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Mitral Valve Repair without Cardiopulmonary Bypass or Atriotomy Using the Coapsys Device: Device Design and Implantation Procedure in Canine Functional Mitral Regurgitation Model

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ABSTRACT

Background: Myocor developed a unique system, the Coapsys annuloplasty system, to treat functional mitral regurgitation (MR) without cardiopulmonary bypass (CPB). This study was conducted to test the feasibility of the Coapsys implantation procedure in a canine functional MR model.

Methods: Functional MR with heart failure was induced in 9 dogs by rapid ventricular pacing (230 beats/min for 30 ± 4 days). The Coapsys device, which consists of anterior and posterior epicardial pads connected by a subvalvular chord, was then surgically implanted. Under epicardial echocardiographic guidance, we placed the Coapsys device across the left ventricular chamber using the delivery instrument and needle assembly. We sized the Coapsys device by drawing the posterior leaflet and annulus toward the anterior leaflet with the sizing instrument. Final device size was selected when MR was minimized or eliminated as assessed by 2-dimensional color Doppler echocardiography.

Results: In all cases, we successfully implanted the Coapsys device without CPB or atriotomy. MR was reduced an average of 2 grades. No adverse events, such as hemodynamic compromise or structural valve damage, were noted.

Conclusion: Coapsys device implantation was feasible and safe on a beating canine heart. All accessory tools used for device implantation were found useful.

INTRODUCTION

Mitral regurgitation (MR) is commonly considered to be one of the initiators of heart failure and to be an ongoing impetus in progression of the disease. Functional MR results from annular dilatation and displacement of the papillary muscles in a dysfunctional left ventricle (LV) [Sabbah 1993, Komeda 1997, Otsuji 1997]. The prognosis among these patients with functional MR and LV dysfunction is poor [Koelling 2002].

Myocor (Maple Grove, MN, USA) has developed a new system, the Coapsys annuloplasty system (Figure 1), to treat functional MR. Details of the Coapsys concept and hemodynamic and echocardiographic data have been described [Fukamachi, in press]. The Coapsys device decreases functional MR by reducing the septal-lateral dimension of the mitral annulus and repositioning the papillary muscles. The Coapsys device is less invasive to patients because it corrects valve dysfunction without the use of cardiopulmonary bypass (CPB) or an open-heart access method. The purpose of this study was to establish safe and consistent procedures for Coapsys implantation without CPB in a canine pacing-induced functional MR model.

MATERIAL AND METHODS

This study was approved by the Cleveland Clinic Institutional Animal Care and Use Committee, and all animals received humane care in compliance with the *Guide for the Care and Use of Laboratory Animals* prepared by the Institute of Laboratory Animal Resources, National Research Council, and published by the National Academy Press, revised 1996.

Coapsys Device Design

The Coapsys device consists of an epicardial posterior pad, an epicardial anterior pad, and a subvalvular chord (Figure 1A). The 2 pads are located on the surface of the heart with the load-bearing subvalvular chord passing through the ventricle (Figure 2), below the mitral valve. The posterior pad has 2 heads. The annular head is located at the mitral annular level to change the mitral annular dimension, and the papillary head is located at the papillary muscle level to move the papillary muscle toward the LV septum. Both pads are made of high-performance engineering thermoplastic and covered by polyester fabric. The subvalvular chord is braided polyethylene coated by expanded polytetrafluoroethylene. The subvalvular chord is attached to the posterior pad. The posterior pad attachment method bears nickel chromium

