Concomitant Robotic Mitral and Tricuspid Valve Repair: Technique and Early Experience

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Background. Robotic mitral valve repair has been successfully performed since the late 1990s, but concomitant robotic tricuspid repair has not yet been widely adopted. We report our first 5 years' experience with concomitant robotic mitral-tricuspid valve repair.

Methods. Records were reviewed for all patients who underwent concomitant robotic mitral-tricuspid valve repair in a single practice. Cardiopulmonary bypass was performed with femoral cannulation, antegrade and retrograde cardioplegia, and aortic cross-clamping by balloon occlusion. Access was through 5 ports. Tricuspid repair techniques included De Vega, modified De Vega with annuloplasty band, and annuloplasty band with interrupted suture repair.

Results. From August 2006 to December 2011, 50 patients underwent concomitant robotic mitral-tricuspid valve repair. The mean age was 73.4±9.3 years, and all patients had mitral or tricuspid regurgitation grades of 2+ or greater preoperatively. Cross-clamp and cardiopulmonary bypass times decreased significantly with surgeon experience. There were no conversions to sternotomy and one conversion to mitral valve replacement. Six patients required reexploration for bleeding or hemothorax, most of them early in the series. There were no infections, no intraoperative strokes, and no new-onset acute renal failure requiring dialysis. Two postoperative strokes resolved completely. Two patients experienced nitinol clip fracture and mitral ring dehiscence requiring reoperation. There were 2 early deaths. All patients had regurgitation grades of less than 2 at follow-up (p < 0.001).

Conclusions. Combined robotic mitral-tricuspid valve repair can be performed safely and reproducibly, with acceptable early results. Long-term follow-up will be needed to establish this as an alternative to traditional sternotomy approaches.

Tricuspid valve regurgitation (TR) often occurs secondary to mitral insufficiency. It has been clearly established that tricuspid valve repair (TVP) should accompany mitral valve repair (MVP) when moderate TR of 2+ or greater is present [1]. It has been further proposed that tricuspid annular dilatation greater than 70 mm, even without significant TR, may be a reasonable indication for concomitant TVP [1, 2].

Since the introduction of robotic techniques for MVP (rMVP) in the late 1990s by Mohr, Chitwood, and Murphy, many surgeons have viewed the need for concomitant TVP as a contraindication for a robotic approach, primarily because of concerns related to cannulation, isolation of the right atrium, and the potential for prolonged cross-clamp and cardiopulmonary bypass (CPB) times. To our knowledge, there has been one report of concomitant rMVP and rTVP, by Jones and colleagues [3], but a combined robotic approach to treatment of mitral regurgitation (MR)-TR is not otherwise common.

Early in our experience with rMVP, we embarked on routine application of robotic techniques to treat combined MR-TR. We have used a retrospective review to evaluate our experience with the first 50 patients treated with concomitant rMVP and rTVP, including early clinical results and the evolution of our surgical techniques, with the goal of defining best practices for this novel procedure.

Patients and Methods

Expedited review and approval of this study was obtained from the Investigational Review Board at Sarasota Memorial Health Care System, and individual patient consent was waived.

Study Population

We reviewed hospital and office records and The Society of Thoracic Surgeons (STS) database to identify all patients who underwent concomitant robotic mitral-tricuspid valve repair.

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patients on whom we had performed rMVP from the inception of our robotics program at one hospital through our current experience at a second hospital.

Preoperative Workup, Planning, Robotic System Setup, and Patient Preparation

All patients with isolated mitral/tricuspid insufficiency were considered candidates for the port-access, robotic, combined rMVP-rTVP. Patients were not excluded for prior open heart operations (other than those listed below), the need for Cox-Maze ablation, or need for atrial septal defect repair. Patients were excluded for one or more of the following reasons: mitral stenosis, prior MVP or replacements, prior TV operation, significant coronary artery disease requiring concomitant revascularization, a history of prior right chest operations, or a history of aortic dissection.

Standard preoperative evaluation included left and right heart catheterization along with surface and transesophageal echocardiography (TEE) to accurately identify all relevant cardiac pathologies and to select patients for a nonsternotomy approach. A preoperative computed tomography angiogram and digital reconstruction were used to help plan the minimally invasive operation.

