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Live 3-Dimensional Echocardiography Guidance for the Insertion of a Retrograde Cardioplegic Catheter through the Coronary Sinus

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ABSTRACT

Objective. We evaluated the feasibility and accuracy of live 3-dimensional (3D) epicardial echocardiography (echo) to guide the insertion of a retrograde cardioplegic catheter into the coronary sinus.

Methods. A real-time 3D echo system with a ×4 matrix transducer was used. Live 3D echo-guided catheter insertion was compared with blind insertion. Completion times and success rates were recorded. During all experiments, the operator was blinded to the target and, in the echo-guided group, the procedure was performed with only ultrasonic guidance.

Results. Live 3D echo provided sufficient spatial resolution and a satisfactory frame rate to provide a "virtual surgeon's view" of the relevant anatomy. Although there was no significant difference in completion time, live 3D echo guidance significantly improved the success rate of catheter insertion as compared to the blind group (90% versus 35%; $P < .001$).

Conclusions. Live 3D echo-guided coronary sinus catheter insertion is feasible and safe.

INTRODUCTION

The use of retrograde cardioplegia (RCP) is a safe, effective, and widespread method for myocardial protection in a broad range of cardiac procedures [Cohen 1999]. RCP may be delivered retrograde alone or, most frequently, in combination with an antegrade way of delivery. In most cases, RCP is delivered through a cuffed catheter inserted blindly into the coronary sinus [Clements 1998]. However, complications of RCP including rupture or perforation of the sinus, hematoma, and rupture of the catheter cuff have been reported [Panos 1992; Kurusz 2002]. In addition, blind insertion of a catheter is sometimes difficult because of occasional anomalies of the coronary sinus.

Echocardiography (echo) is the most widely used noninvasive technique for assessment of myocardial structure and function during cardiac surgery. Recently, live 3-dimensional (3D) echo has been developed, which serves as a new modality for clinicians and surgeons for visualizing the heart noninvasively without electrocardiographic or respiratory gating. We previously demonstrated that live 3D echo provided adequate anatomic detail for surgical-task performance [Suematsu 2004]. We hypothesized that live 3D echo would enhance the accuracy and speed of insertion of the RCP catheter.

MATERIALS AND METHODS

Study Protocol and Animal Model

A pig model weighing 60 kg was used and underwent multiple insertions of RCP catheters. All animal experiments conformed to the Guidelines for Use of Laboratory Animals and were approved by the London Health Science Centre Institutional Animal Use and Care Committee. The pig was anesthetized with ketamine and isoflurane, intubated, and ventilated. The electrocardiogram was continuously monitored throughout the procedure. A median sternotomy was performed, the right side pericardium was suspended upward, and the echocardiographic transducer was directly applied to the surface of the right atrium. A purse-string suture of 3-0 polypropylene was placed around the right atrium, following intravenous heparin administration of 100 U/kg. Our previous water-tank experiment demonstrated that the best images were obtained with the ultrasonic transducer at distances of 4 to 6 cm from the target [Suematsu 2004]. Therefore, where necessary, a stand-off was placed between the transducer and the right atrium so as to optimize the image and range of the field.

In the group of blind insertion of the coronary sinus catheter, the catheter was introduced through the purse-string suture. In the group of live 3D echo-guided insertion, once in the right atrium, the catheter tip was visualized by adjusting the live biplane image, including the tilt function. Live 3D echo was used interchangeably with live biplane echo to confirm the anatomy surrounding the coronary

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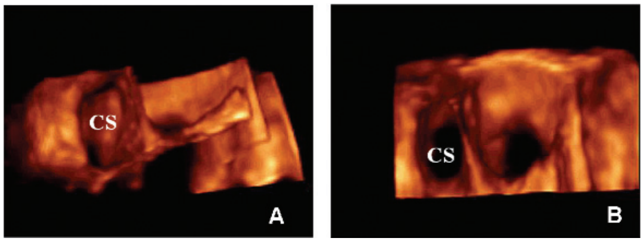

Figure 1. Live 3-dimensional images, showing the coronary sinus (CS) from different angles (A, B).

sinus, and to perform final adjustments of the catheter tip. If necessary, the cropping tool was used to get clear visualization of the coronary sinus and the catheter tip. In both groups, proper placement of the catheter was finally verified by finger palpation and epicardial echocardiography. Each maneuver was repeated 20 times, as groups were randomly alternated.

