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Original Research Article

Numerical prediction of the effect of aortic Left Ventricular Assist Device outflow-graft anastomosis location

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ABSTRACT

A Left Ventricular Assist Device (LVAD) is used to provide haemodynamic support to patients with critical cardiac failure. As LVADs generate continuous flow to better understand the haemodynamic effects of these devices under different working conditions, and particularly in relation to possible outflow-graft anastomosis location, we performed 3D one-way-coupled fluid–structure-interaction (FSI) for three different LVAD working conditions and with the anastomosis location in the ascending aorta and in the descending aorta. The anatomical model used in this study is a patient-specific geometry reconstructed from computed tomography images and the mechanical support considered is similar to the Jarvik 2000® Heart LVAD. Endothelial cells can be influenced by wall stress generated from the blood flow in the artery, so they can produce vascular complications. For this reason, the second aim of this study is to evaluate and analyse, using different mechanical indicators, the wall shear distribution upon the luminal surface of the aorta generated by an LVAD. These numerical investigations demonstrate the utility of one-way-coupled FSI models to compare the haemodynamic conditions for the two LVAD outflow-grafts anastomosis locations and how both affect the aorta and its wall stress. Furthermore, the mechanical indicators allow the identification of wall regions at greater risk of atherosclerosis. The results of this study indicate that an LVAD outflow-graft anastomosis location in the ascending aorta is the optimal configuration.

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1. Introduction

In modern era cardiovascular diseases are the main cause of death in developed countries. In fact heart failure is an increasing health problem globally. Nowadays, it is plausible that the onset of disease is also closely connected to the alteration of the fluid structures of the cardiovascular system [1]. The interest in the relationships between local haemodynamics and the development of physiological and pathological changes associated with cardiovascular malfunctions originated in the late 1970s. Due to advances in cardiac surgery, a number of innovative devices have been introduced in recent years to treat advanced heart failure. One such device, called Left Ventricular Assist Device (LVAD), is a small and efficient pump that is surgically connected to the heart and the aorta in order to increase systemic blood flow. Today, LVADs are routinely employed to provide mechanical circulatory support for patients suffering from advanced heart failure [2]. In particular, this device is a lifesaving tool used when the heart is unable to provide sufficient blood flow. Moreover, it can be used as a bridge to transplantation or as a permanent mechanical circulatory support, producing two different haemodynamic effects:

- end-diastolic pressure decrease in the left atrium;
- systemic flow rate increase and, as a consequence, systemic venous return and right ventricle preload increase.

In order to study and interpret – in a quantitative way – these interrelationships, a certain degree of control over the fluid-dynamic variables is essential, given that the fluid-dynamic simulations depend on the boundary conditions. Unfortunately, conventional methods of investigation that are based on theoretical models or *in vitro*, have proved inadequate to understand the fluid-dynamics of this device in the aorta [3,4]. Moreover, since flow measurements are extremely difficult due to the small dimensions and the complex geometry of arteries, it is helpful to analyse cardiovascular haemodynamics through the use of computational techniques [5]. Different models including this device have been presented in the literature in recent decades to better understand the haemodynamics in specific vascular districts in physiological conditions or in the presence of vascular disease [6–10], or other more complex models to analyse the effects of medical devices, to plan vascular surgery and to predict post-surgical effects [11–16].

Kar et al. [7] carried out a Computational Fluid Dynamics (CFD) study to investigate blood flow patterns in the aorta with LVAD outflow-graft anastomosis locations in the ascending and descending aorta. In particular, they generated two-dimensional (2D) generic aorta models and performed CFD analyses, considering the arterial wall as rigid. Their study contains some limitations due to several idealised aspects, such as a 2D model, a rigid wall and simplified boundary conditions, but nonetheless this is the first comparison of two LVAD outflow-graft anastomosis locations.

Another important study has been conducted by Bazilevs et al. [11]. They performed a fluid–structure-interaction (FSI) analysis of an LVAD outflow-graft anastomosis in the descending aorta using a three-dimensional (3D) patient-specific model. Moreover, they have performed computations for three different LVAD working conditions. A limitation of this study is that only an LVAD outflow-graft anastomosis in the descending aorta is considered.

Therefore, in this work, to better understand the haemodynamic effects of LVAD outflow-graft anastomosis location, a 3D patient-specific model of the aorta including the outflow-graft is considered and one-way-coupled FSI simulations are carried out. The LVAD considered in this work is similar to the Jarvik 2000® Heart (Jarvik Heart Inc, New York, USA), a compact axial flow impeller pump attached to the apex of the left ventricle. The choice of LVAD outflow-graft location depends mainly on the nature of the heart disease [17,18]. Therefore, to better understand the haemodynamic effects within the aorta model, the CFD simulations are conducted using a patient-specific model of an adult male for two of the most common LVAD outflow-graft anastomosis locations: in the ascending aorta (Fig. 1(a)) and in the descending thoracic aorta (Fig. 1(b)).

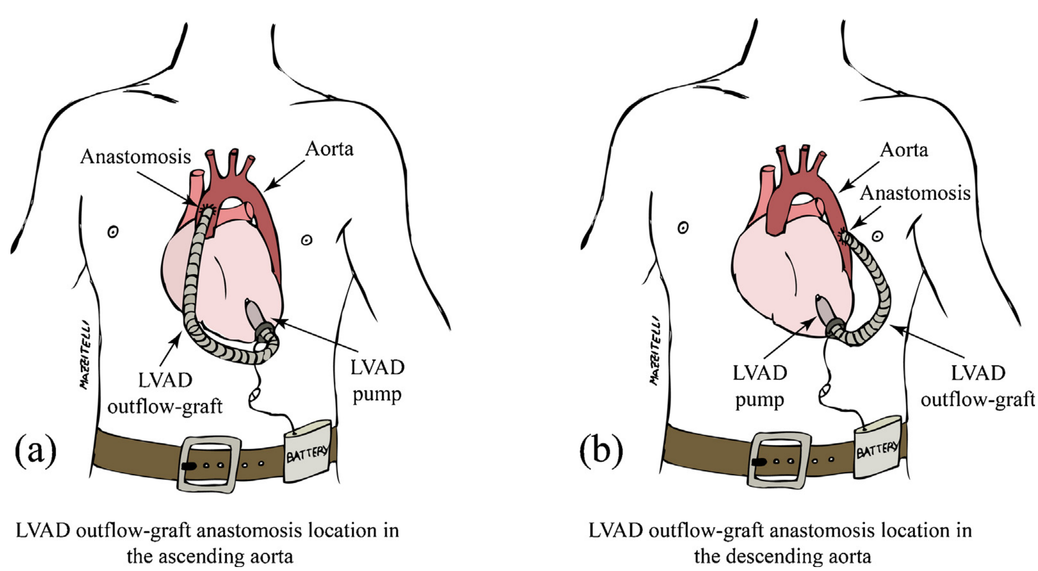

Fig. 1 – LVAD outflow-graft with two different anastomosis locations: (a) in the ascending aorta, (b) in the descending aorta.