COMPLICATIONS OF ATRIAL FIBRILLATION ABLATION

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Catheter ablation complications. Introduction

Currently, catheter ablation can be considered as an effective treatment among patients with symptomatic atrial fibrillation (AF), but both feasibility and safety of the procedure are strongly required (1-9). Due to its complexity as well as the significant length of time needed to successfully ablate all targeted areas in the left atrium, it is mandatory to define an acceptable risk-benefit ratio and how to avoid many of the serious complications (Fig.1). Although complications rates of catheter ablation of AF are declining (1-3), they may nullify any mid-to-long-term benefit of the procedure. There are mechanical complications resulting from catheter manipulation within the cardiac chambers, cardio-embolic complications (stroke and transient ischemic attacks), and complications arising from the effects of RF applications in the left atrium (pericardial effusion/tamponade). The most frequent acute complications arise from the vascular access, trans-septal puncture, and left atrium navigation and ablation, while incessant new onset atypical atrial tachycardias are the most frequent late complications. An evolving and better understanding of the procedure-related risks have helped to limit complication rates by changing ablation approaches to avoid RF applications within PVs or just at PV ostia, thus ensuring an appropriate anticoagulation during the procedure with an accurate monitoring, or by using 3D electro-anatomic mapping systems for an accurate reconstruction of intracardiac structures, and by recognizing complications promptly both during and after the procedure. Hopefully, improved techniques and operator' experience in the next years will be useful to further improve both efficacy and safety of catheter ablation of atrial fibrillation to allow for continued growth of this procedure (Figures 2 and 3). At present, CARTO-guided left atrial circumferential ablation (48.2% of patients) and LASSO-guided ostial electric disconnection (27.4%) are the most commonly used techniques (1-3). Death is a very rare complication (0.03%) and in our experience based on > 15.000 procedures this fatal complication has never occurred. A detailed list of the different complications of CPVA with their relative incidence is reported in Figure 4. Pre-procedural imaging techniques are routinely performed in our Department to evaluate the left atrial size, anatomy, and function as well as to exclude the presence of an atrial thrombus. During the procedure, while fluoroscopy remains a useful modality for guiding both trans-septal catheterization and catheter navigation, several imaging modalities have been developed to improve 3D navigation and ablation within the cardiac chambers. Post-operative imaging is used to monitor the heart function as well as to exclude potential complications like pericardial effusion or pulmonary vein stenosis. While trans-thoracic echocardiography and fluoroscopy are mandatory for all patients in the context of AF ablation, the use of other imaging modalities depend on the single center experience. There must be a balance between irradiation reduction and procedural duration, improvement in catheter manipulation, cost-effectiveness ratio, and potential adverse effects of each imaging procedure.

Vascular complications

Periferal vascular complications are usually considered as minor complications and include hematoma, artero-venous fistula, and femoral pseudoaneuriosm. Major vascular complications of the procedure are rare and include hemotorax, subclavian hematoma, and extrapericardial PV perforation. Vascular complications are detected during ablation by invasive blood pressure monitoring, oxygen saturation, and after ablation by pressure monitoring and blood exams. Management of vascular complications consists in an aggressive approach to repair them while limiting anticoagulation (low ACT).

Trans-septal puncture

Trans-septal puncture is required in patients undergoing AF ablation. Although this approach is safe in the majority of cases (> 99%), potential complications may occur even in experienced hands. In up to 1% of cases trans-septal puncture is not feasible and the main reason for an unsuccessful puncture is related to fossa ovalis/atrial septum anatomy. The majority of the general population does not have a patent foramen ovale and, then, trans-septal puncture for access into the LA is required in most patients undergoing catheter ablation of AF. Using the standard Brockenbrough approach (with fluoroscopy only), a ‘jump’ is seen when pulling the trans-septal sheath down the septum, indicating the position of the foramen ovale. The needle position in relation to the septum can be checked in relation to catheters marking the His bundle and coronary sinus (CS), using orthogonal planes. Injection of contrast onto the septum may help in evaluating the exact location of the needle before advancing the dilator and the sheath. This method provides useful information to safely perform trans-septal puncture in most cases, but variations in the septal anatomy or adjacent structures may increase the risk of complications. Trans-esophageal echocardiography (TOE) can help to localize the septum, with tenting seen when the needle and sheath are pushed onto the foramen. The problem with using TOE is that the patient is in a prone position, making airway management difficult, often with the requirement of general anaesthesia. To overcome this problem, intra-cardiac echocardiography (ICE) is routinely used in some centres to facilitate an accurate definition of the region. Trans-septal puncture may be associated with puncture of adjacent structures such as aortic root, right atrial posterior wall, coronary sinus, and circumflex artery. Perforation of aortic root and posterior wall by needle only is usually “benign” while inadvertent advance of the Mullins introducer into the aortic root is a major and serious complication which requires an aggressive management. Cardiac perforation with tamponade is rare occurring in about 0.1% of cases and requires an aggressive approach (Fig. 5).

