

# Subvalvular techniques enhanced with endoscopic robotic mitral valve repair



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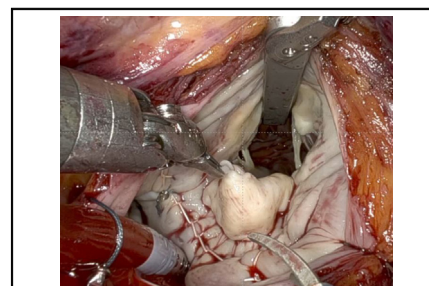
## ABSTRACT

**Objective:** Totally endoscopic intracardiac robotic surgery is generally limited to uncomplicated mitral valve surgery. With experience, our team has developed a more aggressive approach to robotic cardiac surgery that allows for repair of a broad spectrum of mitral valve pathologies. We report complex subvalvular procedural advancements associated with this approach secondary to enhanced team experience and capabilities.

**Methods:** All robotic mitral procedures performed by a 2-surgeon team in a quaternary care medical center from July 2011 to May 2022 were reviewed. Natural language-processing techniques were used to analyze operative reports for subvalvular repair techniques. Complex subvalvular techniques included papillary muscle repositioning, division of secondary anterior leaflet chordae, septal myomectomy, division of aberrant left ventricular muscle band attachments, and left ventricular patch reconstruction. The surgical experience was divided into 2 periods: early robotic experience (pre-2018) versus late (2018 onwards). Baseline demographics, outcomes, and subvalvular techniques were analyzed and compared.

**Results:** A total of 1287 intracardiac robotic operations were performed by a 2-surgeon team. Thirty-day mortality was 0.6% (8/1287). Mitral valve repair was performed in 1024 patients. The mean age was 61 years (range, 18-90 years), and 15% were >75 years old; 29 patients (2.8%) had previously undergone cardiac surgery. There was a significant increase with experience in the application of advanced subvalvular techniques between the early versus late period (52.3% [268/512] vs 74.2% [380/512] ( $P < .001$ )).

**Conclusions:** An experienced 2-surgeon team can perform progressively more complex robotic subvalvular repair techniques. These subvalvular techniques are a surrogate for team proficiency and capabilities. (JTCVS Techniques 2023;22:23-7)



Robotic mitral valve repair allows optimal visualization of the subvalvular apparatus.

## CENTRAL MESSAGE

An experienced 2-surgeon team and dedicated OR personnel allow for the consistent, seamless performance of totally endoscopic robotic subvalvular techniques in mitral valve repair.

## PERSPECTIVE

With the continued expansion of totally endoscopic robotic techniques in mitral valve surgery, our study demonstrates that when an experienced 2-surgeon team works in tandem with dedicated OR personnel, there are additional opportunities to perform adjunctive subvalvular procedures during mitral valve repair.

Over the past 2 decades, there has been widespread acceptance of the robotic platform for performing uncomplicated mitral valve repair (MVR). Several large clinical series have

demonstrated superb hospital outcomes with increasingly improved short-term outcomes.<sup>1-3</sup> There are, however, considerable limitations, and generally “simple” patient subsets are considered most appropriate for the robotic approach.<sup>4</sup> Although these are good initial management principles, in our practice, we have found that an experienced surgical team and a dedicated operating room (OR) staff can routinely exceed these guidelines and perform more complex procedures in nearly all patients presenting for mitral valve surgery.<sup>5</sup> At our institution, with a dedicated 2-surgeon approach, we have developed a more aggressive use of robotic cardiac surgery for a broad spectrum of mitral valve pathologies. With this expansion of indications, a similarly increased performance of complex subvalvular robotic repair techniques has occurred. We report subvalvular procedural advancements associated with the totally

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**Abbreviations and Acronyms**

LV	= left ventricle
MVR	= mitral valve repair
OR	= operating room
SAM	= systolic anterior motion

endoscopic robotic approach as a surrogate marker for team proficiency and capabilities.

**METHODS**

All robotic MVRs performed by a 2-surgeon team from a large, academic, quaternary care center from July 2011 through May 2022 were reviewed. The operative staff included a 2-surgeon team, a group of dedicated cardiac anesthesiologists, and consistent OR nursing personnel. A totally endoscopic port-only surgical approach was used with cardioplegic arrest and either endoballoon or flexible clamp aortic occlusion.<sup>5</sup> A language-processing program was written to analyze the syntax of operative notes for subvalvular techniques performed during robotic MVR. Operative reports were then analyzed in detail by the senior author for adjunctive subvalvular repair techniques performed during robotic MVR. Complex subvalvular techniques included papillary muscle repositioning, division of secondary anterior leaflet chordae, septal myectomy, division of aberrant left ventricle (LV) muscle band attachments, and LV patch reconstruction. In addition, the Society of Thoracic Surgeons and New York State Cardiac Surgery data-collection instruments were analyzed. For this study, we divided the surgical techniques into 2 periods: early robotic MVR experience (operations performed July 2011 through December 2017) or late (operations performed January 2018 through May 2022). This study was performed as part of an ongoing Quality Assessment/Quality Improvement project, and a Self-Certification form is on file with the institutional review board at NYU Langone Health.

