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Robotic versus port-access mitral repair: A propensity score analysis

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Abstract

Background: Port-access (PORT) and robotic (ROBO) mitral repair are well established, but differences in patient selection and outcomes are not well documented.

Methods: A retrospective analysis was performed on 129 ROBO and 628 PORT mitral repairs at one institution. ROBO patients had 4 cm nonrib spreading incisions with robotic assistance, while PORT patients had 6–8 cm rib spreading incisions with thoracoscopic assistance. Propensity score analysis matched patients for differences in baseline characteristics.

Results: Unmatched ROBO patients were younger (58 ± 11 vs. 61 ± 13, $p = .05$), had a higher percentage of males (77% vs. 63%, $p = .003$) and had less NYHA Class 3–4 symptoms (11% vs. 21%, $p < .01$), less atrial fibrillation (19% vs. 29%, $p = .02$) and less tricuspid regurgitation (14% vs. 24%, $p = .01$). Propensity score analysis of matched patients showed that pump time (275 ± 57 vs. 207 ± 55, $p < .0001$) and clamp time (152 ± 38 vs. 130 ± 34, $p < .0001$) were longer for ROBO patients. However, length of stay, postoperative morbidity, and 5-year survival (97 ± 1% vs. 96 ± 3%, $p = .7$) were not different. For matched patients with degenerative valve disease, 5-year incidence of mitral reoperation (3 ± 2% vs. 1 ± 1%), severe mitral regurgitation (MR) (6 ± 4% vs. 1 ± 1%), or ≥2 + MR (12 ± 5% vs. 12 ± 4%), were not significantly different between ROBO versus PORT approaches. Predictors of recurrent moderate MR were connective tissue disease, functional etiology, and non-White race, but not surgical approach.

Conclusions: In this first comparison out to 5 years, robotic versus port-access approach to mitral repair had longer pump and clamp times. Perioperative morbidity, 5-year survival, and 5-year repair durability were otherwise similar.

KEYWORDS
minimally-invasive, mitral repair, robotics

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1 | INTRODUCTION

The port-access (PORT) or endoscopic assisted minithoracotomy approach to mitral surgery dates to 1996.[1–3] Mitral surgery using the Intuitive Surgical robotic platform (ROBO) began in 1998[4,5] with several large series later describing excellent results from robotic assisted mitral surgery.[6–9] Both the robotic assisted (ROBO) and endoscopic assisted (PORT) mitral platforms share many similarities in the minithoracotomy incision, cannulation strategy, and instrumentation. However, for mitral surgery there are only two reports comparing robotic (ROBO) mitral surgery to the endoscopic assisted minithoracotomy or port-access (PORT) approach.[10,11] These reports agreed on longer procedure times with ROBO but disagreed over small differences in transfusion and atrial fibrillation. No randomized comparisons have been reported. No comparisons PORT and ROBO approaches to mitral surgery have reported intermediate-term outcomes after discharge. This study was designed to compare both in-hospital and intermediate-term outcomes for PORT versus ROBO mitral repair.

2 | MATERIALS AND METHODS

2.1 | Patient characteristics

After institutional review board approval including waiver of individual consent, a retrospective analysis was performed for all patients undergoing mitral repair through a mini-thoracotomy approach from 2011 through 2019. Patients undergoing reoperations, concurrent coronary surgery, aortic procedures, or aortic valve surgery were excluded. Patients undergoing concurrent tricuspid valve surgery or atrial maze surgery were included. Follow-up data, including recurrent mitral disease, mitral reoperation, and death were extracted from the electronic medical record which is linked to the Social Security Administration death master file and to several national interhospital data networks.

2.2 | Surgical procedure

Patients were evaluated preoperatively with cardiac catheterization to exclude coronary disease and with echocardiography to assess valvular pathology. Computed tomography was performed selectively based upon the presence of chest wall abnormalities or to assess the vasculature for femoral arterial cannulation. Patients were selected for a robotic approach based on the availability of the robotic equipment and personnel.

