Successful Covered Stent Treatment and Long-term Follow up of Multiple Pulmonary Vein Stenoses Guided by Rotational Angiography with 3D Reconstruction

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ABSTRACT. Pulmonary vein (PV) stenosis is a known complication of circumferential PV isolation. We report the first case of polytetrafluoroethylene (PTFE) stent implantation guided by Rotational angiogram with three-dimensional (3D) reconstruction (3DATG) to treat multiple post ablation PV stenoses. The patient experienced immediate and dramatic clinical improvement that has been sustained for over 30 months. A significant decrease in pulmonary artery systolic pressure and excellent 3DATG results at 13 and 30 months post index procedure were demonstrated during follow-up.

KEYWORDS. pulmonary vein, rotational angiography, stenosis, stent placement, three-dimensional reconstruction.

Introduction

Ablation of atrial fibrillation (AF) has been gaining popularity with expanding indications for the procedure. A number of significant complications have emerged with this procedural growth. Certain complications, such as post ablation pulmonary vein (PV) stenosis have triggered significant controversy regarding their management. Decisions on when, where, and how to intervene are not always clear. Non-invasive management has been advocated for some patients.

Angioplasty of the stenosed veins and stent placement have been used for highly symptomatic patients. However, significant recoil and restenosis have limited the role of this intervention. Use of drug eluting coronary stents showed promising results, but may not be able to prevent restenosis due to small diameter. Stent grafts, polytetrafluoroethylene (PTFE) covered stents, have been recently advocated for their superiority in preventing recoil/restenosis in peripheral vascular disease.

A single case of PV restenosis following prior stent placement and balloon angioplasty successfully treated with a covered stent has been recently reported. Live three-dimensional (3D) visualization of the left atrium (LA) and PVs may facilitate PV interventions. Rotational angiography with 3D reconstruction (3DATG) has never been utilized to evaluate for PV stenosis. We...
describe the first use of 3DATG to visualize PV obstruction and guide PTFE-covered stent placement for multiple post-ablation PV stenoses, with a 2-year follow-up in one patient.

Case

This 45-year-old Caucasian male with a history of highly symptomatic paroxysmal AF underwent radiofrequency catheter PV isolation procedures on two occasions at two different outside institutions. He developed dyspnea on minimal exertion, decreased exercise tolerance, and hemoptysis soon after the second PV isolation. Multislice computed tomography (CT) and cardiac magnetic resonance imaging (MRI) revealed subtotal thrombotic occlusion of the left superior PV (LSPV) and significant stenoses of the left inferior PV (LIPV) and the right superior PV (RSPV). However, the extent and severity of the stenoses remained controversial despite several opinions by experienced radiologists. The patient was thus referred for further evaluation.

Right heart catheterization revealed significant elevation in right-sided pressures and pulmonic capillary wedge pressure (PCWP) (Table 1). 3DATG was performed using the Allura Xper CT 10 angiography system (Philips Healthcare, Best, The Netherlands) and EP Navigator workstation (Philips Healthcare, Best, The Netherlands) with 100 ml of contrast (Omnipaque 300, GE HealthCare, Little Chalfont, UK) injected into the right atrium. LA imaging in the levophase confirmed a subtotal occlusion of LSPV and significant stenoses of the LIPV and RSPV (Figure 1). Transseptal puncture was performed using a Brockenbrough needle and an 8.5F Agilis deflectable sheath (St. Jude Medical, Little Canada, MN) with 3DATG overlay on live fluoroscopy as a visual guide. A modestly elevated 4 mmHg PCWP/LA pressure gradient was then documented while the patient performed maximal handgrip exercise that could be achieved in the supine position. A decision was made to proceed with intervention based on the findings from multimodality imaging (Figure 1) and suspicion for underestimation of the true PV/LA gradient with supine exercise. The LIPV and subsequently RSPV were cannulated using an 8F multipurpose guiding catheter (Cordis, Miami, FL, USA) and a 0.018 V-18 wire (Boston Scientific, Natick, MA). Intravascular ultrasound (IVUS) using the Volcano system (Volcano Corporation, San Diego, CA) and direct PV angiography were used in conjunction with 3D imaging, confirming the severity and location of the stenoses (Figures 1 and 2). 3DATG was used as a guide to position and deploy PTFE-covered stents into LIPV and RSPV (Figure 2). IVUS was used intraprocedurally to confirm full deployment of the stents (Figure 2). Successful stent deployment required repeated balloon inflations of up to 12–14 atm and obvious “cracking” of the stenotic segment. Insufficient stent dilatation in the LIPV resulted in displacement of a partially expanded stent on the guiding catheter. This was successfully managed by advancing a partially inflated balloon through the guiding catheter and into the stent, carefully withdrawing the transseptal sheath and subsequently moving the stent on the partially inflated balloon back into the LIPV. This stent, a 6 × 22 mm iCAST (Atrium, Hudson, NH), was subsequently fully deployed and expanded using a higher pressure balloon with complete resolution of a “napking” type stenosis. An additional 10 × 38 mm iCAST was placed proximally, overlapping with the first, to treat residual ostial stenosis that recoiled after initial balloon dilatation. The RSPV was accessed in a similar fashion, and a 7 × 22 mm iCAST covered stent was placed. An excellent result confirmed by direct angiography and IVUS.

