Robotic mitral repair in echocardiographically symmetrical and asymmetrical Barlow's disease

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Background: Robotic mitral valve repair for mitral regurgitation (MR) is increasingly popular due to shorter hospital stays, reduced perioperative pain, and faster recovery. Barlow's disease is a significant subset of primary MR due to its complex repair requirements. This study presents our surgical and short-term outcomes for patients with Barlow's disease treated using the da Vinci Xi robotic system.

Methods: Since adopting robotic surgery in June 2021, all consecutive patients diagnosed with Barlow's disease through September 2023 were included. Based on preoperative echocardiography, patients were classified into two groups: "symmetrical", involving bileaflet prolapse and a central regurgitant jet, and "asymmetrical", with single-leaflet prolapse and eccentric regurgitation.

Results: Thirty-six patients with Barlow's disease underwent robotic surgery during the study period. Repair success was 100%, with no conversions required. No significant differences were found in baseline characteristics between the prolapse types. Annuloplasty alone was sufficient for the symmetrical group, whereas asymmetrical cases required neochord loops, reflected by shorter aortic cross-clamp (190 *vs.* 151 min; P=0.034) and aortic cross-clamp (121 *vs.* 89 min; P=0.003) durations in the symmetrical group. During a median follow-up of 7.5 months, there were no deaths or reinterventions. Additionally, no cases of progression to ≥ moderate MR were observed during the median echocardiographic follow-up of 5.3 months.

Conclusions: Robotic repair of Barlow's disease is safe, feasible, and yields excellent short-term outcomes. For patients with symmetrical prolapse, annuloplasty alone provides effective repair.

Keywords: Barlow's disease; mitral valve repair; robotic surgery; annuloplasty; mitral annular disjunction (MAD)

Submitted Jun 20, 2025. Accepted for publication Dec 29, 2025. Published online Jan 29, 2026.
doi: 10.21037/acs-2025-dmv-fs-0121
View this article at: https://dx.doi.org/10.21037/acs-2025-dmv-fs-0121

Introduction

Barlow's disease is a complex form of mitral regurgitation (MR) characterized by myxomatous degeneration of the mitral valve leaflets. Surgical intervention for this condition poses considerable challenges due to distinctive anatomical and functional changes in the mitral valve apparatus, including leaflet thickening, chordal elongation and/or thickening, and annular dilation, necessitating tailored approaches for effective repair (1-3). Recent data from experienced centres indicate that an all-repair strategy is increasingly implemented in patients with Barlow's disease, owing to the excellent long-term outcomes observed (4-6).

In the field of cardiac surgery, robotic-assisted procedures have gained significant attention for their

