate the esophagus from the LA[27] and mechanical displacement of the esophagus.[28, 29]

Pericardial Effusion and Cardiac Tamponade

Cardiac tamponade is a serious complication of AF catheter ablation. The incidence of cardiac tamponade with PV isolation procedures is 1% 30 but higher with extensive LA linear ablation.[31] Previous survey reported that 25% of periprocedural deaths are caused by cardiac tamponade.[4] Therefore, prompt recognition and management of cardiac tamponade during LA ablation is critical. Intracardiac echocardiography can be helpful for the early detection of pericardial effusions before the emergence of tamponade physiology. The use of an arterial line that provides continuous blood pressure monitoring also serves as a potential means to detect early hemodynamic compromise. The majority of patients with cardiac tamponade can be managed conservatively by percutaneous drainage, but some may require a surgical closure. It has been described that the LA roof is susceptible to perforation that may not be responsive to conservative therapy. This area may be more vulnerable to persistent bleeding since the pericardium in not closely adherent to the LA and a tight seal of these structures is difficult to achieve by applying negative pressure through the pigtail catheter.[32] The transcardiac access to the pericardium using percutaneous technique and the supportive autologous transfusion using a Cellsaver device for the treatment of cardiac tamponade have been reported to avoid the need of open chest surgery.[33]

How to Avoid Pericardial Effusion and Cardiac Tamponade?

The risk factors of cardiac perforation include the occurrence of "popping" due to tissue boiling related with the delivery of high energy and mechanical trauma. The significant decrease in the incidence of cardiac tamponade has been reported after the limiting of energy delivered.[34] Based on individual operators' preferences, alternative imaging such as intracardiac echocardiography may help lower the risk of cardiac perforation by providing a better visualization of cardiac anatomy and facilitate catheter tracking, manipulation, and stabilization.

Stroke and Thromboembolic Complications

The incidence of postablation thromboembolisms has been reported to be 0.5-1.2%,[35, 36] with the period of highest risk being the first 2 weeks after ablation, usually before achieving of a therapeutic level of anticoagulation after resumption. The thromboembolisms observed early after ablation were not associated with the rhythm or to clinical variables.[36] With this regard, the cause of thromboembolisms was most likely to be char and/or thrombus formation at sites of LA endocardial ablation. This reinforces the importance of proper periprocedural anticoagulation management. Recently, the study from postprocedural cerebral magnetic resonance imaging discovered a substantial risk (14%) of silent cerebral ischemia following ablation. The level of activated clotting time during the procedure and procedural cardioversion to sinus rhythm are important predictors for the silent cerebral thromboembolism.[36] Nevertheless, the current study did not found the impact of those silent cerebral infarctions to the cognitive function after the ablation.[37]

Periprocedural Management with Anticoagulants

The common practice is to discontinuation warfarin 3 to 5 days before ablation, with periprocedural bridging with low-molecular weight heparin. However, such an approach is not supported by adequate evidence and has been derived from methodologically limited uncontrolled studies and expert consensus opinions.[2,38] Several recent studies have shown that AF catheter ablation can be safely performed without warfarin interruption.[39,40] Recent meta-analysis has demonstrated that this approach reduces the risk of thromboembolic complications without increasing the risk of bleeding as compared to the strategy of warfarin discontinuation with heparin bridging.[41] Therefore, current guideline recommends performing catheter ablation of AF on continuous anticoagulation in patients taking warfarin and maintaining at low therapeutic levels (such as an INR of 2 to 2.5) throughout ablation is suggested.[42]