**Statistical Analysis**

Statistical analysis was performed using SPSS (Version 28; IBM Corp). Descriptive analyses were performed on various patient characteristics to summarize variable baseline distributions. Categorical variables are

reported as frequency and percentage. Continuous variables are reported as mean  $\pm$  standard deviation or median with interquartile range where appropriate. Normally distributed variables were compared with a Student *t* test, and non-normally distributed variables were compared with nonparametric testing (Mann-Whitney *U*).

**RESULTS**

A total of 1287 intracardiac robotic operations were performed by a 2-surgeon team during the study period. The 30-day mortality was 0.6% (8/1287). MVR was performed in 1024 patients (79.6%), and this cohort is the subject of our report. Using the predefined stratification of early and late experience, 512 patients were included in each group. Demographic data of this cohort included a mean age of 61 years (range, 18-90 years), and 15% of the cohort were older than 75 years old. Within this cohort, 2.8% (29/1024) had a history of previous cardiac surgery (Table 1). Notably, the mean body mass index was 25.9 (range, 14.4-55.5). Although it is well known that patients with obesity are at increased risk for postoperative complications,<sup>6</sup> there is recent evidence to suggest that patients with a high body mass index have similar outcomes when undergoing robotic cardiac surgery.<sup>7</sup> The clinical preoperative variables did not differ significantly between the cohorts over time, and although the complexity of techniques increased, there was no impact on morbidity or mortality (Table 1). Complex subvalvular procedures included papillary muscle trunk repositioning (5.1%; 51/1024), division of secondary anterior chordae (56.7%; 581/1024), septal myectomy (5.4%; 55/1024), and resection of abnormal LV muscle bands (8.3%; 83/1024). When we compared the early- and late-experience groups, the number of complex subvalvular procedures increased significantly over time, specifically regarding papillary

**TABLE 1. Patient demographics, preoperative, intraoperative, and postoperative variables by early versus late experience**

Perioperative characteristics and outcomes	Total n = 1024	Early experience n = 512	Late experience n = 512	<i>P</i> value
Age, y, mean [range]	61.44 [18-90]	60.26 [18-87]	62.62 [25-90]	<.01
Height, cm, mean	171.67	171.7	171.6	.86
Weight, kg, mean	76.55	77.00	76.00	.33
BMI, mean [range]	25.85 [14.4-55.5]	26.0 [16.3-45.3]	25.7 [14.4-55.5]	.33
Previous MV surgery, n (%)	16 (5.0)	10 (4.5)	6 (6.0)	.58
Previous CABG, n (%)	13 (2.9)	8 (3.1)	5 (2.6)	1.00
Ejection fraction (%), mean	60.9	60.7	61.1	.42
30-d hospital mortality, n (%)	6 (0.6)	2 (0.4)	4 (0.8)	.21
STS predicted mortality*	0.8%	0.8%	0.8%	NS
Conversion to sternotomy, n (%)	10 (1.0)	7 (1.4)	3 (0.6)	.21
Reoperation for bleeding, n (%)	49 (4.8)	27 (5.3)	22 (4.3)	.46
Extubated in OR, n (%)	814 (79.5)	424 (82.8)	390 (76.2)	<.01
Post-operative stroke, n (%)	8 (1.0)	3 (0.6)	5 (1.7)	.15

BMI, Body mass index; MV, mitral valve; CABG, coronary artery bypass grafting; STS, Society of Thoracic Surgeons; NS, not significant; OR, operating room. \*Excluding left ventricular patching and myotomy/myectomy (for which there are no STS mortality models).

muscle repositioning (0.4%-9.6%,  $P < .001$ ), division of secondary anterior chordae (47.5%-66.0%,  $P < .001$ ), and septal myomectomy (6.0%-49.0%,  $P < .001$ ). In addition, although not identified as complex, artificial chordae implantation similarly increased over time (52.3%-74.2%,  $P < .001$ ) (Table 2).