Complications during navigation and ablation

Embolization. Evaluation of a potential presence of an atrial thrombus is required prior to AF ablation for patients at risk since catheter movements may dislodge a thrombus with potential embolic complications. Current guidelines suggest that patients with AF at the time of the procedure should have TOE performed within 48 h of the procedure regardless of whether they have been anticoagulated with warfarin or not. For low-risk lone paroxysmal AF with prior anticoagulation, there is some uncertainty about the utility of performing routine thrombus detection. In this case, TTE can be used to risk-stratify patients before performing TOE with a very high negative predictive value. Catheter ablation of AF requires multiple RF lesions arranged in an accurate geometrical pattern. Multiple burns and extensive endotelial injury potentially increase the risk of acute and subacute thrombpsis (Fig.1). Large surface catheters increase lesion volume mostly by making the ledsion longer rather than thicker. Conventional ablation catheters achieve a maximum lesion depth of 5-6 mm. RF energy is generally safe and the fibrosis induced by RF energy is completed at 8 weeks after the procedure and is not associated with clinical side-effects.The thickness of atrial wall is usually superior to the maximal thickness generated by RF lesions and limited and short RF applications are at very low risk of thrombosis. The left atrial wall is very thin and is surrounded by by critical anatomical structures which may be damaged by heat. RF applications may be delivered to structures that may react with acute and chronic fibrosis. Navigation and ablation may be associated with potential complications which include embolization, perforation, PV stenosis, circumflex artey occlusion, and esophageal perforation. Embolization may be caused by preexisting thrombus dislodgment. In addition, multiple successive burns may cause tip carbonization. In addition, extensive endocardial damage is a potential thrombogenic substrate. Finally, multiple trans-septal punctures may increase the risk of air embolization. Transesophageal echocardiography before the procedure to rule out even laminar not mobile thrombi is the best way to prevent potential embolization in the majority of cases. Ablation must be performed on anticoagulation and heparin doses are tritaed by ACT with values between 250 and 350. Effective anticoagulation should be maintained in the post-operative period. Tip carbonization is a consequence of excessive heating at the tip-tissue interface and it is commonest with 4 mm tip catheters. Larger 8 mm tip catheters still require anticoagulation. Irrigation technology advancement will further reduce embolic complications. In our experience “dragging while ablating” may reduce the risk of carbonization and long consecutive RF applications on the same spot should be avoided. Omogeneous irrigation with a specifically designed catheter can reduce complications while enhancing lesion formation. Proximal irrigation protect this part from charring while delivering energy with the lateral side of the ablation tip catheter permits that lesion is fastly performed. In the next future, heparin-free procedures may be performed with new catheters.

Perforation. Left atrial perforation is usually related to catheter manipulation rather than to RF applications while posterior wall perforation is generally due to RF delivery (Fig 5). Cardiac perforation with tamponade is the most frequent complication, but its rate appears to be comparable to values commonly observed during CA of other arrhythmogenic substrates (9,10). This complication is usually associated with a rapid hemodynamic deterioration which requires a close availability of surgical facilities for management. Cardiac tamponade due to right sided perforation usually becomes clinically manifest in the first hour after the procedure. A continuous invasive monitoring of blood pressure, ACT, and oxygen saturation is recommennded during the procedure. Pericardiocentesis is the treatment of choice and gas analysis of of the blood aspirated from pericardium indicates the site of perforation. “Arterial” blood is diagnostic of left sided perforation. Detection of cardiac perforation is done by pressure monitoring, contrast trial, and echo in laboratory. Management of this complication consists in an aggressive approach to drain associated with reverse anticoagulation and drainage for 48 hours. It is not possible to lose a patient for a pericardial tamponade in 2010! Recently, the use of “fluid” magnetic catheters virtually eliminate the risk of cardiac perforation (Fig. 2).