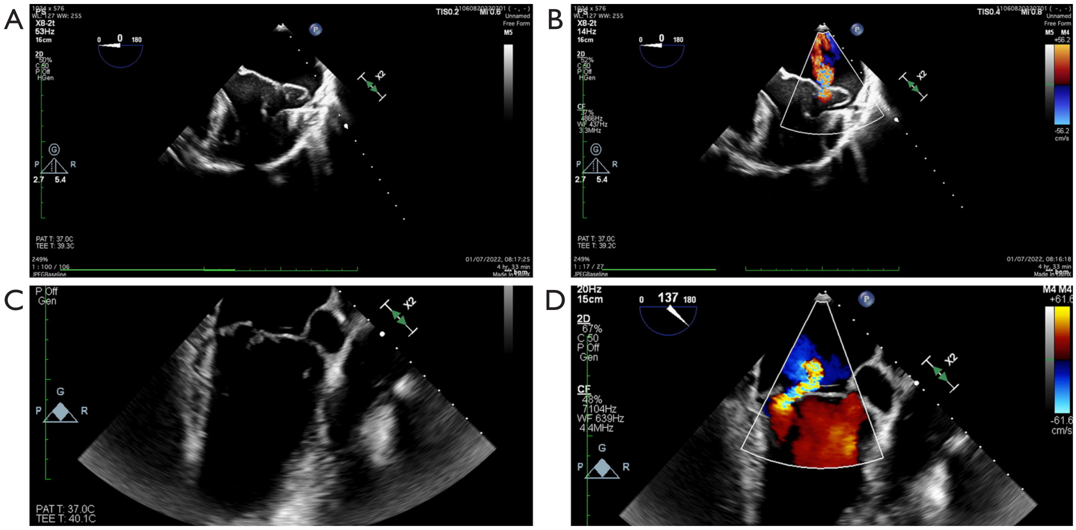

Figure 1 Echocardiographic imaging of symmetric and asymmetric regurgitant jets in Barlow's syndrome. Transesophageal echocardiography image showing bileaflet mitral valve prolapse (A). Corresponding image demonstrating a symmetric regurgitant jet (B). Transesophageal echocardiography of posterior leaflet prolapse (C) with an asymmetric regurgitant jet (D).

potential advantages, such as heightened precision, reduced invasiveness, and faster recovery times compared to traditional open-heart surgeries (7,8). A notable 15-year, single-centre study involving 111 cases of Barlow's disease, with a median follow-up of over 5 years, demonstrated that the use of the robotic system achieved repair success in nearly 100% of cases, with remarkable durability (9).

A specific subset of Barlow's patients presents with bileaflet prolapse characterized by a symmetrical central regurgitant jet on perioperative echocardiography (10). In these cases, mitral annular disjunction (MAD) is often present, defined as a structural abnormality in which the posterior mitral leaflet inserts into the left atrial wall at a point displaced from the junction between the left atrium and the left ventricular (LV) myocardium (11). Remarkably, this complex pathology can be effectively corrected with an annuloplasty ring alone even when performed using minimally invasive techniques (12,13).

This report aims to summarize surgical outcomes and early follow-up after robotic repair of Barlow's disease performed at the Department of Cardiac Surgery, National Medical Institute (NMI), Warsaw, Poland. Additionally, based on perioperative three-dimensional echocardiography, we have divided and compared patients presenting with symmetrical and asymmetrical disease patterns.

Methods

Patients

Since the beginning of our robotic program in June 2021, we prospectively recorded the data of all adult patients undergoing robotic cardiac surgery, capturing pertinent baseline, surgical, and echocardiographic variables. By September 2023, we identified 36 patients diagnosed with Barlow's disease who had undergone robotic repair, constituting the entirety of patients with Barlow's disease cases referred to Department of Cardiac Surgery, National Medical Institute, during the study period. Contradictions to robotic surgery included ≥ moderate aortic insufficiency, significant mitral calcifications, and/or pulmonary distress hindering single-lung ventilation. The diagnosis of Barlow's disease was initially established through preoperative echocardiography, further confirmed by visual inspection during the surgical procedure. We characterized Barlow's disease morphology by significant annular dilation, accompanied by a diffuse excess of thickened myxomatous leaflet tissue, and posterior annulus displacement into the left atrium (13). Symmetrical Barlow's disease was defined by a central regurgitant jet with bileaflet billowing. *Figure 1* depicts the transesophageal echocardiography (TEE) images of both symmetrical and asymmetrical patterns.

Intraoperative TEE and postoperative transthoracic echocardiography (TTE) were conducted for all patients. Subsequently, regular follow-up visits were scheduled at the outpatient clinic, initially at 2 to 3 months post-surgery and annually thereafter. Patient records were integrated with the Krajowy Rejestr Operacji Kardiochirurgcznych (KROK registry), a state registry comprising comprehensive data on cardiac procedures performed nationwide, with links to the National Health Fund to track mortality status. Details on the registry were described previously (14). The study protocol received approval from the institutional ethics board committee.

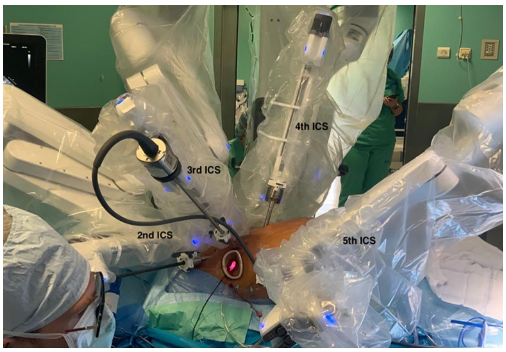

Figure 2 Da Vinci Xi surgical system setup for mitral valve repair. Photograph of the Da Vinci Xi system's working ports positioned in the 2nd, 3rd, 4th, and 5th ICS for mitral valve repair. ICS, intercostal spaces.