All patients underwent general anesthesia and placement of an endobronchial blocker in the right main stem bronchus as tolerated.[12] The patient was placed on cardiopulmonary bypass with venous drainage from the femoral vein and arterial return either centrally in the ascending aorta,[13] the right axillary artery, or the femoral artery. Myocardial protection was generally obtained with anterograde and retrograde cardioplegia after aortic clamping. A variety of external clamps versus transfemoral endoclamp versus transaortic endoclamp were used.[14,15] Retrograde cardioplegia was obtained either via the right internal jugular vein or via a catheter placed in the right atrium through the thoracotomy incision. Some patients with limited aortic access underwent mitral surgery during ventricular fibrillation.[12] The mitral valve was approached through the interatrial groove in all patients, and the field was flooded with carbon dioxide. The heart was de-aired with a combination of ventricular and aortic venting and cardiac manipulation with echo guidance. As needed, tricuspid valve procedures were performed via the right atrium after completing the mitral procedure. Left atrial or biatrial ablations were performed just before the mitral or tricuspid valve procedure.

The nonrib spreading working port in the fourth intercostal space measured 4 cm for ROBO procedures, with a 6–8 cm rib-spreading incision generally used for PORT procedures. ROBO procedures were performed with either the da Vinci, da Vinci Si or da Vinci Xi machines (Intuitive Surgical).[8] ROBO repairs were usually performed using partial flexible mitral bands with running 4-0 PTFE suture,[8] while PORT repairs usually involved complete rigid rings with interrupted annular sutures. A band or ring annuloplasty was performed in all patients. The leaflet and chordal repair techniques otherwise were standard and similar between approaches.

The right pleural and pericardial spaces were drained in both platforms with a combination of a 19 Fr. flexible Silastic drain kept in for 4 days and conventional chest tubes generally removed in 12 h. Most patients were placed on antiarrhythmic amiodarone for 30 days along with daily aspirin. Systemic anticoagulation was used selectively for those patients with preoperative or postoperative atrial fibrillation.

2.3 | Statistics

Statistical comparisons were performed using the χ^2 test, the Student t test, or the Mann–Whitney U test. A p value of less than .05 was considered significant. Survival was computed using the Kaplan–Meier technique. Cumulative incidence of late mitral reoperation or recurrent mitral regurgitation (MR) were as computed using death as a competing risk. Moderate MR was defined as moderate or more (≥2+) MR. Survival estimates were presented as ± *SE*. Means are presented as ± *SD*. Skewed data were presented with median and interquartile range (IQR). Survival curves were compared using the log-rank test. Cumulative incidence curves were compared using Gray's test. To correct for baseline differences between the ROBO and PORT groups, propensity score analysis was performed using greedy nearest neighbor 2:1 matching with a caliper of 0.5 times the common standard deviation. Propensity score analysis matched all preoperative factors differing between treatment groups, including gender, white race, Class 3 or 4 heart failure, moderate or more tricuspid regurgitation, atrial fibrillation, ejection fraction less than 50%, urgent surgery, mitral disease etiology, and year of operation.[16] Stepwise backward logistic regression analysis was performed to find independent predictors of recurrent moderate or more MR. Statistical software was SAS 9.4, SAS Institute Inc.

3 | RESULTS

3.1 | Unmatched patients

A total of 757 patients underwent right minithoracotomy mitral repair during the time period. Of these, 129 patients had mitral repair with robotic assistance. A total of 628 patients underwent mitral repair using the PORT approach (Figure 1). The ROBO patients were more likely to be male or white, had more recent year of operation, and were less likely to have NYHA Class 3–4 symptoms, moderate or more tricuspid regurgitation, atrial fibrillation, ejection fraction less than 50%, or urgent operation (Table 1). Mitral valve etiology was mixed but was most often degenerative in 91% of ROBO and 78% of PORT patients.