Pulmonary vein stenosis. One of the most serious complications of catheter ablation of AF is the development of PV stenosis. This complication is due to RF delivery on the PV ostia and was mainly related to the focal or perimetral approach as initially described by Haissaguerre et al (5). However, at present, its prevalence is declining by at least 3-fold as RF delivery inside the PVs is avoided in all current approaches and precise 3D reconstruction of atrial geometry and PV ostia is performed (1-3). Since pulmonary vein isolation represents the cornerstone of all ablation strategies for both paroxysmal and persistent AF, to minimize or avoid PVs stenosis an accurate knowledge of an individual’s PV anatomy may be useful particularly when using circular or ballon catheters.

Most patients have four PVs, two superior and two inferior with independent ostia. However, there are variations in PV anatomy, such as left common ostium (up to 83% of patients), right common ostium (up to 40%), and a separate origin for the right middle PV (up to 27% of patients). Prior knowledge of the diameter of the PVs ostia may be useful in the sizing of circular mapping catheters or balloon-catheters since a close approximation of the balloon to the PV ostia is essential for successful PV isolation. Although TOE can evaluate PV diameters, computed tomography (CT) scanning or magnetic resonance imaging (MRI) represent the gold standard. Using these imaging tools, the characteristic oval anatomy of the left-sided PVs may be accurately recorded, with a superior–inferior diameter larger than the anterior–posterior one, while the right-sided PVs appear more circular. Additionally, CT or MRI may provide useful information on all anatomical targeted sites. If stenosis occurs in multiple PVs it may be a severe complication causing significant morbidity. PV angioplasty and stenting are associated with a very high re-stenosis rates while PV dilatation is associated with significan increase in lung flow and improvements of symptoms. The clinical presentation of PVs stenosis varies widely. Most patients are symptomatic and symptoms include dyspnea or hemoptysis or may be consistent with bronchitis. Because of the variability in symptoms, clinicians must considered this potential complication in all patients after catheter ablation of AF. Diagnostic tests include magnetic resonance angiography and CT while echocardiography does not usually provide adequate assessment. Progression of stenosis is unpredictable and may be rapid. There is discordant data in the literature concerning the incidence of iatrogenic PV stenosis after AF ablation, varying from 0 to 42%. This can be explained by the lack of a standard definition of PV stenosis, the different imaging modalities used to diagnose PV stenosis, and the inhomogeneity in follow-up. Pulmonary vein stenosis tends to occur immediately after the ablation. In most patients, there will be a progressive narrowing of the stenosis, although acute PV stenosis can rarely heal spontaneously. Of note, some patients without acute/peri-procedural narrowing will still have significant PV stenosis revealed by later imaging. If significant restenosis is identified by preablation and postablation angiography or by MRI, a corrective intervention is required promptly because of the potential for progression to total occlusion. Importantly, about half of the PV stenoses requires interventional treatment, a strategy that does not necessarily abolish symptoms. This complication can be minimized or avoided by creating circumferential lesions > 1.5 cm outside PV ostia as performed by Circumferential Pulmonary Vein Ablation (CPVA), which is our approach (4,6-8). In our experience impedance mapping may be useful to accurately identify the PV/LA junction in order to avoid PV stenosis while assessing lesion formation (11).

Circumflex artery occlusion. Ablation of the left inferior PV-Mitral valve isthmus may damage the circumflex artery (Fig 6). High blood flow protects the artery wall fron heath damage. Acute circumflex artey occlusion has been reported as a complication in surgical series with use of unipolar RF applications but never following RF vatheter ablation. However, endothelial heath injury and medial proliferation may result in chronic circumflex artery damage. Catheter manipulation on the endocardial side of the left AV groove or trans-septal puncture may cause Cx spasm.