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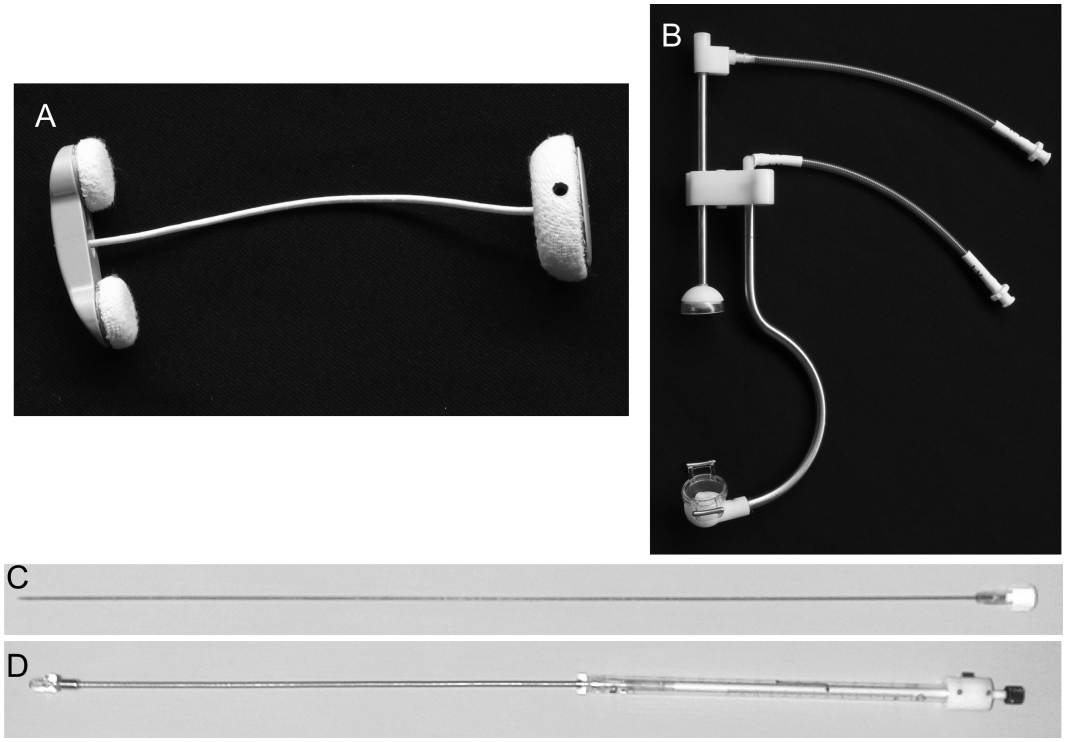

Figure 1. Coapsys annuloplasty system. A, The Coapsys device consists of an epicardial anterior pad, an epicardial posterior pad, and a subvalvular chord. Three accessory tools are required to implant the Coapsys device: delivery instrument (B), needle assembly (C), and sizing instrument (D).

cobalt alloy pins that are passed through the braid of the subvalvular chord. The anterior pad is adjustable with a deployable pin mechanism and is fixed to the opposing end after sizing of the device during the procedure.

Accessory Tools

A delivery instrument (Figure 1B) is used to guide a needle assembly (Figure 1C) from the entry to the exit points of the ventricle. This device is fixed to the heart by a vacuum assistance system and has a special capture system to catch the needle assembly. The needle assembly is used with the delivery instrument to create a pathway through the ventricle for the purpose of delivering the subvalvular chord. A sizing instrument (Figure 1D) is used to measure the epicardial distance of the heart and apply the displacement needed to achieve MR reduction.

In Vivo Study

The canine model of rapid ventricular pacing–induced heart failure was chosen for this study, because hemodynamic and echocardiographic changes are very similar to those found in human functional MR [Takagaki 2003]. In addition, rapid ventricular pacing is well established as a canine heart failure model [Howard 1991, Takagaki 2002].

Nine adult mongrel dogs (body weight, 21.5 ± 1.0 kg) were anesthetized with intravenous thiopental (15 mg/kg) and maintained with isoflurane (0.5%-2.5%). The method of inducing the model has been described previously [Takagaki 2002]. Dogs were paced via the right ventricular (RV) transvenous lead with rapid asynchronous ventricular pacing at 230 beats/min for an average of 30 ± 4 days to induce functional MR with heart failure.

Coapsys Implantation Surgery

After 30 ± 4 days of pacing, the Coapsys device was implanted. On the date of implantation surgery, the pacemaker rate was reduced to demand mode of 30 beats/min so that the animal would resume normal sinus rhythm. The animal was placed under general anesthesia as previously described. Sternotomy was performed, and the chest was opened. When the chest was opened, continuous infusion of lidocaine was started at 1 mg/kg per hour to prevent ventricular arrhythmia.

The appropriate sites for Coapsys device placement were identified through a combination of external landmarks and 2-dimensional (2D) echocardiographic visualization of internal structures. Placement must avoid puncturing papillary muscles, the mitral apparatus, and main coronary artery and vein branches. The posterior insertion point was approximately 2.5 cm from the atrioventricular (AV) groove and midway between the papillary muscles. The anterior insertion point was at the base of the RV outflow tract, approximately 2 cm RV side from the left anterior descending coronary artery (LAD). After site identification, the delivery instrument was fixed to the heart with vacuum assistance (–400 mm Hg). The needle assembly was inserted

