International Journal of Cardiology 203 (2016) 1093–1099

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

In vitro hemodynamic testing of Amplatzer plugs for paravalvular leak occlusion after transcatheter aortic valve implantation

Gaetano Burriesci [a,1], Paolo Peruzzo [b,1], Francesca Maria Susin [b,1], Giuseppe Tarantini [c], Andrea Colli [d,*]

[a] UCL Cardiovascular Engineering Laboratory, UCL Mechanical Engineering/IBME, University College London, United Kingdom
[b] Department of Civil, Environmental, and Architectural Engineering, University of Padova, Italy
[c] Cardiology Unit, Department of Cardiac, Thoracic and Vascular Sciences, University of Padova, Italy
[d] Cardiac Surgery Unit, Department of Cardiology, Thoracic and Vascular Sciences, University of Padova Medical School, Italy

ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form 4 August 2015
Accepted 16 November 2015
Available online 30 November 2015

Keywords:
Transcatheter aortic valve implantation
Transcatheter aortic valve replacement
Paravalvular leak
Aortic regurgitation
Vascular occluder

ABSTRACT

Objective: We aimed to in-vitro test Amplatzer devices (Amplatzer Vascular Plug II and Amplatzer Vascular Plug III, SJM, St. Paul, MN) in closing PVL generated by transcatheter balloon expandable aortic valve prosthesis in order to quantify the effective treatment of PVL.
Background: Transcatheter aortic valve implantation (TAVI) procedures represent the treatment of choice for high risk patients. Despite evolving technologies paravalvular leak (PVL) is still a major unaddressed issue. This severe complication significantly impairs long-term survival. Percutaneous treatment of this complication is usually performed with the implantation of not specifically designed and not approved vascular devices.
Methods: A 26 mm Sapien XT (Edwards Lifesciences, Irvine, CA) was implanted in a rubber aortic root and a semi-elliptical shape PVL was created. The vascular occluder devices were implanted in the PVL and hemodynamic performance was tested in a pulse duplicator according to international standard ISO 5840-3:2013. Different type of comparison tests together with high speed camera recording allowed us to define the global efficiency of the occluders and their interaction with the transcatheter prosthesis.
Results: The results revealed that the use of vascular plugs was not per se sufficient to produce an effective or substantial reduction of PVL with a maximum efficiency of less than 50%. Recorded video showed clearly that the vascular plug always interfered with the leaflet of the prosthetic valve.
Conclusions: Currently used devices do not guarantee effective treatment of PVL and may otherwise compromise the structural integrity of the prosthetic valve implanted. Specifically designed devices are required.
Condensed abstract: Despite evolving technologies, paravalvular leak (PVL) is still a major unaddressed issue after transcatheter aortic valve implantation. Percutaneous treatment of this complication is usually performed with the implantation of Amplatzer devices not specifically designed and not approved for this specific use. We tested Amplatzer devices in a pulse duplicator to occlude PVL generated after implantation of a 26 mm SAPIENT XT prosthesis. The results revealed that the use of vascular plugs was not per se sufficient to produce an effective or substantial reduction of PVL. The video showed clearly that the vascular plug always interfered with the leaflet of the prosthetic valve.

1. Introduction

Transcatheter aortic valve implantation (TAVI) has become the treatment of choice for inoperable patients with severe aortic stenosis [1] and mortality is comparable to surgical aortic valve replacement (SAVR) for patients at high risk [2,3]. However, TAVI may result in severe complications, the most challenging of which is paravalvular leakage (PVL), due to incomplete sealing occurring between the prosthesis and the native host tissues [3–6]. Despite the evolving technology of transcatheter valves, moderate–severe post-TAVI PVL is not uncommon [1–8] and remains a major predictor of adverse outcome after TAVI even in the presence of mild regurgitation. [9–13]. As such, PVL is one of the most important barriers to extending TAVI to lower risk patients [14,15].Given that conventional reintervention surgery is not a viable option because the patient is a high-risk/unoperable candidate, several strategies have been used to prevent or treat PVL after TAVI e.g.: heart pacing, balloon overfilling, valve-in-valve, post-dilatation with conflicting results [16,17]. More recently, percutaneous approaches to PVL closure by mean of different devices (Amplatzer PDA, Amplatzer VSD device, Amplatzer vascular plugs, coils, etc.) have been developed via trans-septal (TS) access, apical left ventricular (LV) access, or retrograde arterial access [18–30] with a reported success rate that ranges from

