Phase-resolved velocity measurements in the Valsalva sinus downstream of a Transcatheter Aortic Valve

A. Ducci*, S. Tzamtzis, M. Mullen, G. Burriesci

Department of Mechanical Engineering, University College London, London, United Kingdom
*Correspondent author: a.ducci@ucl.ac.uk

Keywords: PIV, Valsalva sinus, Tavi, polymeric valve

Two sets of phase resolved PIV measurements were performed in the Valsalva sinuses of a glass mock aortic root including three polymeric valve leaflets, before and after the implant of a Medtronic CoreValve TAVI device. The experiments were carried out in a hydro-mechanical cardiovascular pulse duplicator system (Vivitro Superpump System SP3891) reproducing physiologically equivalent aortic pressures and flows and conforming to the requirements of the standard ISO 5840. The aortic Reynolds number, based on the maximum instantaneous value of the systolic flow, was approximately 7000. The comparison between the two conditions is based on three flow characteristics, namely the phase resolved velocity field, the shear rate and the vorticity. A direct comparison of the phase resolved flow fields before and after TAVI highlights a significant variation of the flow during the early stages of valve opening and during valve closure, while similar counter-clock- vortical structures were identified when the valve is fully open. In general flow activities of the Valsalva sinus after TAVI were found to be reduced in strength and to occur mainly in the mid, top parts of the sinus, while the bottom part is more subject to stagnation.

Introduction

The aortic valve consists of three crescent shaped flaps of tissue of similar size (leaflets), faced by three corresponding pouches of the aorta (sinuses of Valsalva). The leaflets open and close passively, moved by the blood, preventing backflow. When they are dysfunctional, the quality of life of the patient can dramatically deteriorate, and their function needs to be restored with prosthetic devices. Open heart surgical replacement has been the most effective treatment of aortic valve disease in the past, but it is now less suitable for current and future patients' population, which is mainly represented by old individuals subject to calcific aortic stenosis, who cannot undergo the stresses of an invasive operation (Passik et al. 1987, Ghanbari et al. 2008). This disease affects about 3 % of individuals over the age of 65 (Otto et al. 1999) and more than 10 % of adults over the age of 75 (Lindroos et al. 1993). Age related comorbidity and previous surgery (Roques et al 1999, Kvidal et al. 2000, Edwards and Taylor 2003) are common factors in this class of patients, and dramatically increase the risks of operative mortality. As a result, about one third of elderly patients with symptomatic aortic stenosis are deemed high risk and declined for surgery (Iung et al. 2003).

Transcatheter Aortic Valve Implantation (TAVI) has emerged in the last decade as one of the most effective solutions for high-risk patients. It allows the delivery of an artificial valve in the aortic position using a catheter inserted from a peripheral vessel, eliminating some of the main risks associated with conventional invasive operations, such as the need for thoracotomy, cardiac arrest/restart, extracorporeal circulation etc. Clinical experiences with TAVI devices, which have now been implanted in thousands of patients worldwide, have shown excellent short and medium term results (Rodés-Cabau et al. 2010, Attias et al. 2010). However, a better understanding of the hemodynamic implications of this novel approach is essential in order to improve the safety and sustainability of the technique. In fact, whilst standard surgical valves are sutured onto the annulus after dissection of the native leaflets and cleaning of the region, thus restoring physiological-like flow conditions (Figure 1a), TAVI devices are anchored into place by expanding a supporting frame (typically a metal mesh) into the leaflets of the diseased valve (Figure 1b). This necessarily produces alterations in the flow pattern that could promote forms of blood damage such as haemolysis (red blood cell rupture and release of haemoglobin) or thrombus formation (clotting of blood). In particular, these phenomena are directly associated with the level of shear stress; zones of flow recirculation, separation or stagnation; and vorticity (Tillman et al. 1984, Giersiepen et al. 1990, Alemu and Bluestein 2007, Morbiducci et al. 2009, de Tullio et al. 2012). In-vitro studies of the flow associated with TAVI devices to date have been limited, and mainly focused on the central systolic flow emerging from the valve orifice (Stuhle et al. 2011). However, the opening and closing dynamic of the valve is directly associated with the hemodynamics established in the sinuses of Valsalva (Bellhouse et al 1968, van Steenhoven et al. 1979), which is essential to preserve proper ventricular function and coronary flow, and minimize the mechanical stress in the valve tissues (Rainer et al, 1999).

In the present study, the impact of a Medtronic CoreValve® bioprosthesis on the hemodynamic in the Valsava sinuses was analysed *in vitro*, by means of PIV. The physiological valve behaviour were reproduced in a hydro-mechanical cardiovascular pulse duplicator system, where the aortic valve system is modelled by a glass aortic root including three polymeric valve leaflets, replicating anatomical shapes and dimensions. The study indicates that the presence of the TAVI device produces significant modifications of the hemodynamic in the sinuses and of the operative mechanisms of the valve system.