Surgical technique

The newest version of the da Vinci Xi Surgical System was used for all cases. The initial incision for the assistant port was typically made two to three centimetres in length and was located on the right side of the chest in the third intercostal space, conserving the pectoralis major muscle. Four trocar ports were placed in the chest in the second, third, fourth and fifth intercostal spaces, through which the robotic instruments and camera were inserted (*Figure 2*). These ports were strategically positioned to provide access to the mitral valve through robotic arms and to hold various surgical instruments, such as the SutureCut^{TM} needle driver (Intuitive Surgical, Inc., Sunnyvale, CA, USA), monopolar scissors, DeBakey forceps, and the dual blade long retractor. The surgical view of the mitral valve is shown in *Figure 3A*.

Intraoperative echocardiographic assessment

Comprehensive echocardiographic assessment is essential for optimizing mitral valve repair. According to our protocol, TEE is routinely performed following anesthesia induction to guide final surgical planning. Particular emphasis is placed on several key parameters. Jet symmetry assists in determining whether isolated annuloplasty is sufficient or if a more complex repair involving polytetrafluoroethylene (PTFE) neochordae is indicated. The coaptation-to-septum (C-sept) distance, posterior leaflet length, and anterior-to-posterior leaflet

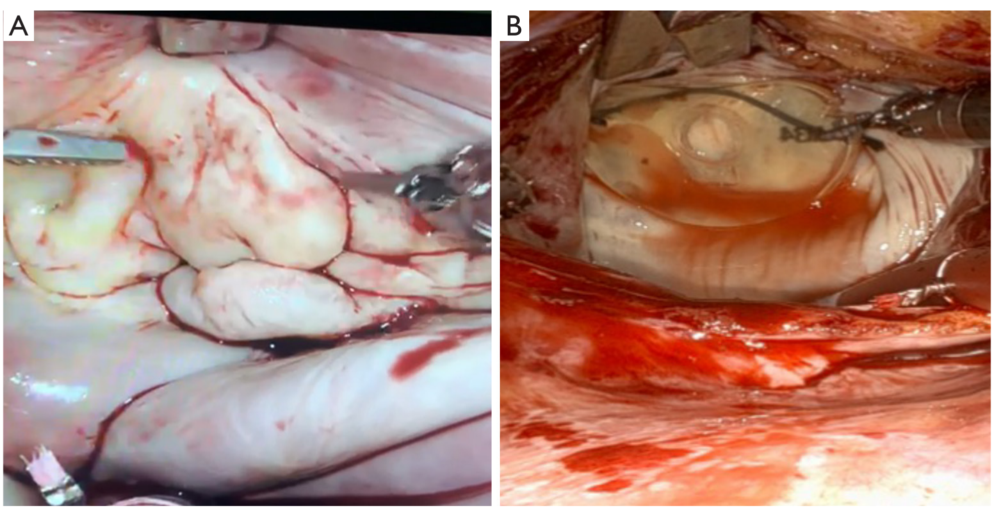

Figure 3 Robotic view of the mitral valve. Visualization of mitral valve prolapse in Barlow's syndrome affecting both leaflets (A). Ring sizing performed with the left ventricle filled with normal saline (B).

ratio collectively help assess the risk of systolic anterior motion (SAM) following repair. The papillary muscle-to-coaptation point distance provides guidance in estimating appropriate neochord lengths. Anterior leaflet height facilitates annuloplasty ring sizing and helps anticipate post-repair leaflet mobility. Additionally, depending on the type of annuloplasty ring selected—as specified by the manufacturer—either the commissure-to-commissure or trigone-to-trigone distance is considered to ensure optimal sizing.