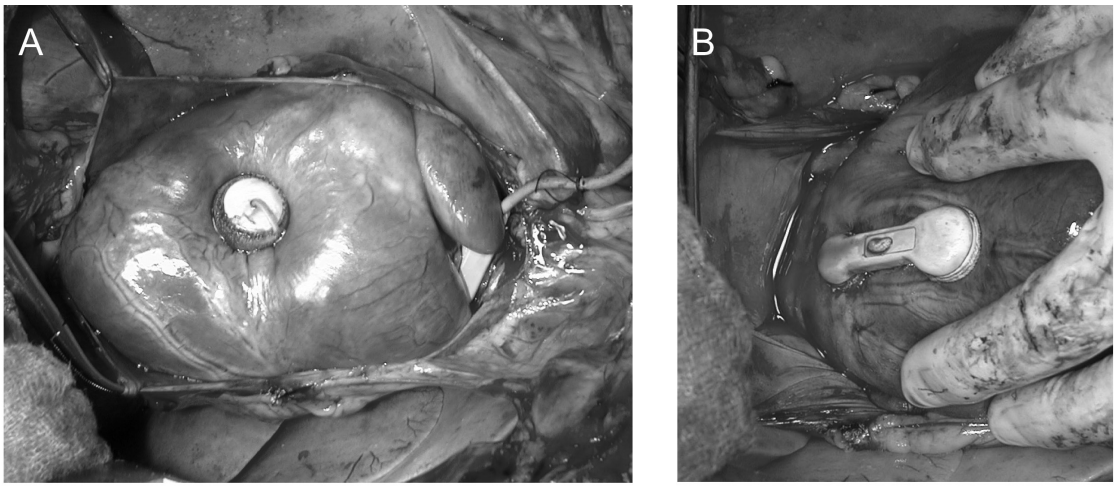

Figure 2. Animal implantation. A, The anterior pad is located 2.2 cm lateral to the left anterior descending coronary artery (LAD) and 4.5 cm from the atrioventricular (AV) groove. B, The posterior pad is located 6.4 cm from the LAD and 2.7 cm from the AV groove.

through the delivery instrument from the RV wall to a point bisecting the area between the papillary muscles and was caught in the capture system (Figure 3A). After passage of the needle assembly, the stylet of the needle assembly was removed, and the subvalvular chord was threaded through the hollow catheter and pulled through both walls. The subvalvular chord was advanced until the posterior pad rested on the LV wall. The anterior pad was inserted over the RV side of the subvalvular chord.

After placement of the Coapsys device, the sizing instrument was placed on the subvalvular chord leader and advanced until secured (Figure 3B). The Coapsys device was then sized by drawing of the posterior leaflet and annulus toward the anterior leaflet. Final device size was selected

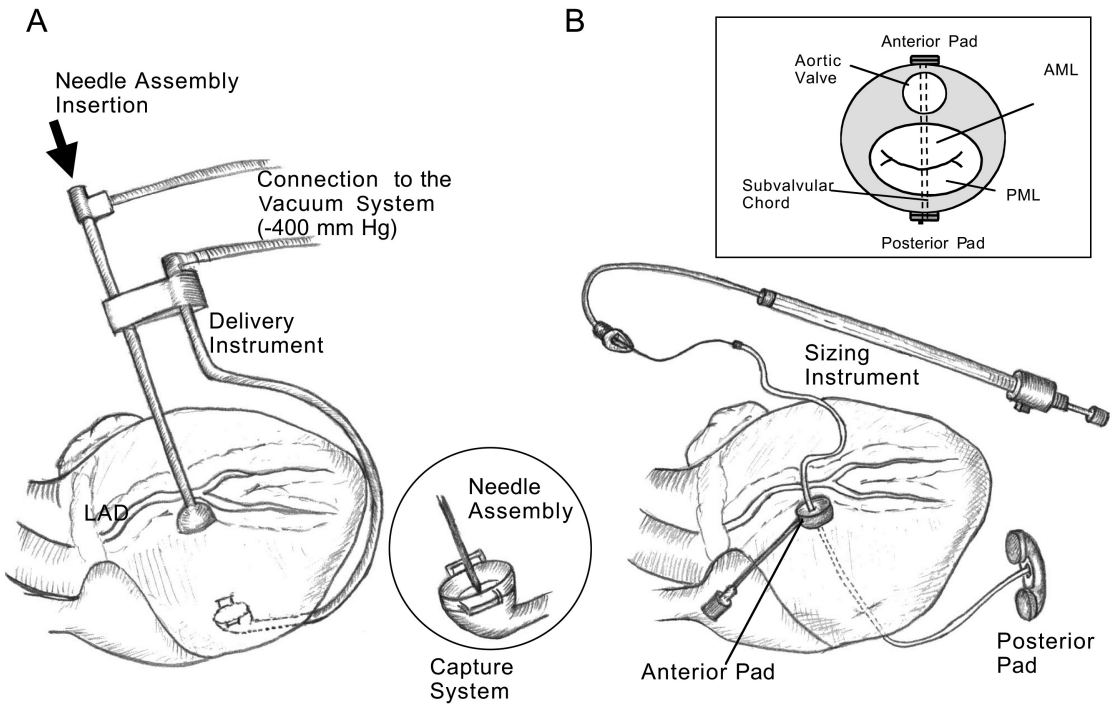

Figure 3. Implantation procedure. The delivery instrument is fixed to the heart by vacuum assistance (–400 mm Hg). A, The needle assembly is inserted through the delivery instrument from the right ventricular wall to a point bisecting the area between the papillary muscles and was caught in the capture system (inset). B, After Coapsys placement, the sizing instrument is placed. The Coapsys device is placed in the midseptal position (inset). LAD indicates left anterior descending coronary artery; AML, anterior mitral leaflet; PML, posterior mitral leaflet.

