

Next-Generation Percutaneous Mitral and Tricuspid Valve Repair Approaches

What's next for transcatheter management of mitral and tricuspid valve disease.

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Mitral and tricuspid regurgitation (TR) are important clinical entities that occur when blood regurgitates from the ventricles to the atria during systole. Mitral regurgitation (MR) results in left-sided volume overload with progressive enlargement of the left atrium and left ventricle. Patients with MR experience shortness of breath, atrial arrhythmias, and symptoms of congestive heart failure. TR can cause symptoms of "right-sided heart failure," such as ascites, congestive hepatopathy, peripheral edema, decreased appetite, and abdominal fullness.

Current percutaneous technologies directed at mitral

valve repair are as diverse as the underlying mechanisms of MR. The three-tier Carpentier classification system (types I, II, and III) incorporates annular size, leaflet mobility, and coaptation, as well as left ventricular and papillary muscle function, in determining the structural changes causing MR.¹ Emerging percutaneous technologies must eventually be able to address all of these pathologies, whether isolated or in combination.

Functional MR usually occurs when mitral leaflets fail to coapt despite normal leaflet motion (Carpentier type I dysfunction). Myocardial infarction, often with regional involvement of the posterolateral left ventricular wall,



Figure 1. The Mitralign Percutaneous Annuloplasty System (Mitralign, Inc., Tewksbury, MA). The positioning of a two-tipped Bident catheter (Mitralign, Inc.) beneath the posterior mitral valve leaflet via the retrograde left ventricular approach (A). Two plicated and locked sutures through the posterior mitral annulus (B). An additional two plicated and locked sutures placed with the Bident catheter (C). A subvalvular view of tensioned anchors, resulting in tissue plication and posterior reductive annuloplasty (D).

can result in ischemic MR as a result of apical papillary muscle displacement with primarily posterior leaflet tethering and restricted motion during systole (Carpentier type IIIb dysfunction). Pathophysiologic studies have demonstrated that septal-lateral (SL, also known as anterior-posterior) mitral annular enlargement is the final common pathway in the development of functional and ischemic MR, and that shortening this dimension is critical in alleviating MR.^{2,3} Multiple percutaneous approaches for the treatment of MR are under development, as described here and in other articles in this issue. We describe the following percutaneous approaches aimed primarily at the treatment of functional or ischemic dysfunction: (1) direct annular plication simulating surgical suture annuloplasty, (2) thermal remodeling of mitral annular collagen, (3) left ventricular remodeling using a percutaneously placed transventricular device, (4) a transatrial system with anchors in the coronary sinus and interatrial septum, and (5) a novel percutaneous ring for the treatment of functional TR.

DIRECT ANNULAR PLICATION

Currently, there are several technologies that have been developed in an effort to reproduce the effects of surgical mitral annuloplasty using suture-, anchor-, or radiofrequency (RF)-based circumferential reduction of the mitral annulus. Surgical closed-ring mitral annuloplasty is currently considered the gold standard for treating functional MR, with predictable and durable reductions in mitral annular circumference and septal-lateral diameter. Before the advent of open and closed rigid rings, suture-based annuloplasty, based on the prior work by Burr et al, had been used.⁴ This technique has been shown to reduce the septal-lateral diameter in patients undergoing adjunctive annuloplasty in the setting of degenerative leaflet repair or repair of functional MR.^{5,6} This approach has been adapted to several percutaneous approaches, as subsequently described.

