Inside the beating heart: Toward a less-invasive approach to surgery

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A new technique for performing minimally-invasive surgery inside the beating heart provides a visual representation of the surgical environment by combining intraoperative ultrasound with virtual reality.

Intracardiac procedures are currently performed after initiation of cardio-pulmonary bypass, aortic cross-clamping, cardiac arrest, and perfusion of the heart for myocardial preservation. Although open-heart surgery provides unobstructed vision and direct access to the intracardiac regions, all these preparatory and ancillary procedures contribute to morbidity. Complications can include blood transfusion mishaps, atrial fibrillation, myocardial ischemia, and neurological dysfunction. Such adverse events are due not to the therapy itself, but to the process of approaching the target to be treated.

Surgery that did not require significant interventions to access the site of disease would shorten the procedure, minimize patient trauma and side effects, and lower costs. New methods to achieve these ends are currently under development.1–3 Our approach combines readily-available 2D and 3D ultrasound (US) imaging technology with magnetic and optical tracking systems to provide a robust and accurate system for guidance inside the beating heart. A custom-built attachment device is employed to gain safe access via a mini-thoracotomy.4

Cardiac US systems are available in several forms including trans-esophageal echocardiography (TEE), and intracardiac echocardiography (ICE). A limited number of 3D systems are also employed; however, the transducers are large and image acquisition is restricted to trans-thoracic views. We track both the US and surgical instruments using the NDI Aurora® magnetic tracking system, which identifies the position and orientation of miniature six-degree-of-freedom (DOF) sensors fixed to the transducer and tools. We are currently evaluating our procedures with respect to implantation of an artificial mitral valve.

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Figure 3. Screen image shows guidance of the artificial mitral valve and tool, 2D ultrasound, left atrium (wireframe), left ventricle (purple), and target location of the mitral valve annulus (green ring).

The first stage of our work assessed the accuracy of our techniques using a cardiac phantom. The phantom is made of clear acrylic and contains port access for either TEE or ICE ultrasound devices. We examined the accuracy with which an experienced cardiac surgeon could guide the valve prosthesis, place it accurately over an aperture in a polyvinyl alcohol cryogel membrane, and staple it in place using a laparoscopic clip-applicer. This process was first performed under 2D US guidance alone, subsequently with US complemented by the virtual reality (VR) representation of all the tools. Positioning that seemed appropriate with US alone was often several millimeters off target, both in translation and angulation—see Figure 1(a). But with the addition of the VR environment, positioning was consistently on target—see Figure 1(b). Perhaps the most helpful characteristic of VR was its ability to visualize the entire 3D valve and insertion tool. This enabled the surgeon to appreciate its orientation with respect to the plane of the target, information unavailable in the US-only approach.

We have recently initiated animal studies in a clinical setting (see Figure 2). Although demonstrating the feasibility of the process, it is too early to report many specific results. Positioning of the valve has been reasonable, but the tools have yet to be optimized. Currently, we are using intraoperative US to define the valve annulus (see Figure 3). Virtual tools guide the valve and stapler close to their targets (see Figure 4), with real-time US employed for final verification. We are optimizing tool design to accommodate the magnetic trackers, and also reconstructing gated intraoperative 3D volumes, based on 2D US, to improve guidance.

Replacing open-heart, on-pump surgical procedures with less invasive techniques has advantages both for the patient and the health care system. This project is still in its infancy, and a great deal of work remains to be done. However, our early series of experiments has convinced us that a VR environment can become a key element for enhancing the safety and performance of off-pump, beating, intracardiac surgery.

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