Periprocedural Management with New Oral Anticoagulants

Recently, new oral anticoagulants have been used as an alternative to warfarin for stroke prevention in many patients with AF. A previous study showed that uninterrupted dabigatran with a dose of 150 mg twice daily significantly increased the risk of bleeding or thromboembolic complications compared with uninterrupted warfarin therapy.[43] In contrast, the other study demonstrated that periprocedural dabigatran use at a dose of 110 mg twice daily was safe for AF ablation in patients with a relatively low risk of thromboemboli.[44] The different results could be due to the different patient selection, dabigatran dose and ablation techniques. The reason for the increased bleeding is unclear but may partly be explained by the interaction between unfractionated heparin and dabigatran at the time of the procedure.[45] Based on this pharmacokinetic consideration, it may not be appropriate to use uninterrupted dabigatran, particularly, at a dose of 150 mg twice daily. However, this does not diminish dabigatran's utility when used in an interrupted manner. Previous study reported the safety of interrupted dabigatran in more than 500 patients (40% of whom were on dabigitran pre-ablation) after AF ablation.[46,47] With this regard, in patients taken off oral anticoagulants before the ablation procedure with heparin bridging, initiation of anticoagulation with new oral anticoagulant shortly after the ablation can be the alternative approach to avoid any bridging with heparin after procedure.[37]

Management of Anticoagulant After AF Ablation

The decision whether to discontinue oral anticoagulant after successful catheter ablation of AF is challenging. AF ablation may not be able to completely eliminate the risk of thromboembolisms due to the fact that patients carrying other risk factors of stroke may still be at risk of thromboembolisms even in the setting of sinus rhythm and patients with successful ablation procedure could have asymptomatic episodes of AF during a long-term follow-up. In addition, AF ablation may reduce LA transport function predisposing to thromboembolisms even when in sinus rhythm.[38] A prior study suggested that anticoagulation can be discontinued safely after radiofrequency ablation in patients ≤65 years old.[36] However, it is still unclear whether anticoagulation also can be stopped safely in patients with higher risk of

stroke.[39] Currently, it has been suggested that the risk of late thromboembolisms after AF ablation and the decision to continue long-term anticoagulation should be considered with respect to the baseline risk of thromboembolisms, regardless of apparent procedural success.[42]

Collateral Nervous Damage

Ganglionated Plexi Ablation

It has been described that vagal reflexes from clusters of autonomic ganglia, so-called ganglionated plexi (GP), at sites around the circumference of the LA-PV junction, may induce and perpetuate AF through spatial heterogeneity of refractoriness.[40] Recent meta-analysis has shown that GP ablation in addition to PV isolation increased the rate of sinus rhythm maintenance in both paroxysmal and nonparoxymal AF patients.[41] However, GP ablation alone yielded a lower success rate when compared with PV isolation. The long-term significance of vagal denervation after ablation is unclear. Recovery of the vagal system has been described in the canine heart and after heart transplantation and could be explained by incomplete ablation, reinnervation of the neural network or increased end-organ sensitivity due to muscarinic receptor remodeling.[42]

It is not infrequent to find that locations of GP are in close proximity to esophagus and phrenic nerve. As a result, the potential complications associated with GP ablation are esophageal injury, phrenic nerve injury and cardiac perforation.[43] Some investigators located GP by applying high-frequency stimulation to both the endocardial and epicardial atrial regions. With this regard, the potential complications related to percutaneous pericardial puncture should also be concerned. Also, anatomic GP modification appears to carry a higher risk of iatrogenic creation of macroreentrant atrial tachycardia than PV isolation.[43]

Vagal Denervation

Gastric hypomotility has been reported as an extracardiac adverse effect after vagal denervation.[44, 45] The vagal fibers innervating the pyloric sphincter and the gastric antrum play an important role of gastric emptying. The damage of this periesophageal vagal plexus which usually locates on the anterior portion of the esophagus may result in gastric hypomotility.[46] The clinical presentation is characterized by abdominal bloating and discomfort occurring within a few hours to few days after the procedure. An earlier onset of symptoms has been shown to correlate with significant residual gastric motor dysfunction.[45] The gastrointestinal evaluation of vagus nerve injury includes an endoscopic study, a barium swallow study and real-time magnetic resonance imaging. The vagus nerve integrity can also be evaluated with the assessment of pancreatic polypeptide secretion with sham feeding or induced hypoglycemia.[47] Although most of the patients eventually recover completely after supportive treatment, some patients with persistent symptoms may require more aggressive options, such as local injection of Botulinum toxin on pylorus, pylorus endoscopical dilatation or surgery.[44, 45]

Real-time esophageal position and temperature monitoring during AF ablation with decreased RF power if there is a temperature rise are considered important strategies to reduce the risk of both atrial-esophageal fistula and gastric hypomotility.

