Computational Fluid Dynamics as a Tool in the Development Process of Left Ventricular Assist Devices.

Zuin M,[1,2] Rigatelli G,[3] Picariello C,[1] G. Faggian,[4] Roncon L,[1]

1. Department of Cardiology, Rovigo General Hospital, Rovigo, Italy
2. Section of Internal and Cardiopulmonary Medicine, Department of Medical Science, University of Ferrara, Ferrara, Italy
3. Section of Adult Congenital and Adult Heart Disease, Cardiovascular Diagnosis and Endoluminal Interventions, Rovigo General Hospital, Italy
4. Department of Cardiac Surgery, University of Verona, Verona, Italy

Corresponding author:
Loris Roncon, MD
Department of Cardiology, Santa Maria della Misericordia Hospital,
Viale Tre Martiri 140, 45100 Rovigo, Italy
Phone: + 390425393286;
Fax: + 390425393597
Email: roncon.loris@azisanrovigo.it

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Computational fluid dynamics (CFD) is an area of mathematics and more precisely a branch of fluid mechanics used in the design of many safety-critical systems in different fields of engineering. Recently CFD has been applied also in the study of the cardiovascular system.[1-3] Since the development of the first blood pumps in the early 1990's this mathematical technique has been adopted in determining pressure-flow relationship and efficiencies before building prototypes.[4] Recently, continuous-flow left ventricular (LV) assist devices (LVADs) have almost supplanted earlier pulsatile flow devices, achieving in most cases the role of "destination-therapy". As known, hemodynamic evaluation is not always easy in subject with VADs, despite good hemodynamic evaluations having been obtained using right heart catheterization (RHC) and echocardiography.[5] However, improvements in the functionality of these devices are desirable and for this aim CFD could be a useful tool both in the design and validation of the prototypes . Indeed, understanding some fluid variables such as velocity, wall-shear stress, stagnation and blood damage parameters including haemolysis, are fundamental to reduce the clinical complications of LVADs implantation.

As we previously reported, the CFD analysis is a multi-step process in which the rheology of the working fluid must be defined.[2-3] These could be described as fluid with constant (Newtonian Fluid) or variable (Non-Newtonian) viscosity. One of the most challenging issues is the application of CFD analysis to slow-moving and/or stagnant fluids; in this case is necessary to take into consideration viscosity.[6] The mathematical technique used in these simulations could be based on the finite volume or finite element (FE) methods. Before performing this simulation is necessary to obtain the geometry of the domain in which the analysis must be performed. Then, another fundamental step is an accurate representation of the boundary conditions (in- and out flows) which are generally the LV and the aorta. Actually there are different types of LVADs which are equipped with different types of pumps: axial, centrifugal and pulsatile flow blood pumps. To obtain the flow's numerical solutions there are different methods; the choice depends on the type of the pump. For example, centrifugal pumps can be modelled through the multiple reference frames (MRF) or the Sliding Mesh technique[7]. In contrast, most studies based on axial pumps have used the MRF approach. Pulsatile pumps often require a simplification of the model, considering a very high blood viscosity in the region of the closed valve, so the velocity in that region is approximately reduced to zero. A device with a hybrid-type operation is the HeartMate III, (Thoratec Corp. Woburn, MA).

This device has been designed and fabricated featuring a centrifugal pump with a magnetically levitated rotor, but it is capable of delivering energy in the form of a pulsed wave. Actually, the energy equivalent pressure (EEP) transmitted on the aortic wall has not yet been investigated. However, in the future CFD analysis will able to describe this interaction. Another problem in analysing the LVADs performances is turbulence. Usually, LVADs operate in the low Reynolds number turbulence range. For this reason, previous CFD analysis have used the k-ε turbulence model, which is based on a two equation Reynolds Averaged Navier-stokes model. In this way, CFD could be used both in LVADs design improvement and optimization, reducing the time required to develop a new device[8]. Moreover, CFD modelling enables investigation of pressure and flow fields at a temporal and spatial resolution unachievable by any clinical methodology.

* Corresponding author. E-mail: roncon.loris@azisanrovigo.it

Another important and contemporary underestimated topic was considered by Kailasan et. Coll., who analysed the heat generated during normal operation of a LVAD on the surrounding tissue. They found that there is a 2.2°C temperature increase in the magnetic suspension system during nominal operation, while the blood temperature increase by 1.6°C. Okamoto and Coll. demonstrated that computer-aided design of the blood pump contributes to the optimization of a blood pump chamber, reducing thrombus formation, haemolysis, and also contributing to reducing cost and time in developing the implantable LVAD.[10] CFD has been adopted also with the aim of modifying the clinical strategy, including surgical techniques.[11-12] Nowadays, CFD has earned a primary position in the arsenal of any device innovator. Validation of the results will be necessary to confirm the efficacy and efficiency of LVADs, considering also the clinical outcomes of the patients.

Declaration of of interests

The authors declare no conflicts of interest

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