* Corresponding author at: Cardiac Surgery Unit, Department of Cardiac, Thoracic and Vascular Sciences, University of Padua Medical School, Via Giustiniani, 2, 35127 Padua, Italy.
[1] These authors contributed equally to this manuscript.

http://dx.doi.org/10.1016/j.ijcard.2015.11.106
0167-5273/

55% to 77%. Reasons for procedure failure are various including inability to cross the defect with a wire or delivery catheter, dislodgement/embolization of the device, incomplete closure of the defect, or interference by the device with the prosthetic valve [19–32]. Even if the device is delivered, remains in place, and reduces flow, the treatment might be clinically inadequate.

In this regard, it is noteworthy that most of the devices used are approved for other purposes and not for PVL closure. In clinical practice the most frequently used PVL closure devices after TAVI are the Amplatzer Vascular Plug II and III (St. Jude Medical, MN) [31,32]. The aim of the present study is primarily to test in vitro the hemodynamic efficiency and efficacy of the Amplatzer vascular plugs when used to close PVL after TAVI performed with a balloon expandable valve.

2. Methods

In order to verify and quantify the benefit of adapting vascular plugs for reduction of PVL after TAVI, test were performed on two different Amplatzer vascular plugs (St. Jude Medical Inc., MN). These are occluding devices, designed to provide embolization of blood vessels by obstructing their lumen. They are self-expandable transcatheter devices, made from a wire mesh tube of superelastic Ni–Ti alloy, thermomechanically shaped into different geometries, and then secured at their ends with platinum caps that act as markers. The proximal cap is welded to a stainless steel screw, which engages to a nitinol pusher-wire, used for the delivery, repositioning or removal of the component. In this study, an Amplatzer Vascular Plug II of 8 mm diameter (7 mm unconstrained length), and an Amplatzer Vascular Plug III of long axis diameter 8 mm (short axis diameter 4 mm, unconstrained length 6.5 mm) were used. The first one is characterized by a multi-layered, multi-segmented cylindrical design, aimed to create six occlusive planes (Fig. 1a). The Amplatzer Vascular Plug III has an oblong cross-sectional shape, designed to enhance stability in high-flow vessels (Fig. 1b).

A 26 mm diameter Edwards SAPIEN XT was used as a testing valve (Fig. 1c). This is the most implanted transcatheter valve, and consists of three leaflets of bovine pericardium attached to a balloon-expandable cobalt–chromium frame. A skirt of PET covers about two-thirds of the inlet portion of the valve, to reduce paravalvular leakage. The valve was released into a silicone cylindrical holder of 23 mm diameter (the 26 mm SAPIEN XT is recommended for annular diameters in the range 22–25 mm), using the standard implantation procedure, and delivered in the same angular and axial position for all tests. The holder included a semielliptical shape axial grove (size 5 mm of minor axis 3 mm of major semiaxis and total area of 12 mm^2), mimicking a paravalvular leak to be occluded (Fig. 1d).

Tests in several physiological pulsatile-flow operating conditions were performed using a hydro-mechanical pulse duplicator (ViVitro System, ViVitro Labs Inc.) in compliance with the international standard ISO 5840-3:2013. In particular, the valves' performance was assessed at six simulated cardiac outputs (*CO*) between 2 and 7 l/min, at a normal heart rate (*HR*) of 70 bpm and a normal mean aortic pressure averaged over the cardiac cycle (p_{Ao}) of 100 mm Hg. Additional tests were run at a normal simulated *CO* of 4 l/min, for combinations of three *HR*s of 45, 70 and 120 bpm and three p_{Ao} of 80, 120 and 160 mm Hg. Phosphate buffered saline solution at 37 °C was used as testing fluid. Pressures in the aortic and ventricular chambers were measured using Millar Mikro-tip pressure catheters (Millar Instruments, Inc., Houston, TX, USA), and the flow through the valve was monitored with an electromagnetic flowmeter (Carolina Medical Electronics, Inc., East Bend, NC, USA). The fifteen total combinations of functional parameters used for each testing configuration are summarized in Table 1.