Intraoperatively, ROBO patients had longer pump and clamp times and were less likely to have surgery performed under ventricular fibrillation (Table 2). Mitral repairs done with ROBO versus PORT approaches were more likely to be done with flexible bands (73% vs. 5%) as opposed to complete rigid rings. ROBO patients had larger ring/band sizes used (median: 40 vs. 36 mm) (Table 2). ROBO patients were more likely to receive an Alfieri stitch or Gortex chords but were less likely to have a leaflet resection. PORT patients were more likely to undergo concurrent tricuspid surgery or atrial maze procedures (Table 2).

Postoperatively, ROBO patients were less likely to receive a pacemaker and had shorter length of stay (Table 3). There were no significant differences in 30-day or in-hospital death, stroke, new atrial fibrillation, or other complications. Five-year survival was similar at 96 ± 3% vs. 94 ± 1% for ROBO and PORT groups respectively (Table 3) (Figure 2).

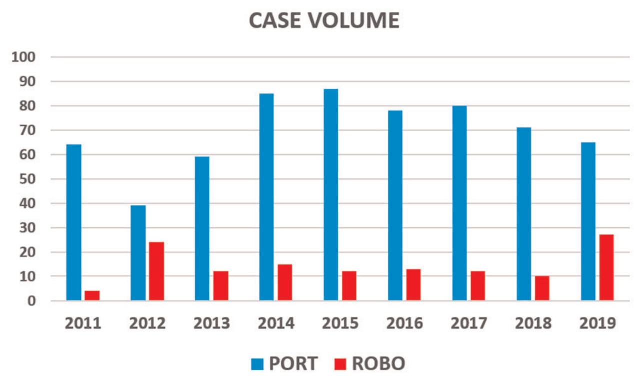

FIGURE 1 Operation year for patients with either port-access (PORT) or robotic (ROBO) approach

TABLE 1 Patient demographics

	Unmatched		Matched	
	PORT	ROBOT	PORT	ROBOT
N	628	129	249	128
Male	397 (63%)	99 (77%)*	185 (74%)	98 (77%)
White	541 (86%)	120 (93%)*	232 (93%)	119 (93%)
Age	61 ± 13	58 ± 11*	59 ± 12	59 ± 11
Diabetes	44 (7%)	8 (6%)	7 (3%)	8 (7%)
Hypertension	312 (50%)	65 (51%)	113 (45%)	65 (51%)
Coronary disease	23 (4%)	3 (2%)	4 (2%)	3 (2%)
CHF Class 3 or 4	130 (21%)	14 (11%)*	28 (11%)	14 (11%)
Atrial fibrillation	183 (29%)	25 (19%)*	44 (18%)	25 (20%)
TR ≥ moderate	150 (24%)	18 (14%)*	33 (13%)	18 (14%)
Ejection fraction less than 50%	99 (16%)	9 (7%)*	13 (5%)	8 (6%)
Degenerative mitral etiology	487 (78%)	115 (89%)*	225 (90%)	115 (90%)
Anterior or bileaflet	86 (14%)	20 (16%)	35 (14%)	20 (16%)
Urgent	31 (5%)	1 (1%)*	3 (1%)	1 (1%)
Year (median)	2015	2015*	2016	2015

Abbreviations: CHF, congestive heart failure; PORT, port-access; ROBO, robotic; TR, tricuspid regurgitation.

*$p < .05$ versus PORT.

TABLE 2 Operative characteristics

	Unmatched		Matched	
	PORT	ROBOT	PORT	ROBOT
N	628	129	249	128
Sternotomy conversion	7 (1.1%)	2 (1.6%)	3 (1.2%)	2 (1.6%)
Peripheral cannulation	131 (21%)	4 (3%)*	37 (15%)	4 (3%)*
Pump time (min)	206 ± 60	274 ± 57*	195 ± 56	275 ± 56*
Clamp time (min)	127 ± 37	155 ± 38*	119 ± 36	152 ± 38*
Ventricular fibrillation	71 (11%)	6 (5%)*	12 (5%)	5 (4%)
Endoclamp	106 (17%)	33 (24%)*	48 (19%)	33 (26%)
Flexible band	34 (5%)	94 (73%)*	16 (6%)	94 (73%)*
Alfieri stitch	362 (58%)	91 (71%)*	171 (69%)	91 (71%)
Gortex chord	372 (59%)	99 (77%)*	185 (74%)	99 (77%)
Leaflet resection	51 (8%)	1 (1%)*	13 (5%)	1 (1%)*
Tricuspid operation	102 (16%)	7 (5%)*	45 (12%)	2 (6%)
Maze	126 (20%)	16 (12%)*	23 (9%)	7 (5%)
Ring/band size (mm) (median)	36	40*	36	40*

Abbreviations: PORT, port-access; ROBO, robotic.