The Mitralign Percutaneous Annuloplasty System

The Mitralign Percutaneous Annuloplasty System is based on surgical suture annuloplasty of the mitral valve. The procedure involves a left ventricular approach through retrograde femoral arterial access. A catheter is placed under the posterior mitral leaflet, adjacent to the annular tissue beneath the valve. The procedure is performed under fluoroscopic and echocardiographic guidance. A specially designed catheter with two tips (Bident) is used to place two to four anchors through the posterior annulus of the mitral valve. These anchors are plicated together, resulting in posterior leaflet annuloplasty and reduction in MR (Figure 1). Although a

“Challenges to emerging minimally invasive or percutaneous approaches are numerous but should be surmountable with evolving surgical, imaging, and interventional techniques.”

three-tip catheter (Mitralign, Inc.) was originally used, the two-tip catheter (Bident) was developed to allow increased maneuverability in the subvalvular space. This approach should not preclude future surgical therapies, if needed. First-in-man studies to evaluate this system were performed in 2007 through 2008 in Europe and South America using the Trident system catheter. A multicenter feasibility study using the Bident system is planned.

The AccuCinch System

The AccuCinch system (Guided Delivery Systems, Inc., Santa Clara, CA) is also based on the suture annuloplasty method and is focused on direct correction of annular dilation. This procedure uses a retrograde femoral arterial approach to gain access to the ventricular aspect of the mitral annulus. A proprietary catheter is placed under the posterior mitral leaflet, adjacent to the annular tissue beneath the valve. Using this catheter, nine to 12 anchors can be placed from the anterior to posterior commissures along the posterior mitral annulus. The anchors are then plicated to provide reduction of the mitral annular circumference and MR. The system is described as reversible, removable, and adjustable. Plication of the posterior wall of the left ventricle has been described as an alternate application of this device to improve ventricular shape and reduce functional MR. Chronic surgical implants in humans have been performed, and percutaneous human implants are planned.

The QuantumCor System

The QuantumCor system (QuantumCor, Inc., Bothell, WA) is based on the concept of thermal remodeling of collagen. Because the mitral valve annulus has a high collagen content, catheter-based application of RF energy at subablative temperatures to the mitral annulus will heat and contract the collagen fibers, thereby reducing mitral annular circumference. This technology has been proven to reduce mitral annular dimensions and MR in an animal model.⁷ Histologic follow-up showed that the lesions generated did not compromise the structural integrity of the atrium or mitral leaflets. The energy is applied circumferentially to the mitral annulus using a proprietary catheter

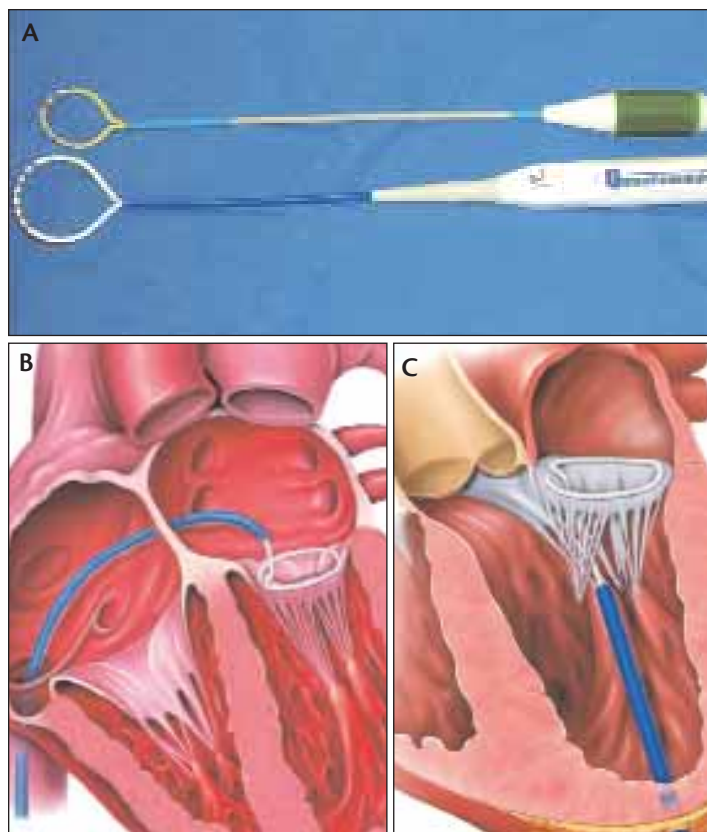


Figure 2. The QuantumCor system. The Boa-Surg RF catheters (QuantumCor, Inc.) (A). Potential transeptal approach to apply RF energy at subablative temperatures to contract collagen fibers and reduce mitral annular circumference (B). Potential transapical approach for RF catheter placement (C).