The other concern after vagal denervation is the possibility of inappropriate sinus tachycardia. Previous studies have reported inappropriate sinus tachycardia as a complication that occurs after ablation of AF for which a change of autonomic tone from vagus nerve injury is the postulated explanation.[47, 48] The treatment options include beta-blocker, ivabradine and sinus node modification in medically refractory cases.

Phrenic Nerve Injury

Phrenic nerve injury is a rare complication that may occur as a result of AF ablation with a reported incidence of 0.5%.[49] The right and left phrenic nerves can be damaged during ablation because the nerves are located in close proximity to the right atrium (RA), right superior PV (RSPV), superior vena cava (SVC), LAA. Phrenic nerve injury secondary to catheter ablation appears to have a benign prognosis and most cases showed full clinical recovery of phrenic nerve function over time. The majority of the patients is asymptomatic or has mild symptoms. Nevertheless, some patients may develop respiratory insufficiency or

pneumonia secondary to phrenic nerve injury.[49, 50]

In order to prevent phrenic nerve injury, high-output pacing prior to ablation, fluoroscopy monitoring of diaphragmatic motility during ablation, and energy delivering away from the phrenic nerve should be considered. In situations where the critical area of ablation has phrenic nerve capture with pacing, protecting the phrenic nerve by placing a balloon placement in the epicardial space has been previously reported.[51]

Epicardial AF Ablation

Percutaneous epicardial catheter ablation has been used for treating epicardial ventricular tachycardia and accessory pathways.[52] Due to the fact that the atrium is a relatively thin structure and transmural lesion could be generally generated by endocardial ablation, the percutaneous epicardial catheter has infrequently been performed in AF patients. However, the endocardial ablation may not be sufficient to target some arrhythmogenic epicardial structures such as the ligament of Marshall or thick ridges between the LAA and left-sided PVs or GP. Previous study has demonstrated that the hybrid percutaneous epicardial catheter ablation and endocardial ablation for AF is an effective strategy in patients who are resistant to endocardial ablation.[53] It has been suggested that the percutaneous epicardial catheter ablation may be favorable in AF patients who need redo-ablation procedures with a high risk for left-sided PV stenosis, those patients with a history of a failed endocardial ablation, and difficult transseptal puncture during redo-procedure.[53]

The postprocedure pericarditis is one of the common complications after percutaneous epicardial catheter ablation. This condition can be reduced or prevented by empirical instillation of intrapericardial corticosteroids at the completion of the procedure.[54] The other common complication is inadvertent right ventricular (RV) puncture. The incidence of RV puncture has been reported to be 17% of cases in which percutaneous access is attempted.[52] Most cases of RV puncture are self-limiting, but some may require surgical repair. Other less common complications related to percutaneous epicardial access include RV pseudoaneurysm, hepatic injury, epicardial vascular laceration, RV-abdominal fistula formation, and coronary arterial vasospasm.[55]

Predictors of Procedural Complications

Many studies have examined the predictors for procedural complications with AF ablation in order to reduce and potentially avoid the overall complication rate in AF ablation.[30, 56, 57] Several investigators have identified subgroups at higher risk for complications including female gender, older age, the presence of heart failure and CHADS2≥2.[30, 56-59] It has been observed that complication rates at high-volume centers are lower than at centers performing fewer procedures. Previous study by Hoyt and colleagues demonstrated that the complication rate decreased significantly from 11.1% in 2002 to1.6% in 2010 as the annual procedure volume and the number of AF ablationists increased.[30] Accordingly, published guideline suggests that a minimum of 50 procedures during clinical training and several ablation procedures per month during practice are needed to gain and maintain proficiency.[60] In addition, the change of practice pattern overtime such as the ablation outside PV ostium, uninterrupted warfarin, the use of irrigated catheters may have a major impact on complication rate. Nevertheless, the changes in AF ablation technology may not be able to completely eliminate procedure-related complications. Therefore, those predictors for procedural complications should be taken into consideration to determine a tailored benefit/risk ratio in each individual patient referred for AF ablation.