## DISCUSSION

Alain Carpentier's classification of leaflet motion in mitral regurgitation includes normal leaflet motion (Type 1), excessive leaflet motion (Type 2), and restricted leaflet motion (Type 3a: restricted opening during systole and diastole; Type 3b: restructure closure during systole).<sup>8</sup> This classification of leaflet motion is relevant to the mitral valve surgeon, considering the mechanism of subvalvular repair techniques required for totally endoscopic robotic MVR. Mitral regurgitation with Type 2 leaflet motion predominates and is generally secondary to abnormalities of the leaflets, annulus, and chordae—collectively referred to as the mitral valve apparatus.<sup>9</sup> Abnormalities such as rupture or elongation of the chordae or papillary muscle result in either mitral valve prolapse or a flail leaflet. The subvalvular techniques used to address prolapse are specifically catered to each component of the mitral valve apparatus and include resection, placement of artificial chordae, and opposite chordal transfer. More complex techniques include secondary chordal transfer and papillary muscle trunklet repositioning. These complex techniques to correct mitral valve prolapse, along with septal myectomy, LV patch reconstruction, and abnormal muscle bundle resection, are part of surgeons' accessible toolbox with an advanced robotic team approach.

With respect to Type 2 anterior leaflet, at our institution we favor papillary muscle shortening or repositioning in cases with a prolapse that mainly involves segments A2 and A3; A1 is rarely prolapsed. Generally, the anterior trunk of the posterior papillary muscle supports A2 and A3. Shortening of the posterior papillary muscle anterior trunk allows for lowering the margin of A2 and A3 all at once. That is typically feasible only if good marginal chordae remains, meaning chordae that are neither too thin nor too elongated. Chordal transfer is preferred in cases with a prolapse limited to one segment like A2 or

A3, especially with the "seagull sign" on transesophageal echocardiography; the "seagull" sign results from the combination of ruptured marginal chordae with good secondary chordae. As a last resort, when the situation is not favorable for either of the 2 previous techniques we employ artificial chordae.

As demonstrated in this report, as our team experience grew, we performed increasingly routine secondary chordae excisions, septal myomectomies, and divisions of LV aberrant muscle band attachments. We used these techniques to avoid postrepair systolic anterior motion (SAM) of the mitral valve leaflets. Although the occurrence of SAM is multifactorial and is usually secondary to either excess leaflet tissue, a narrow aorta-mitral angle, or an undersized annular ring, Manabe and colleagues<sup>10</sup> demonstrated that LV function influences the development of SAM following MVR. In their study, the incidence of SAM significantly increased with greater preoperative ejection fraction and smaller LV diameter, patients not infrequently seen in our advanced guideline-driven practice. Although performing adjunct subvalvular techniques to limit the risk of SAM is not always a decision made by surgeons, we elect to perform such techniques prophylactically with the goal of enlarging the left ventricular outflow tract.<sup>11</sup>

The increasing use of robotics in complex mitral valve surgery has been reported in the literature. Gillinov and colleagues<sup>3</sup> reviewed the first 1000 patients who underwent robotic primary mitral valve minithoracotomy operations from 2006 to 2013. Over time, they noted an increase in frequency of artificial chordae implantations and triangular/quadrangular resections, while at the same time noting decreased cardiopulmonary bypass and myocardial ischemic times as well as intensive care unit and postoperative lengths of stay. In a nonrandomized observational study, Fujita and colleagues<sup>12</sup> enrolled 335 patients to undergo either robotic MVR versus mini-MVR via right thoracotomy. They included repair complexity in their analysis, citing the complexity score developed by Loumet and colleagues.<sup>5</sup> Notably, patients in the robotic MVR cohort had greater complexity scores ( $1.5 \pm 0.8$  vs  $1.2 \pm 0.5$ ,  $P < .001$ ), without any statistically significant difference in postoperative mortality or morbidity.<sup>12</sup>

TABLE 2. Subvalvular techniques between early versus late experience

Subvalvular techniques	Total n = 1024	Early experience n = 512	Late experience n = 512	P value
Complex subvalvular techniques, n (%)	648 (63.3)	268 (52.3)	380 (74.2)	<.001
Papillary muscle repositioning	51 (5)	2 (0.4)	49 (9.6)	<.001
Division of secondary anterior chordae	581 (56.7)	243 (47.5)	338 (66.0)	<.001
Septal myomectomy	55 (5.4)	6 (1.2)	49 (9.6)	<.001
LV patch reconstruction	37 (3.6)	14 (2.7)	23 (4.5)	.18
Division of LV muscle band attachments	83 (8.1)	43 (8.4)	40 (7.8)	.82
Other subvalvular techniques, n (%)				
Artificial chordae implantation	290 (28.3)	100 (19.5)	190 (37.1)	<.001

LV, Left ventricle.