that is used to apply RF energy (Figure 2). The favorable aspects of this technology are that no material is left behind, and repeat applications can be applied. It could also, theoretically, be applied to the tricuspid annulus.

LEFT VENTRICULAR SHAPE CHANGE

The iCoapsys System

The iCoapsys system (formerly Myocor, Inc., Maple Grove, MN) was recently acquired by Edwards Life Sciences (Irvine, CA). First-in-man implants have been performed with this device, which is an innovative method of reshaping the left ventricle with a percutaneously placed system. Although clinical trials with this device have been suspended, the iCoapsys system is notable because of its novel mechanistic importance. The procedure is based on the surgically placed iCoapsys system, which has been shown to result in sustained reduction in MR at 1 year.⁸ Under fluoroscopic and echocardiographic guidance, intrapericardial anchoring devices are placed on the epicardial left ventricular sur-

faces in an anterior-posterior configuration and are connected by a tethering or anchoring suture that passes horizontally through the left ventricle. By applying tension to the anchoring suture, the geometry of the ventricle is changed. Likewise, the mitral annular diameter is decreased, resulting in improved leaflet coaptation (Figure 3).

TRANSATRIAL MITRAL ANNULAR SHAPE CHANGE

Percutaneous Septal Sinus Shortening System

The Percutaneous Septal Sinus Shortening System (PS3 System, Ample Medical, Inc., Foster City, CA) uses magnetic catheters to allow accurate placement of a bridge that connects anchors in the coronary sinus and the interatrial septum. Once this connection is made between the coronary sinus and the interatrial septum, tension can be applied to the bridge element, effectively shortening the SL dimension (Figure 4). The device is placed using standard fluoroscopic and echocardiographic imaging. Using an ovine model, the investigators found that device implantation with an average 24% SL diameter reduction resulted in acute and chronic MR reduction.⁹ The device has been shown to be durable and safe in an animal model at up to 1 year after implantation.¹⁰ This technique has shown early promise in temporary human implants, and recent chronic first-in-man implants have

shown excellent safety with reductions in MR.¹¹

FUNCTIONAL TR

The Millipede System

Until recently, there has been minimal attention paid to tricuspid valve disease, despite the recent introduction of multiple percutaneous treatments for aortic, mitral, and pulmonic valve disease.¹² TR is usually functional and is caused by right ventricular enlargement and tricuspid annular dilation. Left-sided heart failure from myocardial or valvular etiologies, right ventricular volume and pressure overload, or dilation of cardiac chambers can all lead to significant TR. The symptoms of right-sided heart failure are difficult to manage with medical therapy, and few patients are currently offered surgery for isolated tricuspid valve disease. If left untreated at the time of surgical mitral valve repair, significant residual TR negatively impacts perioperative outcomes, functional class, and survival.¹³ As transcatheter therapies for MR arise, parallel percutaneous approaches for TR may be necessary. The Millipede