Conclusions

Despite the advance in AF ablation technology and the improvement of AF ablation techniques, several serious complications still have occurred in patients undergoing AF ablation. Improving the safety remains therefore an important challenge. The prompt recognition and proper management of critical procedural complications is crucial. The possible preventive methods should also be seriously undertaken to avoid the potential dangers of the AF ablation procedure.

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References

1. 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(9):1100-1105.

2. Cappato R, Calkins H, Chen SA, Davies W, Iesaka Y, Kalman J, Kim YH, Klein G, Natale A, Packer D, Skanes A, Ambrogi F, Biganzoli E. Updated worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. Circ Arrhythm Electrophysiol.3(1):32-38.

3. Bohnen M, Stevenson WG, Tedrow UB, Michaud GF, John RM, Epstein LM, Albert CM, Koplan BA. Incidence and predictors of major complications from contemporary catheter ablation to treat cardiac arrhythmias. Heart Rhythm.8(11):1661-1666.

4. Cappato R, Calkins H, Chen SA, Davies W, Iesaka Y, Kalman J, Kim YH, Klein G, Natale A, Packer D, Skanes A. Prevalence and causes of fatal outcome in catheter ablation of atrial fibrillation. J Am Coll Cardiol. 2009;53(19):1798-1803.

5. Haissaguerre M, Jais P, Shah DC, Takahashi A, Hocini M, Quiniou G, Garrigue S, Le Mouroux A, Le Metayer P, Clementy J. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med. 1998;339(10):659-666.

6. Chen SA, Hsieh MH, Tai CT, Tsai CF, Prakash VS, Yu WC, Hsu TL, Ding YA, Chang MS. Initiation of atrial fibrillation by ectopic beats originating from the pulmonary veins: electrophysiological characteristics, pharmacological responses, and effects of radiofrequency ablation. Circulation. 1999;100(18):1879-1886.

7. Jais P, Hocini M, Macle L, Choi KJ, Deisenhofer I, Weerasooriya R, Shah DC, Garrigue S, Raybaud F, Scavee C, Le Metayer P, Clementy J, Haissaguerre M. Distinctive electrophysiological properties of pulmonary veins in patients with atrial fibrillation. Circulation. 2002;106(19):2479-2485.

8. Gerstenfeld EP, Guerra P, Sparks PB, Hattori K, Lesh MD. Clinical outcome after radiofrequency catheter ablation of focal atrial fibrillation triggers. J Cardiovasc Electrophysiol. 2001;12(8):900-908.

9. Saad EB, Rossillo A, Saad CP, Martin DO, Bhargava M, Erciyes D, Bash D, Williams-Andrews M, Beheiry S, Marrouche NF, Adams J, Pisano E, Fanelli R, Potenza D, Raviele A, Bonso A, Themistoclakis S, Brachmann J, Saliba WI, Schweikert RA, Natale A. Pulmonary vein stenosis after radiofrequency ablation of atrial fibrillation: functional characterization, evolution, and influence of the ablation strategy. Circulation. 2003;108(25):3102-3107.

10. Yu WC, Hsu TL, Tai CT, Tsai CF, Hsieh MH, Lin WS, Lin YK, Tsao HM, Ding YA, Chang MS, Chen SA. Acquired pulmonary vein stenosis after radiofrequency catheter ablation of paroxysmal atrial fibrillation. J Cardiovasc Electrophysiol. 2001;12(8):887-892.

11. Taylor GW, Kay GN, Zheng X, Bishop S, Ideker RE. Pathological effects of extensive radiofrequency energy applications in the pulmonary veins in dogs. Circulation. 2000;101(14):1736-1742.