Significant aortoiliac or iliofemoral peripheral vascular disease is a contraindication for peripheral cannulation and is a contraindication to a robotic approach in some centers. In such cases, our preference was to use alternate cannulation strategies, most often direct cannulation of the distal ascending aorta and standard aortic cross-clamping with femoral venous cannulation.

Operative Technique

All operations were performed using the da Vinci S Surgical System (Intuitive Surgical Inc, Sunnyvale, CA), by the same console surgeon (C.L.) and table side surgeon (R.S.). Double-lumen endotracheal tubes were placed for single-lung ventilation. Bilateral brachial arterial catheters for occlusion balloon positioning and a TEE probe for placement of all catheters were routinely used. Neck catheters included two introducers: the first for a retrograde cardioplegia catheter, and the second for a pulmonary artery vent. A 14-gauge Angiocath angiocatheter (BD Medical Franklin Lakes, NJ) was placed into the right internal jugular vein low in the neck and prepared into the operative field to provide access to the superior vena cava during later cannulation.

Five ports were created in the right chest wall (Fig 1). Three 8-mm ports in the second, sixth, and fifth intercostal spaces (ICSs) were created for the robot’s left, right, and third (retractor) arms. A 12-mm camera port was placed in the fourth ICS just lateral to the midclavicular line (MCL), and a 2-cm working port 2 cm lateral to the camera port in the same fourth ICS allowed for a totally endoscopic “CO2 tight” approach. Three long, 14F angiocatheters were placed for retraction of the pericardium; one each in the second and sixth ICS along the anterior axillary line and the third in the sixth ICS at the MCL for retraction of the right diaphragmatic central tendon, when necessary.

A 4-cm oblique incision was made in the right groin to allow access to the femoral artery and vein. All cannulas were placed in the groin using a Seldinger technique under TEE guidance, through Prolene purse strings (Ethicon, Somerville, NJ). A 25F femoral venous catheter was placed in the right femoral vein and advanced into the superior vena cava under TEE guidance. A 23F arterial cannula with a side arm for the aortic occlusion balloon was placed into the right femoral artery and the occlusion balloon advanced into the ascending aorta under TEE guidance. A 15F femoral arterial cannula (Medtronic Inc, Minneapolis, MN) was placed over a guidewire into the superior vena cava through the right internal jugular vein angiocatheter and extended into the venous circuit using a Y connector. We did not perform special monitoring for leg ischemia. When the right femoral artery was too small to accommodate a 23F catheter, a bilateral approach was used with a 19F balloon introducer placed in the right femoral artery and
a catheter sized for arterial return in the left femoral artery.*

After cannulation the robot was docked, pericardial and thymic fat removed, and the phrenic nerve identified and preserved. CPB was then initiated. In primary operations, the core temperature was allowed to drift to 35°C. Patients with a history of prior open heart operations, particularly those with a patent internal mammary artery, were actively cooled to 28°C to 30°C. The pericardium was dissected free from the diaphragm to the innominate vein and then opened back toward the phrenic nerve to create a large pericardial flap, which served to hold the lung back and guide instrument exchange into the heart.

The inferior and superior vena cavae were circumferentially dissected and short tapes prepositioned around them for later use. The intracoronal occlusion balloon was inflated to clamp the ascending aorta, using TEE for guidance and monitoring right arm, left arm, and root pressures to help confirm accurate deployment. The balloon was routinely wedged into the sinotubular junction, a technique that we have determined helps eliminate later migration of the balloon.

The heart was arrested with 1 L of cold-blood antegrade cardioplegia, supplemented at 12- to 15-minute intervals with 200 mL doses of retrograde cardioplegia. For redo operations, retrograde cardioplegia was given more frequently, along with systemic cooling.

Mitral Valve Repair
A vertical left atriotomy was made just posterior to the interatrial groove, and a da Vinci dynamic atrial retractor was placed through the third arm port for exposure. The MV was repaired using a combination of standard techniques, including the “French correction” and the “American correction,” as appropriate. All valve leaflet sutures were 4-0 expanded polytetrafluoroethylene (PTFE) monofilament (Gore-Tex; W. L. Gore and Associates Inc, Flagstaff, AZ). Early in this series we secured the mitral rings with nitinol clips, and later all annuloplasty sutures were 2-0 Ethibond (Ethicon) tied extracorporeally by the table side surgeon.