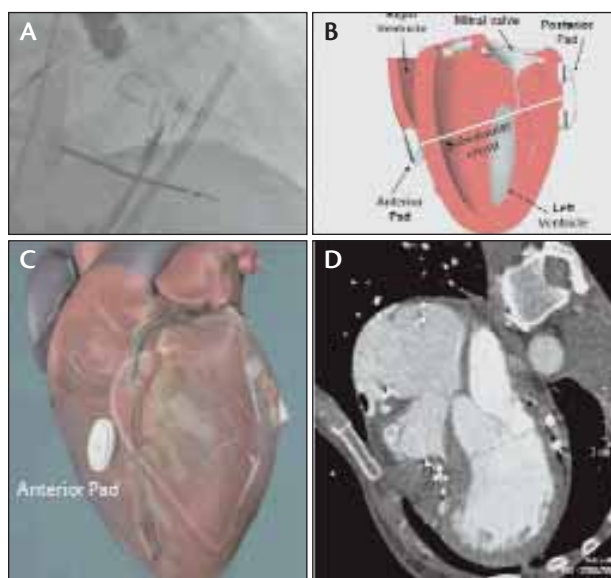


Figure 3. The iCoapsys system. Fluoroscopic right anterior oblique view of percutaneous placement of the anterior pad (A). A schematic demonstrating placement of the posterior and anterior pad (B). Note the relationship of the anterior pad to the right ventricle. Computer animation demonstrating the anterior pad with the subvalvular chord traversing the left ventricle and attaching to the posterior pad (C). Computed tomography scan with the anterior pad located on the left side of the image with a subvalvular chord connecting to posterior pad (D). Note the mild deformation of the right ventricle with the anterior pad.

system (Millipede, LLC, Ann Arbor, MI) involves the placement of a novel tricuspid annular ring with a unique attachment system via either minimally invasive surgical or percutaneous methods to restore the native tricuspid annular shape and diameter (Figure 5). The device is currently under preclinical development, is repositionable and retrievable prior to deployment, and could be used in future iterations to treat mitral annular dilatation.

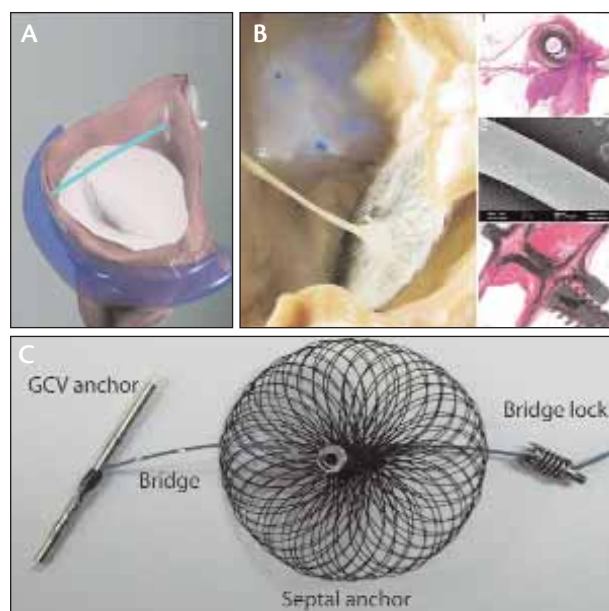


Figure 4. The Percutaneous Septal Sinus Shortening (PS3) System. Three-dimensional model demonstrating septal-lateral orientation with the septal device, bridge, and coronary sinus/great cardiac vein anchor (A). Device deployed in a sheep model with excellent endothelialization of device components at 1 year (B). PS3 system components (C). Note the bridge lock, allowing for application of tension in the septal-lateral dimension.

CONCLUSION

We are entering a new era of transcatheter and minimally invasive valve interventions. Novel tools used to tackle the specific challenges of mitral and tricuspid valve disease will significantly alter future valve therapies. A specific challenge for these new therapies will be to demonstrate cost-effectiveness as well as superior or equivalent efficacy compared to traditional management. It is likely that the cardiac catheterization laboratory and the minimally invasive

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Figure 5. The Millipede system. Delivery of ring assembly to the tricuspid valve (A). Expansion of the annulus and attachment of the annular ring (B). Detachment and release of the ring, reducing annular dimensions and TR (C).

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operating room suite will be used increasingly to treat valve disease. New therapies will benefit patients with shorter hospital stays, decreased morbidity, and provide alternate options for those who are not conventional surgical candidates. ■

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