12. Packer DL, Keelan P, Munger TM, Breen JF, Asirvatham S, Peterson LA, Monahan KH, Hauser MF, Chandrasekaran K, Sinak LJ, Holmes DR, Jr. Clinical presentation, investigation, and management of pulmonary vein stenosis complicating ablation for atrial fibrillation. Circulation. 2005;111(5):546-554.

13. Saad EB, Marrouche NF, Saad CP, Ha E, Bash D, White RD, Rhodes J, Prieto L, Martin DO, Saliba WI, Schweikert RA, Natale A. Pulmonary vein stenosis after catheter ablation of atrial fibrillation: emergence of a new clinical syndrome. Ann Intern Med. 2003;138(8):634-638.

14. Prieto LR, Schoenhagen P, Arruda MJ, Natale A, Worley SE. Comparison of stent versus balloon angioplasty for pulmonary vein stenosis complicating pulmonary vein isolation. J Cardiovasc Electrophysiol. 2008;19(7):673-678.

15. Di Biase L, Fahmy TS, Wazni OM, Bai R, Patel D, Lakkireddy D, Cummings JE, Schweikert RA, Burkhardt JD, Elayi CS, Kanj M, Popova L, Prasad S, Martin DO, Prieto L, Saliba W, Tchou P, Arruda M, Natale A. Pulmonary vein total occlusion following catheter ablation for atrial fibrillation: clinical implications after long-term follow-up. J Am Coll Cardiol. 2006;48(12):2493-2499.

16. Jais P, Cauchemez B, Macle L, Daoud E, Khairy P, Subbiah R, Hocini M, Extramiana F, Sacher F, Bordachar P, Klein G, Weerasooriya R, Clementy J, Haissaguerre M. Catheter ablation versus antiarrhythmic drugs for atrial fibrillation: the A4 study. Circulation. 2008;118(24):2498-2505.

17. Lee G, Sparks PB, Morton JB, Kistler PM, Vohra JK, Medi C, Rosso R, Teh A, Halloran K, Kalman JM. Low risk of major complications associated with pulmonary vein antral isolation for atrial fibrillation: results of 500 consecutive ablation procedures in patients with low prevalence of structural heart disease from a single center. J Cardiovasc Electrophysiol.22(2):163-168.

18. Wongcharoen W, Tsao HM, Wu MH, Tai CT, Chang SL, Lin YJ, Chang CY, Chen SA. Preexisting pulmonary vein stenosis in patients undergoing atrial fibrillation ablation: a report of five cases. J Cardiovasc Electrophysiol. 2006;17(4):423-425.

19. Ghia KK, Chugh A, Good E, Pelosi F, Jongnarangsin K, Bogun F, Morady F, Oral H. A nationwide survey on the prevalence of atrioesophageal fistula after left atrial radiofrequency catheter ablation. J Interv Card Electrophysiol. 2009;24(1):33-36.

20. Bunch TJ, Nelson J, Foley T, Allison S, Crandall BG, Osborn JS, Weiss JP, Anderson JL, Nielsen P, Anderson L, Lappe DL, Day JD. Temporary esophageal stenting allows healing of esophageal perforations following atrial fibrillation ablation procedures. J Cardiovasc Electrophysiol. 2006;17(4):435-439.

21. Lemola K, Sneider M, Desjardins B, Case I, Han J, Good E, Tamirisa K, Tsemo A, Chugh A, Bogun F, Pelosi F, Jr., Kazerooni E, Morady F, Oral H. Computed tomographic analysis of the anatomy of the left atrium and the esophagus: implications for left atrial catheter ablation. Circulation. 2004;110(24):3655-3660.

22. Sonmez B, Demirsoy E, Yagan N, Unal M, Arbatli H, Sener D, Baran T, Ilkova F. A fatal complication due to radiofrequency ablation for atrial fibrillation: atrio-esophageal fistula. Ann Thorac Surg. 2003;76(1):281-283.