Subvalvular Chord Insertion Points*

	From AV Groove	From LAD
Posterior (LV) side, cm	2.5 ± 0.4	6.0 ± 0.9
Anterior (RV) side, cm	4.7 ± 0.8	1.7 ± 0.4

*All values expressed as mean ± SD. AV indicates atrioventricular; LAD, left anterior descending coronary artery; LV, left ventricular; RV, right ventricular.

when MR was minimized or eliminated as assessed by 2D color Doppler imaging. The actual distances from the AV groove and LAD to each of the insertion points were measured. The Coapsys device was tightened at the final device size. The anterior pad was fixed to the subvalvular chord, and the excess subvalvular chord was trimmed.

At the time of sacrifice, the relationships between the device and the intraventricular structures were examined. All measured values were expressed as mean ± standard deviation.

RESULTS

All Coapsys device implantations were performed off pump and without atriotomy. As determined by 2D echocardiography, 8 of the 9 animals had MR ≥2 before sizing of the device. In these 8 animals, MR grade decreased from 3.0 ± 0.8 before sizing of the device to 0.6 ± 0.7 after proper sizing of the device ($P < .001$). Mean percentage linear reduction was 25.0% ± 7.6%.

Hemodynamic data during implantation were stable in all cases. Although we observed some arrhythmias, which were associated with cardiac manipulation, immediate spontaneous recovery occurred without complications.

The distances between each insertion point and the AV groove and LAD are shown in the Table. The anterior (RV) side insertion point was 1.7 ± 0.4 cm RV side of the LAD. The posterior (LV) side insertion point was 2.5 ± 0.4 cm from the AV groove. The annular head of the posterior pad was located close to the circumflex coronary artery. We confirmed there was no compression of the coronary artery by direct visualization.

At sacrifice, there were no injuries to the papillary muscles, mitral valve apparatus, or main coronary artery or vein branches.

DISCUSSION

Annuloplasty is a widely used means of mitral valve repair. Mitral valve surgery also offers survival benefit in patients with severe LV dysfunction and functional MR [Bolling 1998, Bishay 2000]. However, the surgical procedure requires access to and manipulation of the valve annulus via atriotomy. Furthermore, the procedure currently requires CPB. The increased morbidity/mortality profile leads directly to lack of treatment of MR in earlier-stage heart failure patients. The Coapsys device is intended to address these issues by correcting valve dysfunction without CPB or an open-heart access method.

Other minimally invasive methods of mitral valve repair recently have been developed. Downing and associates described the preliminary model and methodology of off-pump mitral valve repair procedures [Downing 2002]. Morales and associates described a mitral valve grasper, which has been developed to coapt leaflets and fasten the structures with a graduated spiral screw without CPB [Morales 1999]. Block described a new technology for percutaneous mitral valve repair of MR [Block 2003]. These procedures and devices change only the shape of the mitral valve leaflet or annulus. The Coapsys device works to reduce the septal-lateral dimension of the mitral annulus and reposition the papillary muscles. This concept has been described previously [Fukamachi, in press].

In all cases, we successfully implanted the Coapsys device without using CPB or left atriotomy. Delivery instrument placement and needle assembly insertion were performed under stable hemodynamics. No adverse events, such as hemodynamic compromise or structural valve damage, were noted. The accessory tools worked well to maintain stable hemodynamics during Coapsys implantation. With the delivery instrument, the needle assembly was placed at the proper position. The delivery instrument was fixed to the heart by a vacuum assist system (–400 mm Hg). The vacuum system is already used in humans to stabilize the heart during off-pump coronary artery bypass grafting [Jansen 1998]. The sizing instrument was useful for adjusting the sizing level to determine the final device size [McCarthy 2001, Takagaki 2001, Schenk 2002].

Study Limitations

There is an anatomical difference between dogs and humans. The space between the heart and lung in the chest cavity is larger in dogs than in humans. In our animal study, placement of the delivery instrument was easy even with a dilated dysfunctional heart.

Conclusion

The Coapsys device was implanted without adverse events in a canine functional MR model. All accessory tools used for device implantation were found to be useful.

ACKNOWLEDGMENT

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