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Virtual positioning of ventricular assist device for implantation planning

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Abstract

The use of Ventricular Assist Devices (VAD) is increasing in the context of refractory heart failure. Nevertheless, there is still a high rate of complications. This preliminary work analyzes more precisely the clinical needs and proposes a first solution for preoperative planning of device implantation. The proposed approach consists in representing within a common space the 3D mesh describing the device and the patient CT image, in order to interactively simulate the device positioning and detect collisions between the VAD and different kinds of surrounding anatomical structures (bones and right ventricle). CT scans from 3 adult patients who have previously received a VAD, were used for the experiments. We analyzed the influence of mesh precision on computation time and accuracy of collision detection. Results show that the proposed approach is compatible with fast and interactive simulation of virtual device positioning, in order to preoperatively plan its implantation. Such a solution could also facilitate the decision-making about the choice of the device taking into consideration the feasibility of implantation.

Keywords: Image processing; Modeling; Simulation; Surgery planning; Implantable device

1. Introduction

1.1. Context

Heart Failure (HF) occurs when the heart cannot pump enough blood to meet the body's needs. This disease is the principal cause of death in Europe and the United States, and is also an economic burden due to the high medical costs (an estimated $32 billion each year for the USA nation [1]). Nowadays, over 23 million of people are living with a HF worldwide. Cardiac transplantation is the first solution for end stage HF but the lack of donors is significant and approximately 300,000 die annually. The number of people living with this disease is rising inexorably with the ageing population while there is stagnation in heart transplantation [2].

Over the last decades, implantable long-term mechanical Ventricular Assist Devices (VADs) have significantly evolved. These devices offer an alternative to delay or avoid the heart transplantation, in order to remedy the lack of donors, and allow patients a better mobility and quality of life [3]. However, although figures show an increase of their implantation, per- and post-operative complications are still reported and are explained by the complexity of the clinical condition of each patient [4] and of the interventional procedure. To limit them patient selection and preoperative management are important [5]. Therefore, there is a need for dedicated preoperative software to help surgeon to plan the implantation of VADs and/or artificial hearts.

The aim of this preliminary work was to analyze the clinical needs and to propose a first solution for preoperative planning of device implantation. In the following, we analyze more precisely the clinical needs. Then we present the solution proposed for the simulation of LVAD implantation, and report the results obtained from preoperative patient CT dataset.

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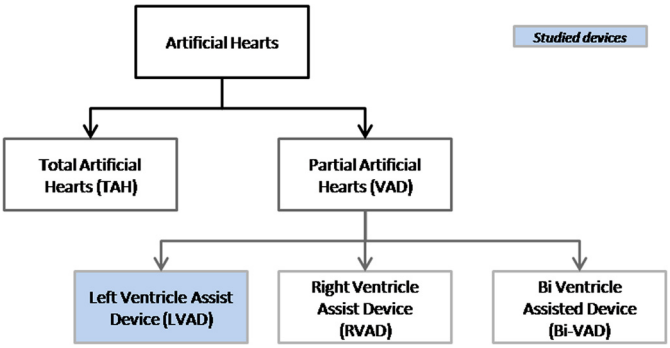

Fig. 1. Artificial hearts organization.

1.2. Clinical needs

1.2.1. Artificial hearts

Cardiac pumps are composed of two external batteries, an external controller, an internal pump (second generation devices), and a percutaneous driveline that connects the controller to the pump. They are divided into two categories: Total Artificial Heart (TAH) that replaces both ventricles and partial artificial heart more commonly called Ventricle Assist Device, used to support heart function and blood flow. Among VAD, one can differentiate Left Ventricular Assist Devices (LVAD) from Right Ventricular Assist Devices (RVAD) and BiVentricular Assist Devices (Bi-VAD) [6]. An organization of these devices is given in Fig. 1.