23. Martinek M, Bencsik G, Aichinger J, Hassanein S, Schoefl R, Kuchinka P, Nesser HJ, Purerfellner H. Esophageal damage during radiofrequency ablation of atrial fibrillation: impact of energy settings, lesion sets, and esophageal visualization. J Cardiovasc Electrophysiol. 2009;20(7):726-733.

24. Good E, Oral H, Lemola K, Han J, Tamirisa K, Igic P, Elmouchi D, Tschopp D, Reich S, Chugh A, Bogun F, Pelosi F, Jr., Morady F.

Movement of the esophagus during left atrial catheter ablation for atrial fibrillation. J Am Coll Cardiol. 2005;46(11):2107-2110.

25. Cummings JE, Schweikert RA, Saliba WI, Burkhardt JD, Brachmann J, Gunther J, Schibgilla V, Verma A, Dery M, Drago JL, Kilicaslan F, Natale A. Assessment of temperature, proximity, and course of the esophagus during radiofrequency ablation within the left atrium. Circulation. 2005;112(4):459-464.

26. Tsuchiya T, Ashikaga K, Nakagawa S, Hayashida K, Kugimiya H. Atrial fibrillation ablation with esophageal cooling with a cooled water-irrigated intraesophageal balloon: a pilot study. J Cardiovasc Electrophysiol. 2007;18(2):145-150.

27. Buch E, Nakahara S, Shivkumar K. Intra-pericardial balloon retraction of the left atrium: a novel method to prevent esophageal injury during catheter ablation. Heart Rhythm. 2008;5(10):1473-1475.

28. Chugh A, Rubenstein J, Good E, Ebinger M, Jongnarangsin K, Fortino J, Bogun F, Pelosi F, Jr., Oral H, Nostrant T, Morady F. Mechanical displacement of the esophagus in patients undergoing left atrial ablation of atrial fibrillation. Heart Rhythm. 2009;6(3):319-322.

29. Koruth JS, Reddy VY, Miller MA, Patel KK, Coffey JO, Fischer A, Gomes JA, Dukkipati S, D'Avila A, Mittnacht A. Mechanical esophageal displacement during catheter ablation for atrial fibrillation. J Cardiovasc Electrophysiol.23(2):147-154.

30. Hoyt H, Bhonsale A, Chilukuri K, Alhumaid F, Needleman M, Edwards D, Govil A, Nazarian S, Cheng A, Henrikson CA, Sinha S, Marine JE, Berger R, Calkins H, Spragg DD. Complications arising from catheter ablation of atrial fibrillation: temporal trends and predictors. Heart Rhythm.8(12):1869-1874.

31. Jais P, Hocini M, Hsu LF, Sanders P, Scavee C, Weerasooriya R, Macle L, Raybaud F, Garrigue S, Shah DC, Le Metayer P, Clementy J, Haissaguerre M. Technique and results of linear ablation at the mitral isthmus. Circulation. 2004;110(19):2996-3002.

32. Bunch TJ, Asirvatham SJ, Friedman PA, Monahan KH, Munger TM, Rea RF, Sinak LJ, Packer DL. Outcomes after cardiac perforation during radiofrequency ablation of the atrium. J Cardiovasc Electrophysiol. 2005;16(11):1172-1179.

33. O'Neill MD, Jais P, Derval N, Hocini M, Haissaguerre M. Two techniques to avoid surgery for cardiac tamponade occurring during catheter ablation of atrial fibrillation. J Cardiovasc Electrophysiol. 2008;19(3):323-325.

34. Hsu LF, Jais P, Hocini M, Sanders P, Scavee C, Sacher F, Takahashi Y, Rotter M, Pasquie JL, Clementy J, Haissaguerre M. Incidence and prevention of cardiac tamponade complicating ablation for atrial fibrillation. Pacing Clin Electrophysiol. 2005;28 Suppl 1:S106-109.

35. 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(10):1265-1271.