The LSPV could not be accessed due to its total occlusion. Immediately post procedure, the PCWP/LA gradient disappeared and cardiac output increased from 3.1 l/min to 4.1 l/min (Table 1). Mild pulmonary arterial hypertension persisted (of note, the patient was previously diagnosed with obstructive sleep apnea). The patient experienced immediate and dramatic clinical improvement that has been sustained for over 30 months. 3DATG was repeated at 13 and 30 months after the index procedure (Figure 3). Widely patent stents and excellent antegrade contrast flow were confirmed in both stented PVs. Repeat right heart catheterization demonstrated persistent mild pulmonary hypertension. However, a significant decrease in pulmonary artery systolic pressure from 73 mmHg pre-procedure to 40 mmHg at the 13-month and 33 mmHg at the 30-month follow-up was discovered.

Discussion

We report the first case of PTFE stent implantation guided by 3DATG to treat post-ablation PV stenoses. 3DATG was utilized to define the PV ostium, its antral

| Table 1: Hemodynamic measurements pre- and post procedure and in follow-up. |
|---------------------------------|------------------|-----------------|-----------------|-----------------|
|                                 | Pre-stent placement | Post-stent placement | 1-year follow-up | 2-year follow-up |
| RA pressure mean, mmHg          | 15                | 15               | 10              | 9               |
| RV pressure (systolic/diastolic), mmHg | 86/5             | 73/13            | 36/10           | 44/11           |
| PA peak pressure, mmHg          | 73                | 71               | 40              | 33              |
| PCWP, mmHg                      | 18 (exercise 20)  | 13               | 15 (exercise 16) | 13              |
| LA pressure mean, mmHg          | 16                | 13               |                 |                 |
| PCWP/LA pressure gradient, mmHg | 2 (exercise 4)    | 0                |                 |                 |
| Cardiac output, l/min           | 3.1               | 4.1              | 6.5             |                 |
portion, and to avoid stent protrusion into the LA body. The procedure was successful despite some technical challenges. During the 2-year follow-up period the patient has sustained dramatic clinical improvement. Repeat 3DATG at 13 and 30 months demonstrated widely patent stents.

PV stenosis is a known complication of circumferential PV isolation. It may occur in about 0.3% of all cases.

**Figure 1:** Pre-procedural pulmonary vein (PV) stenoses visualization using several imaging modalities. (a) The posterior view on three-dimensional (3D) left atrium (LA) shell (red) produced by rotational angiography with 3D reconstruction (3DATG). Right superior PV (RSPV) stenosis (white arrow) is clearly seen at its junction with the LA. (b) Two-dimensional slice of the LA in the anterior–posterior view from 3DATG. The virtual computed tomography (CT) slice demonstrates coronal plane through the posterior part of the left atrium and RSPV–LA junction. The diameter of the stenosed segment of RSPV is measured at 4.17 mm. (c) Standard CT slice in the axial plane. Aortic root (Ao), right ventricular outflow tract (RVOT), right atrium (RA) and left atrium (LA), and LA appendage (LAA) are shown. Black arrow points to the proximal occlusion of left superior pulmonary vein. (d) Direct left inferior PV (LIPV) angiography shows its stenosis due to septation (white arrow) 2–3 cm from the ostium. Transseptal sheath (black arrow) and a guidewire in the LIPV (black arrowheads) are also shown. Ao: aortic root; RVOT: right ventricular outflow tract; RA: right atrium; LA: left atrium, LAA: left atrial appendage.
patients undergoing ablation for AF. There is a range of opinions in the literature regarding the optimal treatment strategy in these patients. Both conservative management and percutaneous interventions have been advocated.\textsuperscript{1} Published data supports the superiority of stenting over balloon angioplasty with better long-term patency rates, especially when large diameter (>10 mm) stents are used.\textsuperscript{9} Drug eluting stents have superior patency rates than bare metal ones. However, commercially available drug eluting stents have smaller diameters, which precludes their use in large proximal PVs.\textsuperscript{3} PTFE-covered stents were shown to be superior to bare metal stents for long-term vessel patency in patients with atherosclerotic aortic bifurcation, occlusive disease, and pediatric patients.\textsuperscript{5,6,10} Therefore, we have selected these stents to treat relatively large proximal PVs. An excellent long-term result not demonstrated previously is described.