A supporting annuloplasty band or ATS Simulus ring (Medtronic Inc) was used for all patients but one. When present, patent foramen ovale and atrial septal defects were closed through the left atrium with PTFE suture. One patient underwent patch repair of an ostium primum atrial septal defect with a pericardial patch and no mitral ring. Cryo-Maze (Cox Maze 3 or 4) procedures were performed as clinically indicated with the ATS CryoMaze Surgical Ablation System (Medtronic). The base of the left atrial appendage was oversewn with 2-layer running PTFE in patients with atrial fibrillation.

The left atrium was closed with a single-layer PTFE suture and tied.

Tricuspid Valve Repair
The caval cannulas were backed into the superior and inferior vena cavae and the tapes tied with a double surgeon’s knot. A vertical right atriotomy was made, and the dynamic atrial retractor was used to retract the anterior right atrial wall. A PTFE suture was used to secure the posterior wall of the right atrium to the pericardial flap and to hold a sump sucker into the low right atrium (Fig 2).

TVPs evolved from a classic De Vega repair (double-armed running vertical mattress purse string sutures of 4-0 PTFE, tied over pledgets) to a modification in which a 25-mm annuloplasty band (ATS Simulus) was sutured over the De Vega stitch with running PTFE, and finally, to an annuloplasty band sewn into place with interrupted 2-0 polyester suture (currently, our strongly favored technique). The right atrium was then closed in 2 layers with PTFE, and the caval tapes were released. The occlusion balloon was deflated during right atrial closure and increasingly during TVP to allow for a reduced crossclamp time. Air removal was not necessary because the endoscopic technique is “CO2 tight.” Patients were weaned from CPB and decannulated.

The femoral vessels were closed with primary suture repair after clamping and removal of the purse strings. A 28F chest tube was placed high in the right pleural space through the right arm port, and a soft Blake drain (Ethicon).

*Note: With the new IntraClude balloon (Edwards Lifesciences, Irvine, CA) we use a 21F introducer with smaller femoral arteries and usually avoid a bilateral approach.

|Note: We, like others, have now abandoned the nitinol clip technique because of ring dehiscence secondary to clip fracture. We currently use the Cor-Knot device (LSI Solutions Inc, Victor, NY).|
was placed in the pericardial space through the third arm port. After hemostasis, the other ports and the groin were closed with Vicryl suture (Ethicon Inc). An On Q pain pump (I-Flow LLC, Lake Forest, CA) was routinely placed.

Data Collection and Statistical Analysis
We reviewed patient records to collect demographic, preoperative, intraoperative, and postoperative data. Body surface area and STS morbidity and mortality risk scores were calculated. Data are expressed as mean ± standard deviation, unless otherwise noted. Significance testing was performed by an independent biostatistician, using the McNemar test to compare preoperative and postoperative valvular regurgitation and the two-sided, two-sample t test (Satterthwaite method) for comparisons between groups. The α level was defined as 0.05 for all tests.

Results
Patient Characteristics and Intraoperative Outcomes
A total of 354 patients underwent rMVP procedures between November 2006 and December 2011. Concomitant rTVP was performed on 50 (14%) of these patients, who formed the population described in this study. Preoperative and intraoperative outcomes are summarized in Table 1.