During the experiments a high-speed camera (1200 frames per second) was used to record the valve dynamics during the cardiac cycle, and its interactions with the occluding devices.

The described tests were repeated for four different configurations: i) open leak (Fig. 2a), ii) partially occluded leak by Amplatzer plug II (Fig. 2b), iii) partially occluded leak by Amplatzer plug III (Fig. 2c) and

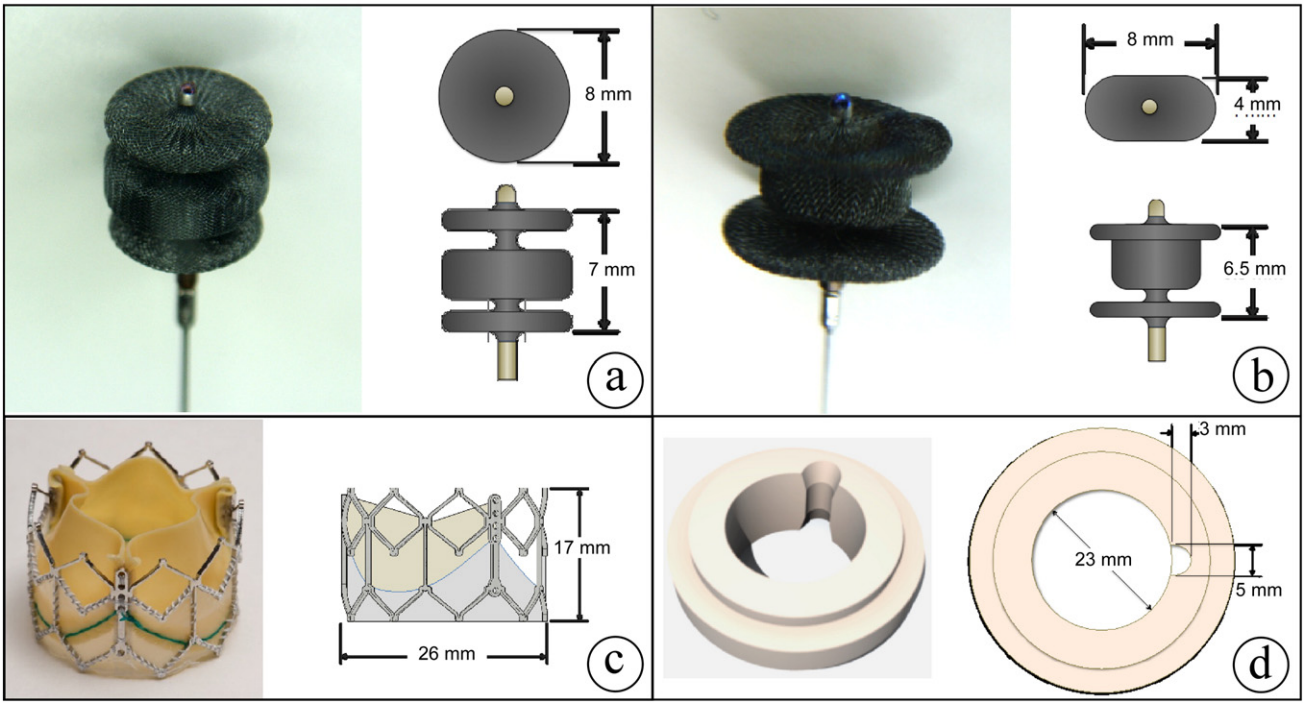

Fig. 1. Amplatzer plug implanted to occlude paravalvular orifice. a) Amplatzer plug II of 8 mm diameter and of 7 mm unconstrained length; b) Amplatzer plug III of long axis diameter 8 mm, short axis diameter 4 mm and unconstrained length 6.5 mm; c) 26 mm size Sapien valve used in the experiments and d) silicon holder with semielliptical lumen.