Echocardiographic Equipment

The transducer technology and imaging principles used to create live 3D echo images have been previously described [Kisslo 2000; Lang 2002]. Live 3D echo was performed using the ×4 matrix transducer on a Sonos 7500 system (Philips Medical Systems, Andover, MA, USA). 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 ~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.

RESULTS

All procedures were tolerated without hemodynamic instability and significant mechanical cardiac damage. There was no significant difference in completion time between the live 3D echo-guided group and the blind group (11.35 ± 6.79 seconds versus 13.35 ± 8.37 seconds; $P = .41$). However, the live 3D echo-guided group significantly improved the success rate of catheter insertion as compared to the blind group (90% versus 35%; $P < .001$). Live biplane and 3D echo successfully guided catheter manipulation in all but 2 cases in which optimal images were not obtained. Figure 1 shows the cardiac anatomy around the coronary sinus. Using blind insertion techniques, catheter placement was as follows: coronary sinus 7, tricuspid valve 5, inferior vena cava 4, right atrium 4. Biplane echo using tilt function and wide-angle display allowed rapid identification of the catheter shaft and tip within a particular short- and corresponding long-axis plane. The tip was easily identified by its reverberation artifact. Live 3D echo confirmed the apposition of the catheter and assisted in proper placement of the tip. Figure 2 represents proper placement of the catheter in the coronary sinus.

DISCUSSION

There are many different ways of administering cardioplegic solutions in addition to a variety of solutions and temperatures. The retrograde technique is one of the methods that is being used more frequently in current clinical practice. This approach originated with a concept developed by Pratt in 1898, who suggested that oxygenated blood could be supplied to the ischemic heart via the coronary venous system. Sixty years later, Lillehei et al used retrograde coronary sinus perfusion to protect the heart during aortic valve surgery [Lillehei 1965]. Today, it is an accepted method for delivering a cardioplegic solution and is used frequently as an adjunct to antegrade cardioplegia.

RCP is usually delivered through a cuffed catheter inserted blindly into the coronary sinus [Clements 1998]. Proper placement of the retrograde catheter is critical, and complications of RCP that include rupture or perforation of the sinus, hematoma, and rupture of the catheter cuff have been reported [Panos 1992; Kurusz 2002]. In addition, blind insertion of a catheter is sometimes difficult because of an occasional anomaly of the coronary sinus.

Real-time 3D echo has been an important recent advance with clinical applications [Lang 2002]. Volume-rendered 3D imaging provides excellent 3D echo displays. It allows detailed anatomical resolution of anatomy and pathology that was impossible with 2D echo images. Live 3D echo also increases the surgeon's confidence during intervention procedures. It could provide live images of intracardiac anatomy during surgery. Our current experiment demonstrated that live 3D echo significantly improved the accuracy of retrograde coronary sinus catheter insertion. We believe that live 3D echo will make a significant breakthrough not only for supporting surgical intervention during conventional cardiac surgery, but also

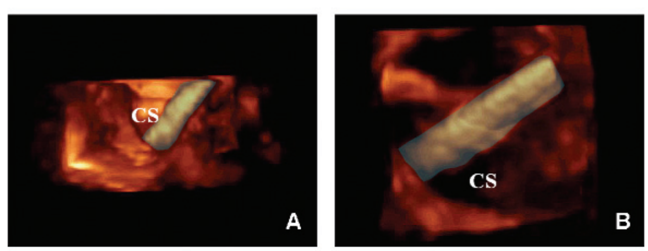

Figure 2. Live 3-dimensional images, showing the cardioplegic catheter located in the coronary sinus (CS) from different angles (A, B). For better comprehension, the catheter is colored light blue.

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for guiding surgeons during closed heart surgery on beating hearts in the future.

In summary, live 3D echo can accurately guide retrograde coronary sinus catheter insertion. Future studies of this technique are needed to demonstrate its usefulness in the clinical setting.

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