Table 1. Baseline Characteristics of Patients Undergoing Concomitant Robotic Mitral and Tricuspid Valve Repair

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. or Mean ± SD (n = 50)</th>
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<tbody>
<tr>
<td>Age, y</td>
<td>73.4 ± 9.3</td>
</tr>
<tr>
<td>Female sex</td>
<td>22</td>
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<tr>
<td>Body surface area, m²</td>
<td>1.9 ± 0.2</td>
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<tr>
<td>STS operative risk score (mortality)</td>
<td>4.3 ± 5.9</td>
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<tr>
<td>NYHA Functional Classification</td>
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<tr>
<td>Class I</td>
<td>3</td>
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<td>Class II</td>
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<td>Class III</td>
<td>29</td>
</tr>
<tr>
<td>Class IV</td>
<td>14</td>
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<td>Comorbidities</td>
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<td>41</td>
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<td>Diabetes</td>
<td>13</td>
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<td>9</td>
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<tr>
<td>LV-EF</td>
<td>0.457 ± 0.141</td>
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<td>Mitral valve dysfunction</td>
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<tr>
<td>Type I</td>
<td>17</td>
</tr>
<tr>
<td>Type II</td>
<td>16</td>
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<tr>
<td>Type IIIa</td>
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</tr>
<tr>
<td>Type IIIb</td>
<td>17</td>
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STS score descriptive statistics were calculated from the 30 patients operated on at the second hospital. STS scores were not available for the first 20 patients. *Carpentier’s functional classification.

LVEF = left ventricular ejection fraction; NYHA = New York Heart Association; SD = standard deviation; STS = The Society of Thoracic Surgeons.

There were no anesthesia- or catheter-related complications. Femoral arterial cannulation was used for 48 patients (96%), and 2 (4%) were cannulated centrally. No intraoperative strokes occurred. There were no conversions to sternotomy and one conversion to a MV replacement for a failed repair of rheumatic mitral insufficiency.

Figure 3 shows the decrease in operative times over the course of the patient series. Mean cross-clamp time was 98.9 ± 31.4 minutes (range, 15 to 198 minutes). The mean cross-clamp time for the first five operations was 153.4 ± 40 minutes and fell to 85.8 ± 8.9 minutes for the last five operations (p = 0.0178). Cross-clamping and cardioplegic arrest were unsuccessful in 1 patient. The repair in this patient was performed under cold fibrillatory arrest at a core temperature of 28°C.

Mean CPB time was 163.3 ± 40.2 minutes (range, 112 to 289 minutes) and fell from a mean of 223.4 ± 51.2 minutes in the first five operations to 139.8 ± 26.7 minutes in the last five operations (p = 0.0176). Three patients (6%) required an intraaortic balloon pump to wean from CPB, with left ventricular ejection fractions of 0.15, 0.20, and 0.25, respectively.

For the MVPs, simple rings were used in 34 patients and more complex repairs were performed in 16. For the TVPs, the first 21 patients underwent a classic De Vega suture repair, the next 8 underwent a modified De Vega, and the last 21 had a simple band annuloplasty (19 patients with a 25-mm band and 2 with a 27-mm band). Concomitant procedures included seven Cryo-Maze procedures and 10 atrial septal defect/patent foramen ovale closures.

Postoperative Outcomes
A comparison of preoperative and postoperative MR and TR, as determined by TEE, is reported in Table 2 (p < 0.001 for both groups). There were six reoperations (12%) for bleeding or hemothorax, four of which were in patients who had had prior open heart operations. Blood transfusions were not required for 16 patients (32%). Postoperative stroke occurred in 2 patients, one at day 6 from heparin-induced thrombocytopenia and the other at day 3 from conversion to atrial fibrillation. Both patients recovered completely.

There were two early deaths, one at day 4 from cardiac arrest (pulseless electrical activity) of unknown etiology (STS risk score, 3.6%), and the other at home on day 23 of unknown causes (preoperative left ventricular ejection fraction, 0.15%; STS risk score, 28.8%).

The average hospital length of stay was 8.7 ± 4.9 days (range, 4 to 28 days). There were no infections, no new-onset acute kidney injury requiring dialysis, and no unilateral pulmonary edema. One patient experienced an iliac artery occlusion requiring revision, and 2 patients required a new permanent pacer. Of the first 10 patients, 2 required reoperation for recurrent mitral regurgitation secondary to ring dehiscence associated with nitinol clip fracture. Both underwent successful repeat repair, one through a redo robotic approach and the other through a...
sternotomy. We have discontinued all use of nitinol clips because of a higher noted incidence of ring dehiscence.