Esophageal perforation. Atrio-esophageal fistulae were not reported in the first worldwide survey of catheter ablation of AF (1) and presented with a 0.04% rate in the second worldwide survey, with 71% of events leading to death (3). The close proximity of the esophagus to the posterior left atrial wall makes it vulnerable to RF induced lesions (12,13). The thickness of the posterior atrial wall is variable, but may be very little. Esophageal fistula as a complication of catheter ablation of AF was first reported by our group (11) (Fig. 7). Previous cases have been reported in patients undergoing surgical ablation of AF by unipolar RF applications on the posterior wall of the left atrium. At present, several cases have been reported after catheter ablation (3). The clinical presentation is late usually days or even weeks after the procedure. Symptoms are consequence of massive air embolism and sepsis. Stroke is usually the first manifestation and may be heralded by fever and chest pain. Acute embolization to other targets may follow (heart, kidney) with septic shock. Mortality rates are higher than 50% and survivors experience major consequences. The late occurrence (6-10 days postablation) of a febrile state with or without neurological symptoms should prompt suspicion of an atrio-esophageal fistula which should be excluded by contrast-enhanced spiral CT. Careful titration of the combination of output, number, location and duration of pulses is critical. Lines of lesion should not be excessively wide and posterior lines should be placed on the roof of LA.

Post-procedure acute complications

The possibility to tailor RF applications, energy settings, irrigation rates in vulnerable areas contributes to minimize post-procedure late complications. Pericardial tamponade must be excluded in patients with postprocedural hypotension but in our experience this complication is very rare if one uses a careful titration of RF power and duration delivery particularly in challenging areas thus reducing tissue boiling and endocardial rupture. Symptoms of pericardial effusion usually become manifest several hours following the procedure and for this reason, all patients should have a repeat TTE prior to discharge following the procedure, especially if there is haemodynamic compromise. Transthoracic echocardiogram is the study of choice as it is easily and rapidly performed and invaluable in the follow-up of the effusion. Only a few patients have required pericardiocentesis for cardiac tamponade while small, nonhemodynamically significant pericardial effusion may develop in up to 4% of patients. Pericarditic discomfort may occur during the first days and aspirin is an adequate treatment.

Late arrhythmic complications

Early recurrences of AF after the index procedure usually occur within the first 2 months, but in half of cases they are a transient phenomenon not requiring a redo procedure(4,6-8). If recurrence of persistent AF or monthly episodes of symptomatic paroxysmal AF occur beyond the first month after ablation or new onset incessant highly symptomatic left or right atrial flutter is present, then a second procedure is scheduled at 6 months after the index procedure. A maximum of three ablation procedures per patient are allowed. Atypical atrial flutter of new onset (iatrogenic) is a serious arrhythmic complication after catheter ablation of AF representing a challenge for curative treatment (7,14). With a significantly larger number of patients with persistent or long-standing AF undergoing catheter ablation, iatrogenic left atrial flutter appears to be a more frequent complication regardless of the operator'experience. Initially, this iatrogenic arrhythmic complication has been reported in a minority of cases (about 4 %), but its prevalence is increasing (> 8%) as catheter ablation is increasingly being offered to siker AF patients with left ventricular dysfunction and larger atria. More frequently the arrhythmia has been observed in centers using 3D-guided compartmentalization strategies (up to 14%) than in centers exclusively performing ablation of the triggering substrate or PV electrical disconnection alone using the Lasso catheter (3). In our approach (CPVA) if all end points are successfully achieved in the index procedure, postablation ATs may develop in less than 5% of patients (7), and usually they are macro or microreentrant gap-related rather than focal tachycardias (Figures 8-12). These ATs should initially be treated conservatively, with medical therapy and cardioversion. Only incessant ATs in symptomatic patients require a repeated procedure to optimize ablation therapy which will lead to a cure in most cases. Ablation should be tailored to the arrhythmia mechanism rather than performing empiric lesion lines**.** Close inspection of the 12-lead ECG with P-wave morphology and axis evaluation should be done initially since continuous activation suggests a macroreentrant mechanism, whereas a clear isoelectric baseline between P waves suggests a focal mechanism. We routinely perform both activation and voltage maps combined with entrainment pacing maneuvers to optimize the ablation therapy (7,14). Usually, the activation map reveals earliest and latest activations in different colors relative to the reference site within a time window equal to the tachycardia cycle length. The commonest postablation AT is macroreentrant (> 80% of the cycle length) perimitral annular tachycardia (Fig. 9), but PV or septum may be involved in the reentry circuit (Fig. 10-11). Entrainment with post-pacing intervals (PPI) ≈ tachycardia cycle length (TCL) from ≥ 3 sites around the superior and inferior mitral annulus, with an activation time around the mitral annulus ≈ to the AT cycle length strongly suggests a mitral annular AT. Like the right atrial isthmus dependent flutter, the narrowest area of the circuit is between the LIPV and the mitral annulus and the most appropriate approach is to perform reablation of the mitral isthmus looking for residual gaps. For focal microreentrant ATs (<80% of the cycle length) originating from reconnected PV ostia, ablation of sites with earliest activation that demonstrate concealed entrainment will usually be successful. Frequently, voltage maps show areas of preserved voltage at the site of earliest activation suggesting areas not previously targeted or incompletely ablated during the index procedure. Reentry around left or right PVs can be demonstrated by proximal and distal coronary sinus, left atrial roof and septal pacing. Their management requires the use of 3-D activation maps for delineating the tachycardia course, and for deploying a lesion line connecting anatomic obstacles to interrupt AT circuits (Figures 8-12). RF applications are delivered after critical isthmuses have been identified by detailed electroanatomic maps and concealed entrainment. Usually, few RF applications on the critical isthmus are sufficient to eliminate such tachycardias and their inducibility, but in some cases a further ablation line is required. Successful ablation is defined as termination of tachycardia during ablation and noninducibility of the same tachycardia morphology with burst pacing and/or programmed pacing.

