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Virtual implantation of a novel LVAD: toward computer-assisted surgery for heart failure

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ABSTRACT

Background: Mechanical and hemodynamic factors are among the determinants of patient-device interaction and early-term and long-term outcomes in left ventricular assist device (LVAD) recipients.
Material and methods: We are currently developing computer simulation tools aimed at (1) analyze the intrathoracic and intracavitary positioning of LVADs after implantation and establish correlation with clinical outcomes; (2) assist surgeons in the choice of device and of left ventricular coring site for optimized intrathoracic placement and function; and (3) facilitate the planning of less-invasive LVAD implantation. A virtual representation of LVAD (mesh device component) was created through cone-beam computed tomography and semiautomatic segmentation. A modular framework software (CamiTK, Grenoble, France) was used to create a three-dimensional representation of patients' computed tomography (CT) scan and incorporate the mesh device component for virtual implantation.
Results: Device reconstruction was included into a dedicated software with the purposes of virtual implantation, based on the preoperative CT scan of surgical candidates.
Conclusions: We present herein the first digital reconstruction of the novel HeartMate 3 LVAD. Virtual implantation on the basis of preoperative CT scan is feasible within a user-friendly interactive software. Future studies will be focused on correlation with clinical variables.

Introduction

Despite its effectiveness in improving survival and quality-of-life in patients with advanced heart failure,[1] left ventricular assist device (LVAD) treatment is still associated with severe complications such as thromboembolic events, pump thrombosis, and pump dysfunction. Mechanical and hemodynamic factors related to suboptimal pump implantation and positioning have been associated with an increased likelihood of developing adverse events.[2-4] Our ultimate research purpose is to develop innovative tools to assist surgeons in the choice of devices, of optimal site of left ventricular wall coring and in intrathoracic pump positioning, with the scope to optimize pump function, avoid secondary migration after chest closure, and minimize thromboembolic risk due to mechanical and hemodynamic factors in a patient-specific fashion. We assembled a team consisting of heart failure surgeons (A.A. and E.F.), biomedical engineers (S.C.),

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and an expert in biomedical image processing for innovative clinical applications (P.H.). The preliminary results of this project have included the development of a computer interface allowing spatial manipulation and virtual implantation of LVADs within a three-dimensional representation of patients' computed tomography (CT) scan and an analysis tool for intraventricular cannula positioning in implanted patients presenting LVAD-related complications at follow-up (Fig. 1).

The HeartMate 3 (Thoratec Inc., Pleasanton, CA) is a novel rotary magnetically driven LVAD which has recently obtained the CE mark and is entering the clinical practice. We present the inclusion of this device within a virtual implantation tool (which is currently for investigational and pre-clinical use only). We highlight the features of the device and the potential for computer-assisted surgery in the domain of heart failure.

Methods and results

The HeartMate 3 device was represented by a three-dimensional digital object (mesh component) later included in the virtual implantation software. To this purpose, a rotational imaging of the device was performed (cone-beam computed tomography—CBCT) using an Artis Zeego fluoroscopy equipment (Siemens Healthcare Inc., Munich, Germany) to minimize artifacts (Video 1). The ITK-Snap software (Philadelphia, PA) was used to perform semiautomatic segmentation of the acquired images and obtain the three-dimensional mesh component representation (Fig. 2). This reliably depicted the volumes of the device, including the inflow cannula, the apical sewing ring, the pump body, and the outflow tract (Video 1). The Dacron portion of the outflow was not reconstructed given its adaptability to native anatomy. The HeartMate 3 LVAD has a more compact size than the HeartMate II device to improve ease of implantation, although the site of left ventricular coring and the orientation of the apical cannula still represent important features in the determinism of pump function. For the performance of virtual implantation, the mesh device component is incorporated into a three-dimensional representation of the patient's CT scan within a modular framework software (CamiTK—Computer Assisted Medical Intervention Toolkit, Grenoble, France). Through such software, the user can visualize and browse the coronal, sagittal, and transverse views of the CT scan; a three-dimensional representation of the cardiac chambers is also obtained through a multiatlas-based methodology and a pervoxel majority voting procedure, as previously described[4,5] (Video 2). This three-dimensional representation of cardiac chambers is superimposed to CT-scan images (augmented visualization of CT-scan). Coaxiality with the mitral valve orifice and nonconflict with the interventricular septum and left ventricular cavity walls are considered as requirements for correct placement of LVAD inflow cannula. Hence, the user elaborates the CT scan through dedicated widgets to identify the mitral valvular orifice. Subsequently, the software suggests the LVAD implantation site and left ventricular coring location which maximize mitral

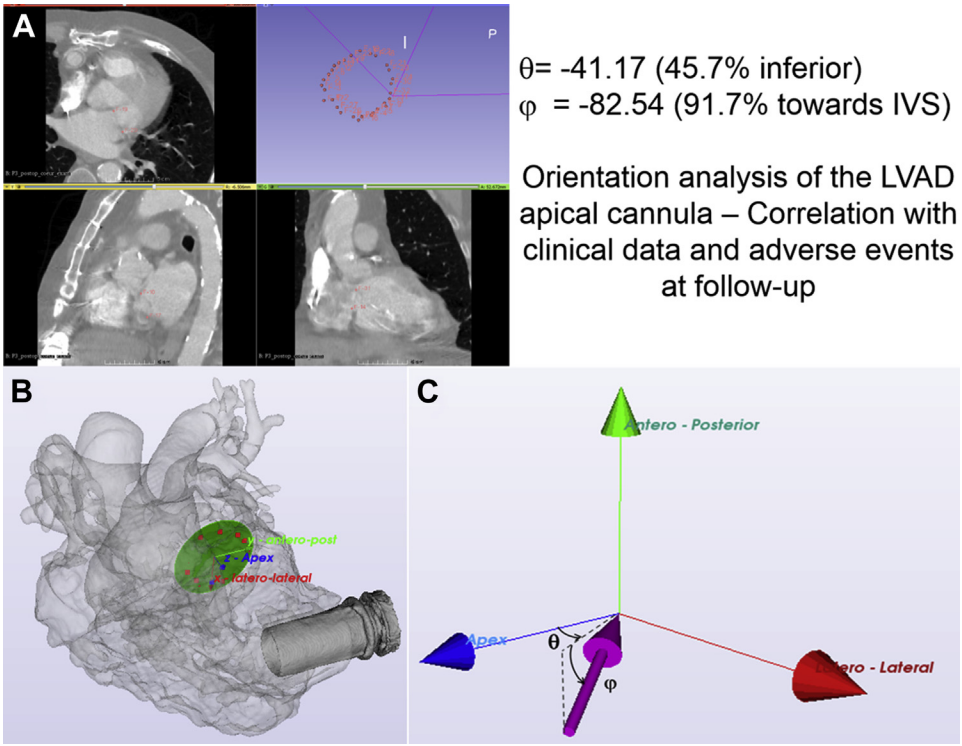

Fig. 1 – (A) Screenshot of an LVAD implantation preoperative planning and postoperative analysis tool: definition of the mitral annulus by the user on post-implantation CT scan. (B) Three-dimensional representation of the cardiac chambers after segmentation with the obtained mitral orifice plane. (C) Coordinates system for the LVAD apical cannula orientation with respect to the mitral valvular orifice; description through angles θ and φ for quantification of displacement from ideal orientation. IVS = interventricular septum. (Color version of figure is available online.)