Our work focuses on two commercially available LVADs implanted at CHU—Rennes (HeartMate II (HM II) – Thoratec Inc., Pleasanton, CA; HeartWare (HW) VAD – HeartWare Inc., Framingham, MA). Their composition includes an inflow cannula placed through the apex of the LV, an outflow cannula anastomosed to the ascending aorta, and the pump with a continuous- or pulsatile-flow rotator, refer to Fig. 2. The appropriate device is chosen by the surgeon considering the patient needs, his metabolism and specificities of each device.

1.2.2. Clinical requirements

During the surgical procedure, the pump has to be placed in the attended anatomic location [7]. The proper positioning has to be evaluated for a long-term prevention of infection and damage. Nowadays, surgeons plan it preoperatively by examining patients' data but some difficulties are still subsisting. They are related to: (i) *the positioning of the device*. Surgeons have to place the inflow cannula pointing toward the mitral valve. A cannula oriented toward the septum or other free wall facilitates inflow obstruction with potential device malfunction and the creation of thrombus. In the same way, the outflow cannula must be positioned with an orientation that gives the maximum flow into the ascending aorta. (ii) *The device collision with anatomical structures*. Collisions between the device and specific neighboring organs can cause post-operative complications related to the device functioning or the patient health. On the one hand, during the chest closure a device collision with the thorax can occur and increases the risk of damage, bleeding and malfunctioning, as well as of improper inflow. On the other hand, the RV compression due to the device positioning may facilitate RV dysfunction, which is one relatively common and dreadful complication encountered after a LVAD implantation [8]. Patients in this case may require heart transplantation. (iii) *The deformations*. Certain parts of the device can be distorted during the implantation. Additionally, the device start-up causes a depletion of the assisted ventricle. These deformations could provoke the displacement of the device, deflecting it from its initial placement.

The work presented in this paper is aimed at assessing the collision between the LVAD and two surrounding anatomical structures that are: the chest wall and the RV.

2. Materials and methods

This section presents the method proposed for the virtual positioning of LVADs. It involves the devices and patient-specific

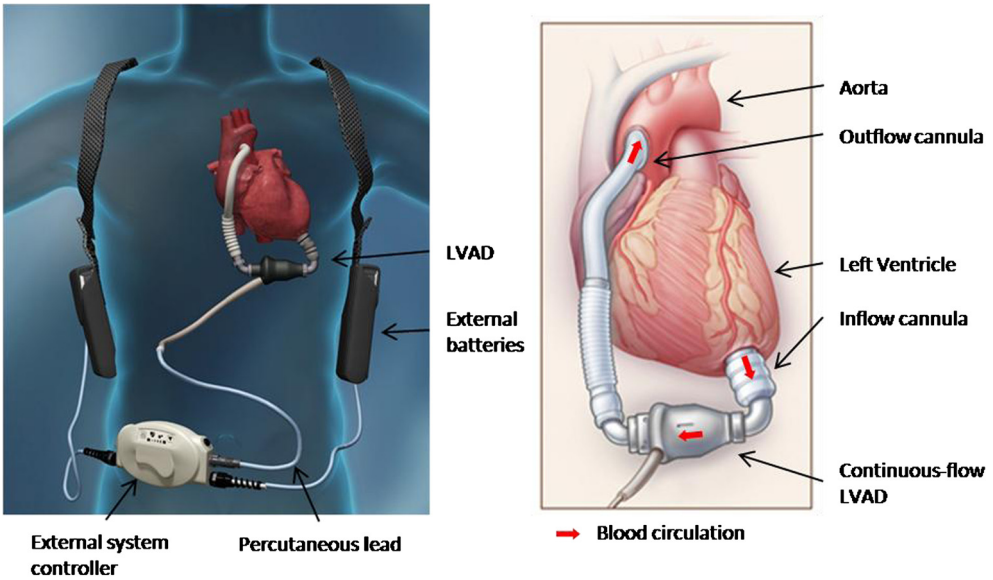

Fig. 2. LVAD composition (HeartMate II).