Atrial remodeling after ablation

The assessment of potential consequences of RF ablation on the LA contractility is important for a potential relationship to thromboembolic risk. After ablation, we evaluate carefully the left atrial transport function before and after the procedure and serially during the long-term follow-up. In our experience, usually 6 months after ablation LA diameters decrease and LA contractile function may improve but the magnitude of this benefit mainly depends on the atrial dimensions before ablation. In patients without recurrences and with improved atrial transport and function (reverse atrial remodeling) we discontinue chronic anticoagulation therapy.

Catheter ablation complication rate. Worldwide experience

Recently, 2 extensive worldwide surveys from early experiences of catheter ablation of AF have offered an unique opportunity to better understand, prevent, and treat AF ablation procedure-related complications (1,3). The published literature has reported a lot of data, many of which from experienced centers, which necessarily do not reflect the true frequency of potential procedure-related complications. A total of 32 deaths, which corresponds to a prevalence of about one death per 1,000 patients or 0.7 deaths per 1,000 procedures has been reported. Deaths were due to bleeding, thromboembolism, or collateral injury. The first worldwide survey of catheter ablation has found a high number of complications, at 6% (1). Since these data were from early catheter ablation strategies, a higher rate of complications should be expected due to "the learning curve." It is conceivable that most complications were due to early catheter ablations than to later ones. In the second worldwide survey of catheter ablation of AF (3), the overall major complications rate was lower, at 4.5% than in the first one (1). The rate of pulmonary vein stenosis greatly decreased, and in all propbability this was due to the move away from ablating within the pulmonary veins toward ablating outside of them at least 1 cm aways from PV ostia. Other major complications included cardiac tamponade as well as transient ischemic attacks, stroke, and death. It is possible that many of these centers were still in the learning curve. Currently, there are increasing numbers of patients with comorbid conditions—including structural heart disease and congestive heart failure— who are candidate for catheter ablation. Since procedure-related complications in some cases may be life-threatening, minimizing their occurrence represents an important goal. A careful manipulation of catheters with close monitoring of RF applications and safe energy settings, certainly will minimize potential complications such as cardiac tamponade, which still represents a major cause of death. Its recognition followed by immediate perdicardiocentesis avoids tamponade-related death. Cardiac surgery 'back-up' should be available for patients with persistent bleeding. Subclavian vein access should be avoided since AF ablation procedure needs an aggressive anticoagulation. The risk of cerebrovascular events, including stroke, can be further reduced by appropriate anticoagulation both during and after the procedure. Esophageal injury is an extremely rare but potentially devastating complication of AF ablation, which in many cases (>80%) results in major morbidity or death. Real-time visualization of the esophagus with barium or a radio-opaque marker, and avoidance of RF energy applications over the esophagus, may be useful to minimize esophageal injury. If esophageal injury is suspected, a prompt diagnosis with immediate intervention is required for the patient'survival. Data collection of procedure-related complications rates according to the AF type (paroxysmal versus persistent/long-standing AF) and the use of the newest ablation tools and technologies or better energy sources are lacking. Hopefully, the complication rate of catheter ablation of AF will be further minimized in the next years. Usually, an increased experience with further thecnological advancement is associated with better results in terms of efficacy and risks, also considering that additional lesions or additional targets within the left or right atrium beyond pulmonary veins isolation are necessary in persistent or long-standing AF.

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