36. Oral H, Chugh A, Ozaydin M, Good E, Fortino J, Sankaran S, Reich S, Igic P, Elmouchi D, Tschopp D, Wimmer A, Dey S, Crawford T, Pelosi F, Jr., Jongnarangsin K, Bogun F, Morady F. Risk of thromboembolic events after percutaneous left atrial radiofre-

quency ablation of atrial fibrillation. Circulation. 2006;114(8):759-765.

37. Camm AJ, Lip GY, De Caterina R, Savelieva I, Atar D, Hohnloser SH, Hindricks G, Kirchhof P, Bax JJ, Baumgartner H, Ceconi C, Dean V, Deaton C, Fagard R, Funck-Brentano C, Hasdai D, Hoes A, Knuuti J, Kolh P, McDonagh T, Moulin C, Popescu BA, Reiner Z, Sechtem U, Sirnes PA, Tendera M, Torbicki A, Vahanian A, Windecker S, Vardas P, Al-Attar N, Alfieri O, Angelini A, Blomstrom-Lundqvist C, Colonna P, De Sutter J, Ernst S, Goette A, Gorenek B, Hatala R, Heidbuchel H, Heldal M, Kristensen SD, Le Heuzey JY, Mavrakis H, Mont L, Filardi PP, Ponikowski P, Prendergast B, Rutten FH, Schotten U, Van Gelder IC, Verheugt FW. 2012 focused update of the ESC Guidelines for the management of atrial fibrillation: an update of the 2010 ESC Guidelines for the management of atrial fibrillation. Developed with the special contribution of the European Heart Rhythm Association. Eur Heart J.33(21):2719-2747.

38. Lemola K, Desjardins B, Sneider M, Case I, Chugh A, Good E, Han J, Tamirisa K, Tsemo A, Reich S, Tschopp D, Igic P, Elmouchi D, Bogun F, Pelosi F, Jr., Kazerooni E, Morady F, Oral H. Effect of left atrial circumferential ablation for atrial fibrillation on left atrial transport function. Heart Rhythm. 2005;2(9):923-928.

39. Guiot A, Jongnarangsin K, Chugh A, Suwanagool A, Latchamsetty R, Myles JD, Jiang Q, Crawford T, Good E, Pelosi F, Jr., Bogun F, Morady F, Oral H. Anticoagulant therapy and risk of cerebrovascular events after catheter ablation of atrial fibrillation in the elderly. J Cardiovasc Electrophysiol.23(1):36-43.

40. Bettoni M, Zimmermann M. Autonomic tone variations before the onset of paroxysmal atrial fibrillation. Circulation. 2002;105(23):2753-2759.

41. Zhang Y, Wang Z, Wang W, Wang J, Gao M, Hou Y. Efficacy of cardiac autonomic denervation for atrial fibrillation: a meta-analysis. J Cardiovasc Electrophysiol.23(6):592-600.

42. Sakamoto S, Schuessler RB, Lee AM, Aziz A, Lall SC, Damiano RJ, Jr. Vagal denervation and reinnervation after ablation of ganglionated plexi. J Thorac Cardiovasc Surg.139(2):444-452.

43. Po SS, Nakagawa H, Jackman WM. Localization of left atrial ganglionated plexi in patients with atrial fibrillation. J Cardiovasc Electrophysiol. 2009;20(10):1186-1189.

44. Pisani CF, Hachul D, Sosa E, Scanavacca M. Gastric hypomotility following epicardial vagal denervation ablation to treat atrial fibrillation. J Cardiovasc Electrophysiol. 2008;19(2):211-213.

45. Shah D, Dumonceau JM, Burri H, Sunthorn H, Schroft A, Gentil-Baron P, Yokoyama Y, Takahashi A. Acute pyloric spasm and gastric hypomotility: an extracardiac adverse effect of percutaneous radiofrequency ablation for atrial fibrillation. J Am Coll Cardiol. 2005;46(2):327-330.

46. Sanchez-Quintana D, Cabrera JA, Climent V, Farre J, Mendonca MC, Ho SY. Anatomic relations between the esophagus and left atrium and relevance for ablation of atrial fibrillation. Circulation. 2005;112(10):1400-1405.

