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Experimental Mitral Valve Plasty under the Beating Heart Guided by Real-Time 3-Dimensional Echocardiography

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ABSTRACT

Background. This study examines whether real-time 3-dimensional echocardiography can provide an image resolution to serve as a substitute for optical visualization in performing mitral valve plasty.

Methods. Three pigs were used in this study. A 3-dimensional echocardiographic system was evaluated on an epicardial surface. Beating heart mitral valve plasty was performed with a surgical stapler inserted from the apex of the left ventricle using only 3-dimensional echocardiographic visualization.

Results. The high-quality images of the mitral valve were obtained with the probe at the epicardial position. However, by inserting the surgical instrument into the left ventricle, an acoustic shadow developed on the images. The images became indistinct because of the acoustic shadow, and operation became difficult. For the mitral valve plasty, an edge-to-edge mitral valve repair was carried out using a stapler (10 mm) under the beating heart. The stapler was confirmed to seize both leaflets evenly in only 1 of the 3 pigs.

Conclusions. Real-time 3-dimensional echocardiography provided clear 3-dimensional images of the mitral valve; however, when a surgical instrument was inserted into the left ventricle, an acoustic shadow appeared on the image and made detailed confirmation difficult. Lessening or eliminating the acoustic shadow would be a key point to improve this procedure.

INTRODUCTION

Satisfactory surgical performance has been attained with mitral valve plasty using cardiopulmonary bypass for patients with mitral regurgitation [Braunberger 2001; David 2003]. Others are attempting the development of mitral valve plasty techniques via a percutaneous approach [Liddicoat 2003; Messas 2003; Condado 2006]. Presently, percutaneous approaches are indicated for inoperable cases; however, indications in the future remain unknown.

Real-time 3-dimensional ultrasound imaging [Sugeng 2003] of the heart has become a reality because of technical innovations in echocardiography. Recently, some studies have used real-time 3-dimensional echocardiography for catheter intervention [Lu 1998] and during surgery for congenital heart disease [Suematsu 2003, 2004; Vasilyev 2006]. In the present report, we investigated whether mitral valve plasty could be performed under the beating heart using real-time 3-dimensional echocardiography.

METHODS

Three pigs with a mean weight of 42.5 ± 7.2 kg were used. The procedures and handling of the animals were in compliance with the Principles of Laboratory Animal Care formulated by the National Society for Medical Research and with the Guide for the Care and Use of Laboratory Animals published by the National Institutes of Heath (publication no. 85-23, revised 1996). Prior to surgery, each pig was given 25 mg/kg of pentobarbital and 10 mg/kg of ketamine hydrochloride intravenously to induce anesthesia. During the operation, the heart was exposed by a bilateral thoracotomy with a transverse sternotomy. For real-time 3-dimensional echocardiography, a Philips Sonos 7500 system (Bothell, WA, USA) was used. An ×4 Matrix transducer (Philips) was placed

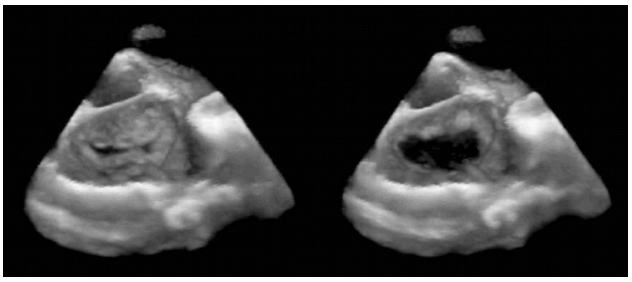

Figure 1. A 3-dimensional echocardiography image of the mitral valve from the left atrial.

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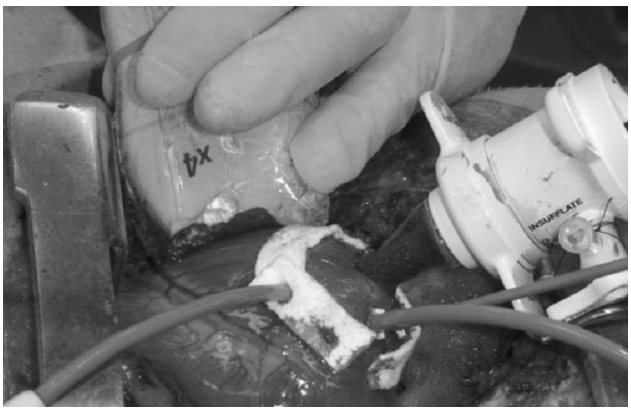

Figure 2. An operative view. The transducer was placed on the heart and a 10-mm port was inserted from the apex of the left ventricle.

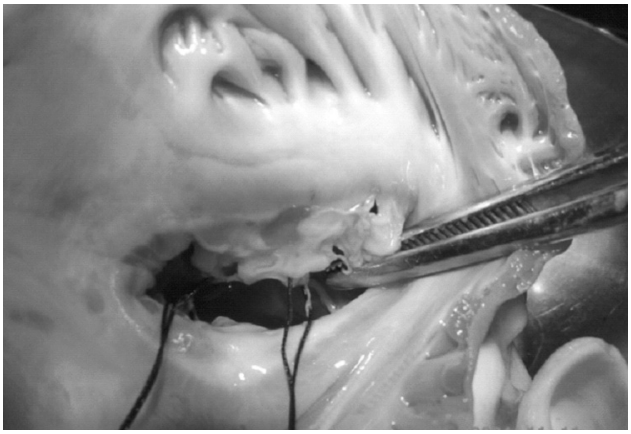

Figure 4. An operative view of the mitral valve. Surgical sutures were fixed to the mitral valve using a suturing device.

directly in contact with the heart surface to obtain the echocardiography images (Figure 1).