Annulus measurement

Annular sizing was guided primarily by anterior leaflet length, measured both preoperatively using TEE and intraoperatively. Depending on the specific annuloplasty ring used, we also considered manufacturer-recommended metrics, including commissure-to-commissure or trigone-to-trigone distances. With time, we developed an additional technique for intraoperative annulus measurement by filling the left ventricle with saline and inserting annuloplasty sizers under direct vision (*Figure 3B*). This allows the left ventricle to fill and the mitral valve to fully expand, enabling a more accurate evaluation of leaflet size.

Statistical analysis

For continuous variables, means and standard deviations are presented if they followed a normal distribution, whereas medians and interquartile ranges (IQRs) were used if they did not follow a normal distribution. Categorical variables are expressed as numbers and percentages. To compare baseline comorbidities, operative details, and short-term postoperative outcomes between study groups, the Mann-Whitney *U* test or Student's *t*-test was employed for continuous variables, whereas the Fisher's exact test was used for categorical variables. Computations were conducted using R (R Core Team 2021, Vienna, Austria).

Results

Baseline characteristics

The median age was 51 (IQR, 44–68) years, and the median European System for Cardiac Operative Risk Evaluation (EuroSCORE) II was 1.42 (IQR, 0.90–2.01). The majority of patients were male and presented with severe MR. Baseline characteristics did not significantly differ between patients with symmetrical and asymmetrical regurgitant jets on echocardiography. Detailed information is provided in *Table 1*.

Surgical outcomes

All patients underwent annuloplasty ring placement. In the group with symmetrical Barlow's disease (11 patients), annuloplasty alone sufficed for satisfactory repair, obviating the need for additional PTFE loops. Conversely, all patients in the asymmetrical group required additional loops, with an average of 3.4 neochords used. In the asymmetrical Barlow's group, 24 out of 25 patients received PTFE loops to the posterior leaflet, whereas one patient received a neochord for both leaflets. Notably, isolated anterior PTFE loops were not utilized. Cleft closure was performed for one patient in each group.

We observed a significantly shorter cardiopulmonary bypass (CPB) time [median (IQR), 190 (110–340) *vs.* 151 (100–230) min; P=0.034] and aortic cross-clamp [121 (75–175) *vs.* 89 (64–124) min; P=0.003] in the symmetrical Barlow's group. One patient in the asymmetrical regurgitant jet group required an additional aortic cross-clamp for moderate MR, after which the regurgitation was corrected with an Alfieri stitch. The repair success rate was 100%, and no patients required conversion to sternotomy. Concomitant procedures included tricuspid valve repair, surgical ablation, and closure of the left atrial appendage or a patent foramen ovale. Surgical details are presented in *Table 2*. There were no perioperative deaths, and remaining in-hospital outcomes are outlined in *Table 3*.

Follow-up

The median clinical follow-up duration was 7.5 months and was 100% complete. No late deaths occurred during the follow-up period, and no patients required re-intervention. The median echocardiographic follow-up duration was 5.3 months, achieving a completion rate of 94%. No progression to ≥ moderate MR was observed. Echocardiographic follow-up is presented in *Table 4*.

Discussion

Our study has two key findings. First, it underscores the complete feasibility of robotic repair in patients with Barlow's disease. In our view, unless there are specific contraindications, such as pleural adhesions, previous cardiac surgery, previous chest trauma, or peripheral