*$p < .05$ versus PORT.

TABLE 3 Postoperative outcomes

	Unmatched		Matched	
	PORT	ROBOT	PORT	ROBOT
N	628	129	249	128
Death**	4 (0.6%)	0 (0%)	1 (0.4%)	0 (0%)
Stroke	7 (1%)	0 (0%)	0 (0%)	0 (0%)
New atrial fibrillation	136 (22%)	27 (21%)	72 (24%)	27 (21%)
New pacemaker	21 (3%)	0 (0%)*	12 (5%)	0 (0%)*
Renal injury	13 (2%)	2 (2%)	3 (1%)	2 (2%)
Length of stay (median dy)	6	5*	5	5
Reoperation for bleeding	9 (1.4%)	4 (3%)	1 (1%)	4 (3%)
5-year survival	94 ± 1%	96 ± 3%	97 ± 1%	96 ± 3%
5-year CI mitral reoperation	2 ± 1%	6 ± 3%	1 ± 1%	6 ± 3%
5-year CI severe MR	5 ± 2%	5 ± 3%	1 ± 1%	5 ± 3%
5-year CI moderate or more MR	12 ± 2%	18 ± 6%	11 ± 4%	18 ± 6%
Degenerative patients				
5-year CI mitral reoperation	2 ± 1%	3 ± 2%	1 ± 1%	3 ± 2%
5-year CI moderate or more MR	12 ± 3%	12 ± 5%	12 ± 4%	12 ± 5%

Abbreviations: CI, cumulative incidence; MR, mitral regurgitation; PORT, port-access; ROBO, robotic.

*$p < .05$ versus PORT.

**30-Day or in-hospital mortality.

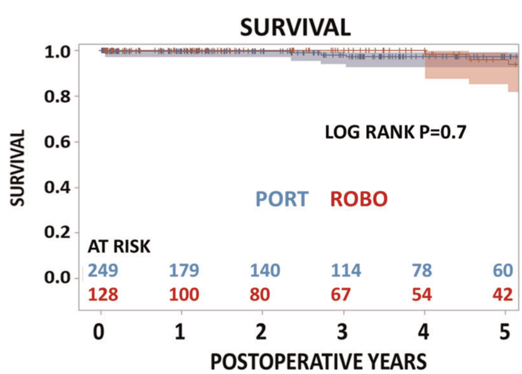

FIGURE 2 Survival (±95% confidence interval) of matched patients with either port-access (PORT) or robotic (ROBO) approach

Echocardiographic follow-up was available for 689/757 (91%) patients. Patients without echo follow-up differed only in having an earlier operative year (median: 2014 vs. 2016, $p < .0001$). Median echo follow-up interval was 0.9 (IQR: 0.1/3.4) years. Mitral repair durability was similar between ROBO and PORT groups. Five-year cumulative incidence of mitral reoperation was 6 ± 3% for ROBO versus 2 ± 1% for PORT ($p = .2$). Two of the four reoperated ROBO patients were reoperated for aortic connective tissue disease in the presence of moderate MR. For degenerative mitral etiology only, 5-year cumulative incidence of mitral reoperation was 3 ± 2% for ROBO versus 2 ± 1% for PORT ($p = .9$). For all patients, mitral reoperation was for recurrent MR in 7/13 (54%), endocarditis in 2/13 (15%), other valve disease in 2/13 (15%), mitral stenosis in 1/13 (8%), and hypertrophic obstructive cardiomyopathy in 1/13 (8%). Five-year cumulative incidence of severe MR was 5 ± 3% for ROBO and 5 ± 2% for PORT ($p = .7$).