**Comment**

TVP is sometimes indicated in patients who have severe MV insufficiency requiring repair, but the precise indications for repair of secondary TR are controversial. Some authors reserve concomitant TVP for patients with TR classified as moderate or greater, while others prefer to operate on patients exhibiting tricuspid annular dilatation alone [2]. The choice of repair techniques also remains a matter of debate: some reports have found that suture annuloplasty alone is sufficient [4], but a number of recent studies have found that this technique’s risk of late failure is unacceptable and that support with an annuloplasty ring is preferable [5–7]. Moreover, the risks of concomitant TVP are not yet well defined. Current STS risk models do not include TVP as an incremental risk factor, but some groups, including Bernal and colleagues [8] and LaPar and colleagues [9], believe this should be changed.

Robotic MVP has been successfully performed since the late 1990s [10] and has been validated as an acceptable approach to treating complex MV pathology in centers that are experienced with the da Vinci system and with minimally invasive techniques [11–27]. Routine rTVP in conjunction with rMVP, however, has not been widely adopted among surgeons using robotic techniques, presumably due to long CPB and cross-clamp times and early learning-curve issues. Patients with combined mitral-tricuspid pathology are thus limited to more traditional surgical approaches.

The first combined rMVP/rTVP was performed by Jones and colleagues in 2003, who later published a report detailing clinical experience with robotic valve repair in 32 patients [3]. Of those, 4 patients underwent concomitant rMVP/rTVP, and 1 of these patients died early [3]. We were unable to identify any other reports of this technique in the literature.

In our current series of 50 patients treated over 64 months, we have found that we can routinely apply an endoscopic, port-access robotic approach in patients who have combined MR and TR with acceptable results. Consistent with other groups and other robotic valve repair techniques, we noted a several-case learning curve. During the course of our experience, we have modified our operative approach and have continued to improve our techniques, for example, modifying our suturing techniques and use of annuloplasty rings for TVP. As we have done so, CPB times and other operative variables have improved. Reoperation for bleeding and repair failure have both decreased in incidence as experience has been obtained, even as the severity of illness and the complexity of the patient population has increased. Consequently, we have relaxed our criteria for

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**Table 2. Preoperative and Postoperative**

**Echocardiographic Results (N = 50)**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Mitral Valve Regurgitation</th>
<th>Tricuspid Valve Regurgitation</th>
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<tbody>
<tr>
<td></td>
<td>Pre-op</td>
<td>Post-op</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>48</td>
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<tr>
<td>Trace</td>
<td>0</td>
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</tr>
<tr>
<td>1+</td>
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<td>0</td>
</tr>
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<td>2+</td>
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<td>1</td>
</tr>
<tr>
<td>3+</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>4+</td>
<td>46</td>
<td>0</td>
</tr>
</tbody>
</table>

* Postoperative echocardiographs were obtained at the time of discharge from the hospital. \(^b\) Data are expressed as number/50. \(^c\) This patient was converted intraoperatively to a mini-mitral valve replacement.
concomitant rTVP to include those patients exhibiting tricuspid annular dilatation alone, as recommended by Dreyfus and colleagues [2]. Longer-term follow up will be needed to validate this approach as a truly viable one for combined rMVP/rTVP.

This study has several limitations, the first being the retrospective nature of the data collection and the second being the absence of long-term follow-up for recurrent MR or TR. The robotic, port-access approach did not appear to dramatically increase the length of stay, return to the operating room, or transfusion rates compared with what could be reasonably expected after open sternotomy; however, that it also did not appreciably decrease these adverse events is notable. This was surprising, given that one of the objectives of minimally invasive, robotic surgery is to reduce such complications. Cross-clamp and CPB times improved with experience but remain an item of concern, particularly for surgeons not experienced with robotic techniques. We believe that many of these are learning-curve issues and will be resolved with more experience and that concomitant rMVP/rTVP is a reasonable surgical alternative to traditional sternotomy MVP/TVP.

Disclosures and Freedom of Investigation

The authors self-funded this study and paid for professional editorial and statistical assistance. Illustrations were donated by Edwards Lifesciences. The robotic surgical systems used in this study were the property of the 2 hospitals. The authors had full control of the design of the study, methods used, outcome parameters and results, analysis of data and production of the written report.

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References