Table 1 Baseline characteristics

Baseline characteristics	Total (n=36)	Asymmetrical Barlow's (n=25)	Symmetrical Barlow's (n=11)	P value
Age (years)	51 [44, 68]	53 [25, 74]	48 [29, 76]	0.264
Male gender	23 (63.9)	17 (68.0)	5 (45.5)	0.273
EuroSCORE II	1.54 [0.90, 2.13]	1.54 [1.09, 2.03]	1.30 [0.88, 2.16]	0.905
Diabetes	2 (5.6)	2 (8.0)	0 (0.0)	1.000
Smoking	5 (13.9)	3 (12.0)	2 (18.2)	0.631
Previous MI	1 (2.8)	0 (0.0)	1 (9.1)	0.306
Previous PCI	2 (5.6)	1 (4.0)	1 (9.1)	0.524
Hypertension	18 (50.0)	13 (52.0)	5 (45.5)	1.000
Hyperlipidemia	11 (30.6)	9 (36.0)	2 (18.2)	0.439
BMI (kg/m^2)	25.9 [24.3, 27.9]	25.2 [20.7, 30.0]	26.5 [22.1, 36.1]	0.291
Atrial fibrillation	12 (33.3)	8 (32.0)	4 (36.4)	1.000
eGFR (mL/min/1.73 m^2)	83 [69, 93]	83 [50, 113]	76 [31, 121]	0.726
Pulmonary hypertension	1 (2.8)	1 (4.0)	0 (0.0)	1.000
CVD disease	1 (2.8)	1 (4.0)	0 (0.0)	1.000
Asthma/COPD	1 (2.8)	1 (4.0)	0 (0.0)	1.000
LVEF (%)	65 [58, 68]	66 [50, 75]	62 [40, 70]	0.477
CAD	6 (16.7)	3 (12.0)	3 (27.3)	0.343
NYHA class				
NYHA I	2 (5.6)	2 (8.0)	0 (0.0)	1.000
NYHA II	14 (38.9)	9 (36.0)	5 (45.5)	0.716
NYHA III	18 (50.0)	13 (52.0)	5 (45.5)	1.000
NYHA IV	2 (5.6)	1 (4.0)	1 (9.1)	0.524

Data are presented as median [interquartile range] or n (%). BMI, body mass index; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; CVD, cerebrovascular disease; eGFR, estimated glomerular filtration rate; EuroSCORE, European System for Cardiac Operative Risk Evaluation; LVEF, left ventricle ejection fraction; MI, myocardial infarction; NYHA, New York Heart Association; PCI, percutaneous coronary intervention.

atherosclerosis, adopting robotic mitral surgery could be considered the default strategy for patients with MR, rather than being selectively applied to specific cases. Second, our results highlight that patients with Barlow's disease and a symmetrical central regurgitant jet on preoperative echocardiography can be effectively managed with annuloplasty alone, resulting in shorter CPB and aortic cross-clamp times compared to those with an asymmetrical jet.

As described by Raanani *et al.*, in cases of isolated posterior prolapse, the regurgitant orifice results from a disproportion in the forces acting on the leaflets, with greater force exerted on the posterior leaflet due to its larger surface area (as force equals pressure multiplied by surface area) (15). In contrast, with bileaflet prolapse, the forces on the leaflets are more balanced, so the regurgitant orifice is primarily caused by abnormal annular motion and/or dilation, making it suitable for treatment with annuloplasty alone. Previous studies involving both median sternotomy and minithoracotomy endoscopic approaches have shown that, in carefully selected patients with Barlow's disease, correcting abnormal annular motion through annular remodeling and stabilization can resolve valve insufficiency

Table 2 Surgical variables

Surgical characteristics	Total (n=36)	Asymmetrical Barlow's (n=25)	Symmetrical Barlow's (n=11)	P value
Redo surgery	0 (0.0)	0 (0.0)	0 (0.0)	N/A
Non-elective	0 (0.0)	0 (0.0)	0 (0.0)	N/A
Severe MR	33 (92.0)	24 (96.0)	9 (81.8)	0.216
Annuloplasty ring	36 (100.0)	25 (100.0)	11 (100.0)	N/A
Implanted ring size (mm)	36 [34, 38]	36 [28, 40]	34 [32, 40]	0.738
Any neochord used	25 (69%)	25 (100.0)	0 (0.0)	<0.001
Number of neochords per patient	2±2	3±2	N/A	<0.001
Tricuspid repair	4 (11.1)	4 (16.0)	0 (0.0)	0.290
Surgical ablation	11 (30.6)	7 (28.0)	4 (36.4)	0.703
PFO closure	2 (5.6)	1 (4.0)	1 (9.1)	0.524
LAAO	11 (30.6)	7 (28.0)	4 (36.4)	0.703
CPB time (min)	184 [147, 215]	190 [110, 340]	151 [100, 230]	0.034
X-clamp time (min)	105 [85, 134]	121 [75, 175]	89 [64, 124]	0.003
Second crossclamp required	1 (2.8)	1 (4.0)	0 (0.0)	1.000
Conversion	0 (0.0)	0 (0.0)	0 (0.0)	N/A

Data are presented as n (%), median [interquartile range] or mean ± standard deviation. CPB, cardio-pulmonary bypass time; LAAO, left atrial appendage occlusion; MR, mitral regurgitation; N/A, not applicable; PFO, patent foramen ovale; X-clamp, aortic cross clamp.

