Evolving Technology

Three-dimensional echo-guided beating heart surgery without cardiopulmonary bypass: Atrial septal defect closure in a swine model

Yoshihiro Suematsu, MD, PhD,[a] Joseph F. Martinez, DVM,[a] Benjamin K. Wolf, BS,[b] Gerald R. Marx, MD,[a] Jeffrey A. Stoll, BS,[b] Pierre E. DuPont, PhD,[b] Robert D. Howe, PhD,[c] John K. Triedman, MD,[a] and Pedro J. del Nido, MD[a]

Drs del Nido and Suematsu

ET

From the Departments of Cardiac Surgery and Cardiology, Children's Hospital and Harvard Medical School,[a] Boston, Mass, the Department of Aerospace and Mechanical Engineering, Boston University,[b] Boston, Mass, and the Division of Engineering and Applied Sciences, Harvard University,[c] Cambridge, Mass.

This study was supported in part by National Institutes of Health grant HL71128 and HL 73647 (P.J.D.) and by the Japan Society for the Promotion of Science (Y.S.).

Read at the Eighty-fifth Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif, April 10-13, 2005.

Received for publication March 28, 2005; revisions received June 20, 2005; accepted for publication June 28, 2005.

Address for reprints: Pedro J. del Nido, MD, Department of Cardiac Surgery, Children's Hospital-Boston, 300 Longwood Ave, Boston, MA 02115 (E-mail: pedro.delnido@tch.harvard.edu).

J Thorac Cardiovasc Surg 2005;130:1348-57

0022-5223/$30.00

doi:10.1016/j.jtcvs.2005.06.043

Objective: In this study, we tested 3 techniques of atrial septal defect closure under real-time 3-dimensional echocardiography guidance in a swine model.

Methods: The operations were conducted under the sole guidance of a modified real-time 3-dimensional echocardiography guidance system with a ×4 matrix transducer (Sonos 7500, Philips Medical Systems, Andover, Mass). Eighteen swine were anesthetized, and after median sternotomy, the echo probe was applied directly to the surface of the right atrium. To create an atrial septal defect, balloon atrial septostomy and atrial septal defect enlargement were performed. Subsequently, 3 different techniques of atrial septal defect closure were attempted: group I, direct suture closure; group II, closure of the atrial septal defect using the Amplatzer device (AGA Medical Corp, Golden Valley, Minn); and group III, patch closure of the atrial septal defect (n = 6 each).

Results: Real-time 3-dimensional echocardiography guidance provided sufficient spatial resolution and a satisfactory frame rate to provide a "virtual surgeon's view" of the relevant anatomy during the entire procedure. All atrial septal defects were enlarged, and the mean final size was 8.5 ± 1.8 mm. Atrial septal defect closure was successfully accomplished with all the 3 surgical techniques examined. In groups I and III, the needles (1-3 sutures) and staples (6-12 staples) penetrated the tissue and patch material consistently, whereas in group III, the Amplatzer atrial septal defect device was easily deployed. There was no incident device/staple embolization or air introduction. Neither intraoperative 2-dimensional color Doppler echocardiography nor postmortem macro-evaluation revealed any residual shunts.

Conclusions: Beating heart atrial septal defect closure under real-time 3-dimensional echocardiographic guidance is feasible and, unlike catheter-based devices, applicable for any type of secundum atrial septal defect.

Despite allowing direct visualization of intracardiac structures, cardiopulmonary bypass (CPB) has a number of adverse effects, including generation of microemboli and an inflammatory response associated with increased cytokine production and complement activation, which together can result in neurologic dysfunction in adults and neurodevelopmental dysfunction in children.[1,2]

Abbreviations and Acronyms

ASD	= atrial septal defect
CPB	= cardiopulmonary bypass
OPCARE	= off-pump cardiac repair
RT3DE	= real-time 3-dimensional echocardiography
3D	= 3 dimensional
2D	= 2 dimensional

Furthermore, the long-term effects of CPB still remain unclear, and its deleterious effects may be more pronounced in infants than in patients of older age. Recently, investigators have attempted beating heart intracardiac surgery without CPB;[3,4] however, the imaging systems used were deemed suboptimal for satisfactory visualization of the intracardiac structures.