The 5-year cumulative incidence of moderate or more (≥2+) MR was not different between groups (18 ± 6% vs. 12 ± 2%, $p = .3$) (12 ± 5% vs. 12 ± 3% for degenerative patients). The 60 patients with recurrent moderate or more MR differed significantly from the remaining patients only in terms of being less white (77% vs. 89%, $p = .008$), more likely to have a band (32% vs. 17%, $p = .005$), more likely to have functional etiology (23% vs. 10%, $p = .002$) and more likely to have connective tissue disease (5% vs. 0.6%, $p = .001$). Logistic regression analysis confirmed that independent multivariable predictors of recurrent moderate or more (>2+) MR were connective tissue disease (odds ratio [OR]: 8.8, $p = .007$), functional etiology (OR: 3.1, $p = .003$), and non-White race (OR: 2.0, $p = .04$). When intraoperative variables were considered, band use (OR: 4.5, $p = .001$) was also an independent predictor of recurrent moderate or more (>2+) MR. ROBO versus PORT approach was not associated with recurrent moderate or more MR ($p = .25$).

3.2 | Matched patients

Propensity matched patients were well matched for preoperative patient characteristics (Table 1). Some operative and technical differences between ROBO and PORT approaches persisted with ROBO patients having longer clamp time (152 ± 38 vs. 119 ± 36 min, $p < .0001$) and pump time (275 ± 56 vs. 195 ± 56 min, $p < .0001$), more use of bands (94 [73%] vs. 16 [6%], $p < .0001$), larger ring/band size (median: 40 vs. 36 mm, $p = .0001$) and less leaflet resection (1/128 (1%) versus 13/249 (5%), $p = .03$) (Table 2). Early postoperative outcomes were similar between matched groups with the exception of less pacemaker insertion in ROBO patients (0/128 [0%] vs. 12/249 [5%], $p = .01$) (Table 3). New pacemaker insertion tended to be associated with use of a rigid ring versus a flexible band (11/256 [4%] vs. 1/109 [1%], $p = .08$).

Five-year survival for matched patients was not different between groups (96 ± 3% vs. 97 ± 1%, $p = .7$) (Table 3) (Figure 2). Cumulative incidence of mitral reoperation for all matched patients tended to be greater in the ROBO group (6 ± 3% vs. 1 ± 1%, $p = .05$) but was not significantly different for matched degenerative patients (3 ± 2% vs. 1 ± 1%, $p = .3$) (Table 3) (Figure 3). Cumulative incidence of severe MR (5 ± 3% vs. 1 ± 1%, $p = .4$) did not differ between groups (Table 3) (Figure 4). Cumulative incidence of moderate or more (≥2+) MR (including severe MR) was not significantly different between matched ROBO and PORT groups for

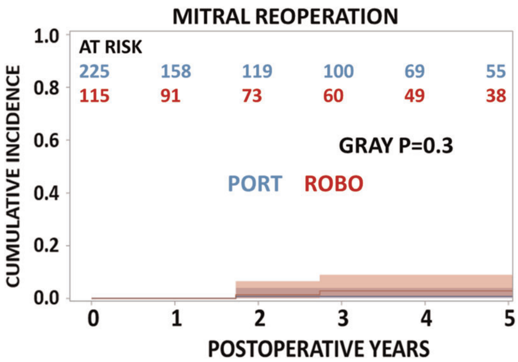

FIGURE 3 Cumulative incidence (±95% confidence interval) of mitral reoperation for matched degenerative patients with either port-access (PORT) or robotic (ROBO) approach