Table 3 In-hospital outcomes

In-hospital outcomes	Total (n=36)	Asymmetrical Barlow's (n=25)	Symmetrical Barlow's (n=11)	P value
In-hospital mortality	0 (0.0)	0 (0.0)	0 (0.0)	N/A
Atrial fibrillation	8 (22.2)	5 (20.0)	3 (27.3)	0.678
TIA	1 (2.8)	1 (4.0)	0 (0.0)	1.000
Stroke	0 (0.0)	0 (0.0)	0 (0.0)	N/A
Acute kidney failure and/or dialysis	1 (2.8)	0 (0.0)	1 (9.1)	0.306
Cannulation site complications	0 (0.0)	0 (0.0)	0 (0.0)	N/A
PPM	0 (0.0)	0 (0.0)	0 (0.0)	1.000
Bleeding requiring intervention	1 (2.8)	1 (4.0)	0 (0.0)	1.000

Data are presented as n (%). N/A, not applicable; PPM, permanent pacemaker; TIA, transient ischemic attack.

(12,13,15,16).

These findings have shifted valve repair strategies away from the earlier assumption that the valve appeared to prolapse in all segments—an assumption that led to the utilization of many neochords to both leaflets (17). Preoperative analysis of patients who might be candidates for an annuloplasty-only approach typically shows a broad, symmetrical prolapse of both leaflets, no chordal rupture, significant annular dilation, and a wide central regurgitant jet. These features seem to identify a specific subgroup where annular dysfunction is the primary cause of MR, despite the apparent prolapse of both leaflets.

Table 4 Echocardiographic follow-up

Disease presentation	Asymmetrical Barlow's (n=25)	Symmetrical Barlow's (n=11)	P value
Post-op MR			
None	16 (64.0)	6 (54.5)	0.716
Mild or less	9 (36.0)	5 (45.5)	0.716
≥ moderate	0 (0.0)	0 (0.0)	N/A
MR at longest follow-up			
None	12 (46.0)	5 (45.5)	0.656
Mild or less	13 (54.0)	6 (54.5)	0.656
≥ moderate	0 (0.0)	0 (0.0)	N/A

Data are presented as n (%). MR, mitral regurgitation; N/A, not applicable.

In a series of median sternotomy cases, De Paulis *et al*. described how, with an annuloplasty-only approach, postoperative TEE observations showed that during systole, the papillary muscles moved toward the LV apex, pulling down the entire subvalvular apparatus (16). This movement helped relieve leaflet prolapse and restore proper mitral valve morphology, even with significantly enlarged leaflets. Furthermore, follow-up stress testing confirmed the positive outcomes of annuloplasty alone, as no changes in mitral valve function or morphology were observed despite significant variations in heart rate and blood pressure during exercise (16).

In addition to annular dilation, abnormal annular motion can impair proper coaptation and prevent the normal systolic reduction and saddle-shaped configuration of the mitral valve (11). A major contributor to this dysfunction is MAD—a structural abnormality in which the posterior leaflet inserts into the atrial wall, displaced from the true atrioventricular junction (11). Although once considered incidental, MAD is now recognized as a contributor to myxomatous degeneration and as a risk factor for malignant arrhythmias and sudden cardiac death (18-20).

Lee *et al*. demonstrated that when the MAD distance exceeds 5 mm, the annulus becomes flattened and fails to contract normally during systole (21). Thus, the aim of annuloplasty potentially extends beyond reducing annular size and thereby increasing coaptation; it also includes restoring physiological annular dynamics and geometry (22). The effectiveness of an annuloplasty-only approach in a subgroup of patients with Barlow's disease has been demonstrated in conventional surgery, and our findings support its feasibility in robotic-assisted repair. However, we acknowledge that the mechanism by which annuloplasty may reduce or correct MAD remains theoretical. Our observations, though promising, are limited by the absence of systematic post-repair imaging to confirm anatomical changes, and by the small size of our cohort. As such, these findings should be considered preliminary and hypothesis-generating. Future studies incorporating high-resolution imaging and long-term follow-up will be essential to determine the true impact of annuloplasty on MAD anatomy and mitral valve function.