Performing complex subvalvular techniques innately requires progression along an advanced learning curve. We would argue that these techniques are enhanced with the robotic platform in 2 main ways: improving intraoperative visualization of the subvalvular apparatus and facilitating micromanipulation of surgical instruments. The visualization of the subvalvular apparatus and left ventricular outflow tract when the stereoscope is advanced inside the left atrium close to the mitral valve orifice reveals exquisite detail. It additionally allows a 2-surgeon team to see clearly and simultaneously without obstruction, an important condition for efficient work. The great dexterity of fine and precise robotic tools in a small space like the LV facilitates instrument micromanipulation, permitting us to execute maneuvers not previously accessible with traditional surgical instruments via a transmitral approach.

Although our data demonstrate the expanded role of robotic surgery in performing adjunctive subvalvular repair techniques during MVR, these advancements are largely attributed to the development of an experienced and a dedicated surgical team working in tandem both at the robot and at the bedside. Advanced robotic subvalvular procedures such as septal myotomy–myectomy have been reported,<sup>13,14</sup> although are quite limited and frankly do not use advanced subvalvular techniques. For instance, subvalvular knot-tying cannot easily, if at all, be accomplished with robotic instruments given the intraventricular space limitations. Two-surgeon teams are of benefit here, as an experienced bedside surgeon is able to offset the limitations of the robotic surgeon by performing specialized techniques from the bedside. Murphy and colleagues<sup>2</sup> demonstrated that by having a bedside surgeon available, conventional MVR procedures historically performed only with 2 hand-held instruments can now be choreographed with the bedside surgeon central for allowing seamless transition between robotic and hand-held instruments.<sup>2</sup> For example, tying an LV patch to the LV myocardium requires precisely controlled suture tension when tying with either a knot pusher or a suture crimping device, a task that the bedside surgeon can accurately perform when working in tandem with the robotic surgeon at the console. Expectedly, there is an initial learning curve to overcome at the outset as team dynamics evolve. However, once the experience and cohesiveness of the team improves over time, so too do the technical capabilities of performing subvalvular repairs competently and expeditiously.

Beyond these technical achievements, the importance of a cohesive and integrated OR team to successfully perform complex robotic MVRs cannot be understated. A useful analogy to convey the importance of 2-surgeon teams is to consider the aviation industry, and the lessons learned on managing errors, which many times stem from cognitive overload, poor interpersonal communication, and flawed decision making.<sup>15</sup> More specifically, when comparing the

feasibility of reduced crew models in pilot operations, Bailey and colleagues<sup>16</sup> demonstrated that several parameters were negatively impacted, including frequency of checklist usage and accuracy of flight path performances. As a pilot's workload was increased during single pilot operations, the propensity of performance errors whether by poor execution or omission of tasks likewise increased. These observations are directly transferrable to the OR, where surgeons who perform robotic mitral valve surgery understand the information overload that exists in unpredictable environments and can opt to take advantage of having an experienced copilot. With a dedicated and experienced surgical team, communication, problem-solving, and task management become more fluid and ultimately successful. This is a hallmark of a "high functioning team."

### Limitations

This is a series conducted by 2 experienced mitral valve surgeons, both of whom have developed and have been performing intracardiac robotic surgery for more than 2-and-a-half decades.<sup>17,18</sup> As such, we realize these conclusions may not be easily applicable to other practices. Furthermore, this experience extends to the several iterations of robotic technology that has evolved into what it is today. Loulmet performed the first robotic MVR in Paris in May 1998; at our institution, we performed the first robotic MVR in April 2000 using the Computer Motion ZEUS Robotic Surgical System. This was later replaced by the Da Vinci Surgical System, to include its iterations from the S, Si, and Xi, all of which have been used and learned from to expand our practices.

### CONCLUSIONS

In this report, we demonstrate that, over time, a dedicated 2-surgeon team in conjunction with specialized OR personnel and the robotic platform allows for the continued expansion of techniques for MVR without an appreciable compromise in morbidity or mortality. Specifically, we report an increase in the performance of adjunctive complex subvalvular techniques in our robotic MVRs, largely attributed to the benefits of incorporating cohesive teams that learn together over time, improve in interpersonal communication, problem-solve as one, and distribute tasks efficiently and expertly to tackle the demanding and unpredictable workload that these procedures elicit.

### Conflict of Interest Statement

Dr Grossi has intellectual property and receives royalties from Medtronic for valve repair devices and has intellectual property and receives royalties from Edwards Lifesciences. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict

of interest. The editors and reviewers of this article have no conflicts of interest.

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**Key Words:** robotic, mitral valve repair, subvalvular techniques, minimally invasive surgery