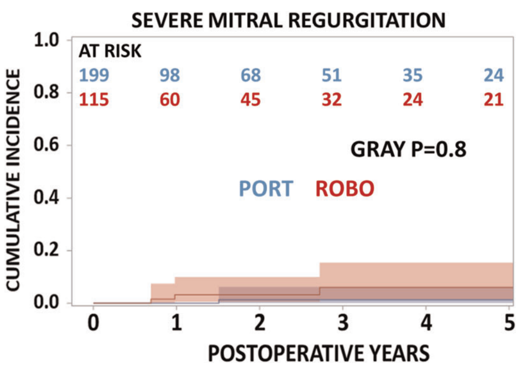

FIGURE 4 Cumulative incidence (±95% confidence interval) of severe mitral regurgitation for matched degenerative patients with either port-access (PORT) or robotic (ROBO) approach

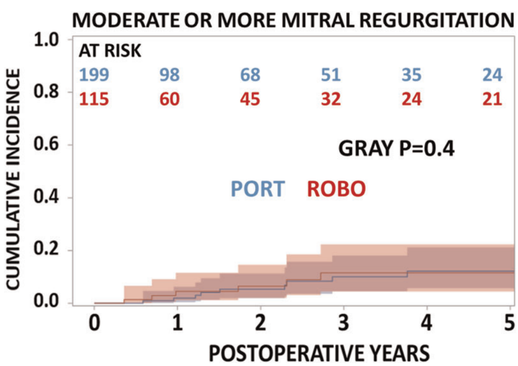

FIGURE 5 Cumulative incidence (±95% confidence interval) of moderate or more (≥2+) mitral regurgitation for matched degenerative patients with either port-access (PORT) or robotic (ROBO) approach

all patients (18 ± 6% vs. 11 ± 4%, $p = .6$) or for degenerative patients (12 ± 5% vs. 12 ± 4%, $p = .8$) (Table 3) (Figure 5). Note that the cumulative incidence of moderate (2+) but not severe MR was also not significantly different between groups for all matched patients (13 ± 6% vs. 10 ± 4%, $p = .6$).

4 | CONCLUSIONS

The current study may be only the third to compare clinical in-hospital results between ROBO and PORT mitral repair.[10,11] Mihaljevic examined a matched series of 114 PORT and 261 ROBO patients and found that ROBO had longer pump and clamp times but less pain, less atrial fibrillation, and shorter length of stay.[11] Hawkins matched 295 PORT and 295 ROBO patients and found that ROBO had longer pump and clamp times with more atrial fibrillation, more transfusion, longer length of stay, and longer intensive care stay.[10] Our matched comparison of 249 PORT and 128 ROBO patients confirms the longer operative times with robotics versus mini-thoracotomy port-access for mitral repair. However, we did not see any differences in length of stay or atrial fibrillation with the robotic approach. The decreased pacemaker use with ROBO approach may have resulted from less use of rigid rings. Discordance between the three studies may result from interinstitutional differences in patient population and/or in the PORT and ROBO techniques themselves. For example, the predominant use of central aortic cannulation in this series may have biased the operative time, exposure, and opportunities to create or correct bleeding.

The current study is the first to compare intermediate-term outcomes after discharge between the PORT and ROBO approaches. These data show that survival and recurrence of moderate or severe MR were not significantly different between ROBO versus PORT out to 5 years. The borderline trend for more mitral reoperation ($p = .05$) in matched patients with ROBO versus PORT approach is likely due to small numbers with 2/4 reoperated ROBO patients reoperated for aortic connective tissue disease in the presence of moderate MR. While the two techniques are similar, each approach requires some modification of standard sternotomy techniques that could potentially affect late durability. These differences include differences in visualization, in instrumentation, and in the technical aspects of the repair such as suturing, tying, and choice of ring or band.

Echocardiographic outcomes at 5 years after mitral repair have seldom been reported for either PORT[17,18] or ROBO approaches alone.[8,19–21] The 5-year incidence of reoperation for this series (1%–6% for all patients, 1%–3% for degenerative patients) is similar to that reported for sternotomy (2%–5%),[22,23] ROBO (1%–10%),[6,19,21,24] or PORT (2%–5%).[17,18] In this series, the 5-year incidence of recurrent moderate or more (≥2+) MR (12%–18% for all patients, 12% for degenerative patients) is similar to that reported for sternotomy (3%–18%),[22,23] ROBO (5%–15%),[8,19] or PORT (3%–6%).[17,18] Another decade or more of close echo follow-up will be needed to establish late mitral repair durability using the newer techniques of either ROBO or PORT.