Our study adds to the existing literature by showing that robotic mitral repair can be applied to complex cases (3,9). Complex repairs often require intricate adjustments, chordal replacement, or other tailored techniques. The robotic system facilitates these maneuvers, leading to optimal outcomes. In our study, we achieved 100% repair feasibility with infrequent need for a second clamp due to residual regurgitation. Only one patient in our study group required an additional clamp run (33 min) after TEE revealed moderate MR; this was resolved with the placement of an additional Alfieri stitch, resulting in an optimal mitral repair. Importantly, no patient required conversion to mini-sternotomy.

Although the aortic cross-clamp time and CPB time in our series were longer than those reported in published series of patients with Barlow's disease undergoing sternotomy (13,15,16), the low rate of perioperative complications suggests the safety of this approach. It is important to note that this series represents initial experience with the robotic approach, and it has been shown in large series that CPB and cross-clamp times decrease significantly after 200 cases (23). It is noteworthy that more patients in the asymmetrical prolapse group required tricuspid repair, though without statistical significance.

We acknowledge that an annuloplasty-only strategy for mitral valve repair may carry an increased risk of SAM of the anterior leaflet. Although the use of relatively large prosthetic rings in this cohort likely helps reduce this risk by posteriorly displacing the coaptation point, certain anatomic features—such as a C-sept distance <2.5 cm, a disproportionately long posterior leaflet, or a low anterior-to-posterior leaflet length ratio—may still predispose patients to SAM. In such cases, we believe that adjunctive techniques beyond annuloplasty alone should be considered to mitigate this risk. Notably, in our present series—although limited in size—we did not observe any cases of postoperative SAM among patients treated with annuloplasty alone. This favorable outcome likely reflects our rigorous perioperative echocardiographic assessment and patient selection.

Additionally, we created an *in-vivo*, trial-based model by filling the left ventricle with saline to achieve reproducible results in ring measurement (depicted in *Figure 3B*). Using this approach, we observed no instances of SAM in this cohort. Moreover, none of the patients required permanent pacemaker (PPM) implantation after surgery. Several studies have shown that the rate of PPM implantation is lower after minimally invasive techniques (24-26). We believe that the excellent visualization provided by the robotic technique allows for careful suture placement, reducing the risk of injury to cardiac conduction tissue (27).

In this series, we demonstrate for the first time in the context of robotic mitral repair that annuloplasty alone can achieve excellent repair in cases of functional symmetrical prolapse, with good durability in the short-term echocardiographic follow-up available. Due to the simplicity of the repair, the symmetrical prolapse group had significantly shorter CPB and aortic cross-clamp times.

Our study has several limitations. First, the short duration of echocardiographic follow-up limits our ability to draw conclusions about long-term durability, particularly for patients who underwent annuloplasty alone. However, the available follow-up showed no progression beyond moderate regurgitation. Second, because most procedures were performed by a single high-volume mitral surgeon, the findings may not be applicable to all cardiac surgery programs. Lastly, there is a spectrum of degenerative mitral valve disease between fibroelastic deficiency and Barlow's disease, and the clinical diagnosis of Barlow's disease may vary among surgeons.

Acknowledgments

None.

Footnote

Funding: None.

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: Ethical approval was waived by the local Ethics Committee of University in view of the retrospective nature of the study and all the procedures being performed were part of the routine care.

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Cite this article as: Suwalski P, Pasierski M, Brączkowski J, Żurawska M, Finke J, Głowniak Z, Kowalewski M, Staromłyński J, Bartczak M, Szymański P, Gil R, Smoczyński R. Robotic mitral repair in echocardiographically symmetrical and asymmetrical Barlow's disease. Ann Cardiothorac Surg 2026;15(1):6. doi: 10.21037/acs-2025-dmv-fs-0121