47. Bunch TJ, Ellenbogen KA, Packer DL, Asirvatham SJ. Vagus nerve injury after posterior atrial radiofrequency ablation. Heart Rhythm. 2008;5(9):1327-1330.

48. Hsieh MH, Chiou CW, Wen ZC, Wu CH, Tai CT, Tsai CF, Ding

YA, Chang MS, Chen SA. Alterations of heart rate variability after radiofrequency catheter ablation of focal atrial fibrillation originating from pulmonary veins. Circulation. 1999;100(22):2237-2243.

49. Sacher F, Monahan KH, Thomas SP, Davidson N, Adragao P, Sanders P, Hocini M, Takahashi Y, Rotter M, Rostock T, Hsu LF, Clementy J, Haissaguerre M, Ross DL, Packer DL, Jais P. Phrenic nerve injury after atrial fibrillation catheter ablation: characterization and outcome in a multicenter study. J Am Coll Cardiol. 2006;47(12):2498-2503.

50. Bai R, Patel D, Di Biase L, Fahmy TS, Kozeluhova M, Prasad S, Schweikert R, Cummings J, Saliba W, Andrews-Williams M, Themistoclakis S, Bonso A, Rossillo A, Raviele A, Schmitt C, Karch M, Uriarte JA, Tchou P, Arruda M, Natale A. Phrenic nerve injury after catheter ablation: should we worry about this complication? J Cardiovasc Electrophysiol. 2006;17(9):944-948.

51. Rubenstein JC, Kim MH, Jacobson JT. A novel method for sinus node modification and phrenic nerve protection in resistant cases. J Cardiovasc Electrophysiol. 2009;20(6):689-691.

52. Sacher F, Roberts-Thomson K, Maury P, Tedrow U, Nault I, Steven D, Hocini M, Koplan B, Leroux L, Derval N, Seiler J, Wright MJ, Epstein L, Haissaguerre M, Jais P, Stevenson WG. Epicardial ventricular tachycardia ablation a multicenter safety study. J Am Coll Cardiol.55(21):2366-2372.

53. Pak HN, Hwang C, Lim HE, Kim JS, Kim YH. Hybrid epicardial and endocardial ablation of persistent or permanent atrial fibrillation: a new approach for difficult cases. J Cardiovasc Electrophysiol. 2007;18(9):917-923.

54. d'Avila A, Neuzil P, Thiagalingam A, Gutierrez P, Aleong R, Ruskin JN, Reddy VY. Experimental efficacy of pericardial instillation of anti-inflammatory agents during percutaneous epicardial catheter ablation to prevent postprocedure pericarditis. J Cardiovasc Electrophysiol. 2007;18(11):1178-1183.

55. Koruth JS, Aryana A, Dukkipati SR, Pak HN, Kim YH, Sosa EA, Scanavacca M, Mahapatra S, Ailawadi G, Reddy VY, d'Avila A. Unusual complications of percutaneous epicardial access and epicardial mapping and ablation of cardiac arrhythmias. Circ Arrhythm Electrophysiol.4(6):882-888.

56. Baman TS, Jongnarangsin K, Chugh A, Suwanagool A, Guiot A, Madenci A, Walsh S, Ilg KJ, Gupta SK, Latchamsetty R, Bagwe S, Myles JD, Crawford T, Good E, Bogun F, Pelosi F, Jr., Morady F, Oral H. Prevalence and predictors of complications of radiofrequency catheter ablation for atrial fibrillation. J Cardiovasc Electrophysiol.22(6):626-631.

57. Shah RU, Freeman JV, Shilane D, Wang PJ, Go AS, Hlatky MA. Procedural complications, rehospitalizations, and repeat procedures after catheter ablation for atrial fibrillation. J Am Coll Cardiol.59(2):143-149.

58. 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(6):627-631.

59. Wongcharoen W, Chen SA. Management of atrial fibrillation in patients with heart failure: from drug therapy to ablation. Expert Rev Cardiovasc Ther. 2009;7(3):311-322.

60. 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(6):816-861.