Confirming the clinical diagnosis of PV stenosis with hemodynamic values can be challenging. In the Mayo Clinic series, the stenotic orifice diameter was 3±2 mm and the stenosis was deemed severe with a trans-stenotic gradient of 10–12 mmHg.\textsuperscript{2} On the other hand, Di Biase et al.\textsuperscript{11} have shown that even total PV occlusion can be

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**Figure 2:** Multimodality imaging during pulmonary vein (PV) stents placement. (a) Three-dimensional left atrium (LA) shell by rotational angiography with 3D reconstruction (3DATG) (blue) registered on live fluoroscopy using bronchial carina (purple) is shown. Angioplasty balloon is inflated in the left inferior PV (LIPV) (white arrow). Transseptal sheath (black arrow) and a guidewire (black arrowhead) in LIPV are also shown. (b) Direct angiography immediately after successful stent deployment into right superior PV (RSPV) shows widely patent lumen with no recoil. Transseptal sheath (black arrow), guidewire in RSPV (black arrowheads), previously deployed stents in LIPV (white arrow) and Swan–Gans catheter (white arrowheads) in the right pulmonary artery are also shown. (c,d) Intravascular ultrasound images of the RSPV before and after stent placement respectively: dramatic improvement in PV diameter from 4.6 mm to 11.9 mm.
asymptomatic if there is no concomitant stenosis of the other ipsilateral PV. However, intervention should not be deferred for less than severe stenosis if the cumulative stenotic index is more than 75%. In our case, the stenotic segment diameters were not very narrow: 5.8 mm in the LIPV and 4.17 mm in the RSPV. There was a minimal resting PV/LA gradient suggesting non-critical obstruction. Limited handgrip exercise increased the gradient to only 4 mmHg. We suspected that the gradient would have been significantly higher with real exercise. Given the fact that the LSPV was occluded, the LIPV was the only drainage for the left lung, and with intraoperative multimodality imaging, we concluded that the patient had a severe PV stenosis necessitating intervention. A significant drop in the PCWP/LA gradient, coupled with dramatic clinical improvement, confirmed our suspicion that the severity of PV stenosis was initially underestimated by baseline hemodynamic and pre-procedural anatomical measurements. Excellent clinical results despite the occluded LSPV can be probably explained by the now widely patent LIPV draining blood from the entire left lung.

Several imaging methods have been advocated to characterize PV stenosis: CT, MRI, intracardiac, transesophageal, and transthoracic echocardiography. In the described case, both CT and MRI methods brought conflicting results regarding the extent and severity of PV stenoses. Intraprocedural multimodality imaging helped to define the critical degree of obstruction and the need for intervention. 3DATG showed the absence of any antegrade blood flow through the LSPV and severe narrowing of the LIPV and RSPV. IVUS allowed for the precise measurement of the stenotic segments in the RSPV and LIPV. The PV stenting procedure was also guided by the 3DATG image, which helped to define the PV ostium (and prevent stent protrusion into the LA body) and troubleshoot any untoward scenarios. The use of 3DATG in this setting has not been previously reported. In addition to stent placement, 3DATG imaging was used to guide the transseptal puncture and PV cannulation.

PV stenting may be technically challenging. An intimal flap with transient neurologic deficit, PV tear resulting in tamponade, hemoptysis and PV dissection have been reported. We encountered an incomplete stent dilatation causing its dislodgement on the guiding catheter. Fortunately, the stent was successfully repositioned using a partially inflated balloon and apposed satisfactorily, as confirmed by IVUS. Multimodality imaging was helpful to resolve this complex issue. Loss of access and subsequent rewiring of the vein through a partially expanded stent to the distal PV proved to be challenging and prolonged the procedure. Therefore, maintaining stable access to the distal PV throughout the procedure is of paramount importance.

**Conclusion**

Multiple stenoses of PVs after AF ablation can be successfully treated with PTFE-covered stents that maintain their patency over an extended follow-up (>30 months). 3DATG is an important part of a complex imaging strategy to guide the assessment of such patients and direct their intra- and postoperative management.

**References**