The 5-year cumulative incidences of mitral reoperation, severe MR, or moderate or more (≥2+) regurgitation seen in this series are neither the highest nor lowest reported for either sternotomy or minimally invasive approaches. This series is probably more representative of the academic surgical community than are series from the few highest volume centers.[7–9] As seen in this analysis, mitral repair durability can be impaired by many nontechnical factors, including larger valve size associated with Barlow's or bileaflet disease,[22] connective tissue disease,[25] and functional etiology.[26] The decreased repair durability with repair bands in this series may have resulted from a tendency to favor bands in larger valves, like Barlow's disease. However, surgical approach of PORT versus ROBO was not predictive of mitral durability in this series. The current analysis suggests that the differences between PORT versus ROBO are probably less than the differences between either approach versus median sternotomy.[10,11] One would expect that in experienced, high-volume robotic centers where the working port can be reduced to 15 mm or less for mitral repair, the ROBO approach has the potential to minimize postoperative pain, narcotic use, and even hospital stay relative to PORT, but the data are yet lacking to confirm this speculation.

4.1 | Limitations

The current study is not definitive in being retrospective with an attempt to correct for selection biases using propensity score analysis. The current study is also biased in having a higher volume experience with PORT over ROBO approaches. The 129 robotic mitral repairs in this series may be just beyond the learning curve for robotics variously reported to be between 20 and 100 cases.[27] However, the average volume of robotic mitral surgery in the real world is low[10,28] and closer to the volume reported here than to the volumes of a few high volume elite institutions. Prior reports have suggested that less invasive mitral surgery can have worse outcomes with higher stroke, bleeding, and mortality rates, particularly in lower volumes.[29] This study is important in showing that, even with a lower robotic mitral repair experience of 129 cases, no inferiority of ROBO versus PORT was seen other than longer pump and clamp times. The 628 PORT and 129 ROBO patient numbers may have been insufficient to detect more subtle outcome differences. Given that the numbers of minimally invasive mitral patients available to any one institution are not large, most institutions tend to favor either PORT or ROBO approaches but not both. More discerning comparisons of the two approaches may await multiinstitutional experiences. The pump and clamp times in this series are longer than reported in larger series of the ROBO approach,[6,8,10] perhaps due to less experience or due to the use of primarily central aortic cannulation in this series.

Robotics and port-access can be each performed in several ways with different cannulation strategies, different incisions, and different choice of repair techniques. These choices may affect outcomes of robotic mitral surgery independently of robotics per se. Although any mitral repair technique can be adapted to robotic assistance, robotics tends to favor running suture or fasteners instead of interrupted tied sutures, and partial bands are favored over rigid rings.[6–8,19] Because of linkage between repair technique and robotic approach at any one institution, this single institution study was not suited to differentiate the effects of a robotic approach from the repair techniques associated with the robotic approach. Potential differences in outcome such as narcotic use or pain scores were not assessed.

This study presented no data beyond 5 years of follow-up, and differences in longer-term valve durability may have been overlooked. In fact, this is a recent series with only some patients having echo follow-up at 5 years.[19] Longer term data comparing repair durability between PORT and ROBO approaches will require more follow-up time than was available for this recent, first reported comparison of outcomes after discharge.

This initial series is only the third to document similar perioperative outcomes from port-access and robotic approaches to mitral repair. These may be the first concurrent data to demonstrate similar intermediate-term patient survival and repair durability after port-access versus robotic mitral repair. More subtle outcomes differences in early morbidity and late valve durability will require further investigation.

CONFLICT OF INTERESTS

Rahul S. Loungani receives research support from Pfizer and Boston Scientific. The other authors declare that there are no conflict of interests.

DATA AVAILABILITY STATEMENT

Data are available from the corresponding author upon reasonable request.

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