For the mitral valve plasty, an edge-to-edge mitral valve repair [Maisano 1998] was carried out using an Endo Universal stapler (10 mm; Tyco Healthcare, Mansfield, MA, USA). The mitral valve was led by inserting a 10-mm port with a backflow prevention valve from the apex of the left ventricle. Surgical manipulation was performed by passing the instrument down via the port (Figure 2). The purpose of the experiment was to determine the effectiveness of real-time 3-dimensional echocardiography as well as the functionality of the surgical instruments and the possibility of performing a mitral valve plasty using real-time 3-dimensional echocardiography guidance under the beating heart.

RESULTS

Functionality of Surgical Instruments

Figure 3 shows an echocardiogram taken when an Endo Grasp (2 mm; Tyco Healthcare) was passed down the mitral valve into the left atrium. Figure 3A shows a 3-dimensional image, while Figure 3B is an ordinary 2-dimensional image recorded at the same time. An acoustic shadow can be observed in both images; however, the 3-dimensional image was less affected by the acoustic shadow. The positions of the mitral valve and the Endo Grasp were confirmed more easily and clearly in the 3-dimensional image than in the 2-dimensional image.

The mobility of an Endo Stitch suturing device (10 mm, Tyco Healthcare) could be confirmed by the 3-dimensional image; however, the suturing needle could not be seen clearly because of the effect of the acoustic shadow, which made precise manipulation impossible. Figure 4 shows surgical sutures that were fixed to the mitral valve using a suturing device under the beating heart. In the experiment, the correct placement of the suture point was not confirmed because of the acoustic shadow (Figure 5).

Mitral Valve Plasty Using a Stapler

Figure 6 is a 3-dimensional image showing an Endo Universal stapler that has grasped the anterior and posterior

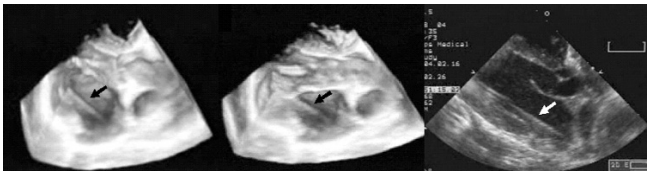

Figure 3. Echocardiographic images showing the surgical instrument (2 mm, arrows).

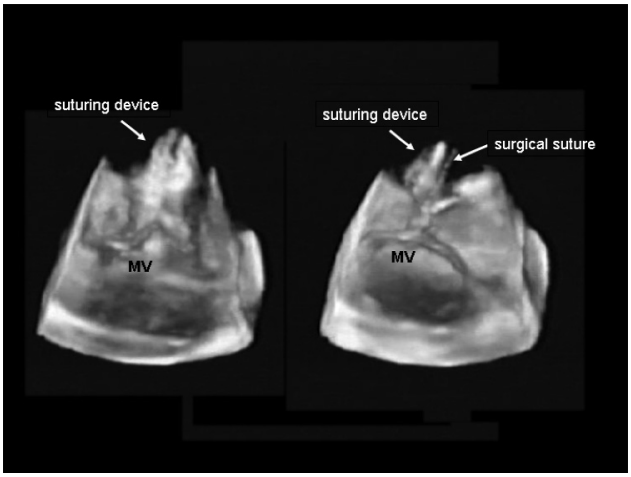

Figure 5. A 3-dimensional image of the suturing device and surgical suture. An acoustic shadow appeared on the image. MV indicates mitral valve.

Figure 6. A 3-dimensional image of the mitral valve (a view from the left atrium). The stapler was fixed to the anterior and posterior leaflets.

Figure 7. An operative view of the mitral valve. The stapler was fixed to the anterior and posterior leaflets.

leaflets of the mitral valve evenly. It confirms that the Endo Universal stapler has pressed the valve around it. After confirming the condition, the stapler was attached. Figure 7 show the stapler fixed to the anterior and posterior leaflet. The stapler was confirmed to seize both leaflets evenly in only 1 of the pigs. In the other 2, only the anterior leaflet, posterior leaflet, or myocardium under the mitral valve was seized.

DISCUSSION

The 3-dimensional construction of the heart under a beating heart condition can be confirmed immediately by the development of real-time echocardiographic devices. Thus, anatomical abnormalities can be confirmed at the bed side in patients with congenital heart disease and mitral regurgitation.

In the present study, we attempted to treat mitral valves under the beating heart surgically while viewing a 3-dimensional echocardiogram in real time. We were able to suture the mitral valve in only 1 of the 3 pigs. Three-dimensional images of the mitral valve were clearly visualized; however, when a surgical instrument of about 10 mm in diameter, such as a stapler, was inserted into the left ventricle, an acoustic shadow appeared on the image and made detailed confirmation of the leaflets and surgical instrument difficult. Because the low resolution was disturbed by an acoustic shadow, reconstruction of the chorda might be more difficult. Lessening or eliminating the acoustic shadow would be a key point to improve this procedure.

In the present study, the apex approach was used to reach the mitral valve, but a septal approach might be more useful clinically. In addition, the development of surgical instruments such as a flexible stapler with a smaller nozzle size would be helpful for performing septal manipulation.

CONCLUSION

Real-time 3-dimensional echocardiography provided clear 3-dimensional images of the mitral valve, even when the device was placed on the heart surface. However, we concluded that performance of a mitral valve plasty under the beating heart using real-time 3-dimensional echocardiography as a guide would be difficult when using currently available thoracoscopic surgical instruments. Therefore, development of surgical tools that do not create an acoustic shadow would be indispensable.

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