Over the last 4 decades, echocardiography has evolved from single-beam imaging to sophisticated 3-dimensional (3D) techniques that enable study of the cardiac structures and functions, and the hemodynamics in great detail.[5] Recently, real-time 3-dimensional echocardiography (RT3DE) was developed, which serves as a new modality for clinicians and surgeons for visualizing the heart noninvasively without electrocardiographic or respiratory gating. A new probe was developed that creates a fully sampled 2-dimensional (2D) array and allows 3D imaging with instantaneous on-line volume-rendered reconstruction, direct manipulation of thresholding, and planes cut on the ultrasound unit. This new 3D probe has great potential for expanded applications, not only for medical diagnosis but also for image-guided surgical intervention. We previously demonstrated that RT3DE provided adequate anatomic detail for surgical-task performance in an in vitro model.[6] In this study, we assessed the feasibility of 3 techniques for beating atrial septal defect (ASD) closure without CPB in a swine model.

Materials and Methods

Echographic Equipment

RT3DE was performed using the ×4 matrix transducer on a Sonos 7500 system (Philips Medical Systems, Andover, Mass). The transducer operates in a broadband range of 2 to 4 MHz and scans a 3D volume by electronically steering the acoustic beam using a matrix of approximately 3000 transducer elements and associated electronics that allow scanning of a 64° × 64° pyramidal volume in real time at up to 28 frames per second. The Sonos 7500 base system volume renders the data in any viewing orientation desired, at a frame rate of 28 Hz, and the orientation of the target object on the screen can be controlled with a rollerball. The image processing and rendering platform is based on a dual 2.2 GHz Pentium 4 processor PC, which supports multiple imaging modalities, including conventional B-mode 2D echo, 2D color flow Doppler imaging, biplanar 2D echo, and several real-time volume rendering modes.

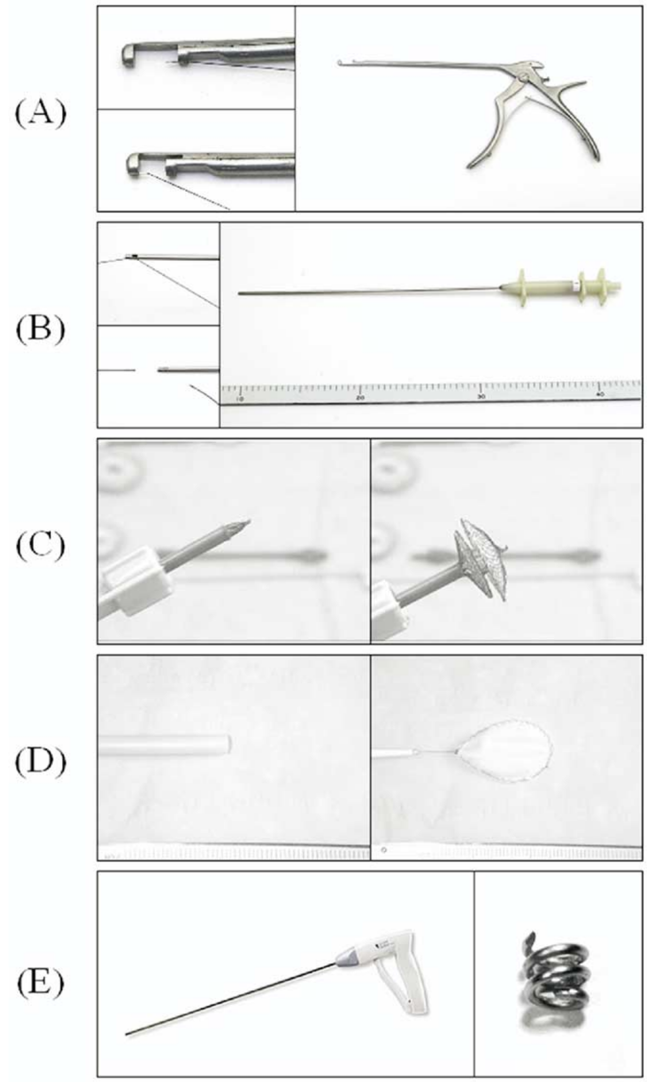

Figure 1. A, Semiautomatic suturing device. B, Suture cutting device. C, Amplatzer ASD device (AGA Medical Corp, Golden Valley, Minn). D, Patch-deployment device. E, Endoscopic stapler (Tacker, Autosuture, Norwalk, Conn).

Surgical Devices

A semiautomatic suturing device developed by us for off-pump intracardiac surgery was used as previously described (Figure 1, *A*).[7,8] In brief, a needle with a conical point is threaded with 4-0 silk thread. The base of the needle is affixed in a niche on the tip of the proximal jaw of the semiautomatic suture device by pulling the thread down with 1 hand. The jaws close after the needle is passed through the tissue to be fixed. When the jaw is slowly opened again, the tip of the needle is automatically grasped by the distal jaw, which has a resilient slit. When the device is gently moved off the tissue, it is ensured that the thread has penetrated the tissue appropriately. After the device is pulled out of the cardiac cavity with the needle, the same action is repeated for the opposing