MAYO CLINIC

MAYO CLINIC PROCEEDINGS:
INNOVATIONS, QUALITY & OUTCOMES

BRIEF REPORT

A Case Series of Minimally Invasive Robotic-Assisted Resection of Cardiac Papillary Fibroelastoma: The Mayo Clinic Experience

Ali Ahmad, MD; Edward A. El-Am, MD; Piotr Mazur, MD, PhD; Elias Akiki, MD; Ahmed A. Sorour, MD; Reto D. Kurmann, MD; Kyle W. Klarich, MD; Arman Arghami, MD, MPH; Phillip G. Rowse, MD; Richard C. Daly, MD; and Joseph A. Dearani, MD

Abstract

Papillary fibroelastomas (PFEs) are small, slowly growing benign cardiac tumors with clinically significant risk of embolization. Surgical excision is the definitive treatment of symptomatic PFE and is conventionally performed through a median sternotomy. In this study, we report a series of 12 patients, who underwent robotic-assisted PFE removal at the Mayo Clinic. PFE involved the mitral valve, left atrium, and tricuspid valve. No major complications occurred after the procedure, and most patients were discharged 4 days after the surgery. On follow-up, 1 patient demonstrated pericarditis.

 ■ Mayo Clin Proc Inn Qual Out 2024;8(2):143-150

Papillary fibroelastomas (PFEs) are small, slowly growing benign cardiac tumors with clinically significant risk of embolization.[1-5] PFEs are commonly located on the cardiac valves, but can also be present on nonvalvular endocardial surfaces. Involvement of the left-sided valves is the most common.[4,6]

Surgical excision is the definitive treatment of symptomatic PFE.[7] The definite incidence of PFE is unknown, but it has been recognized more frequently in recent years owing to advances in imaging, particularly echocardiography (transthoracic and transesophageal), along with cardiac computed tomography and magnetic resonance imaging. We have previously demonstrated that PFE referrals were twice as common compared with cardiac myxoma.[8]

Surgical excision of PFE is conventionally performed using a median sternotomy approach.[7] Minimally invasive robotic-assisted cardiac procedures focus mainly on mitral valve (MV) and/or tricuspid valve repair and less often for aortic valve (AV) surgery[9]; however, the applications are ever-expanding. A robotic approach has also been used for the excision of cardiac masses.[10] With growing experience with robotic surgery, cardiac tumors are addressed more often with this minimally invasive approach. In this report, we summarize the Mayo Clinic experience with the robotic removal of PFE.

From the Department of Cardiovascular Medicine (A.A., E.A.E., A.A.S., R.D.K., K.W.K.) and Department of Cardiovascular Surgery (P.M., A.A., P.G.R., R.C.D., J.A.D.), Mayo Clinic, Rochester, MN.

PATIENTS AND METHODS

This study was approved by the Mayo Clinic Institutional Review Board, and all patients included had authorized the use of their health records for research purposes. The institutional pathology and surgical databases were searched from August 2011 until August 2022 to identify patients with pathology-confirmed papillary fibroelastoma removal using a total endoscopic robot-assisted approach. We retrospectively reviewed their medical records including patients' charts, imaging, and complete operative and pathology notes.[7]

Surgical resection of the PFE was performed using a robot-assisted endoscopic approach with cardiopulmonary bypass (CPB) and cardioplegic arrest, through a left atriotomy. General inclusion criteria for a robotic procedure include body mass index of $\leq$33 kg/m^2 and adequate thoracic anatomy

and iliofemoral access. If anatomy is inadequate, the mass present in a location not easily accessible robotically, or other procedures are required (eg, coronary revascularization, and myectomy),[7] median sternotomy is offered. Prebypass intraoperative transesophageal echocardiography (TEE) is used to confirm the presence of a PFE at baseline. For peripheral CPB, the right femoral artery and right femoral vein (surgical cutdown) and right internal jugular vein (percutaneous Seldinger technique cannulation) were used. Perfusion was maintained with mild hypothermia (32.0-34.0 °C) and with a flow of 2.4 L/min/m^2, as previously described.[11] The following thoracic ports were used (Figure 1):

- working port—3.0 cm right lateral fourth intercostal space thoracotomy, used also for 0° scope insertion;
- left robotic arm port—second intercostal space laterally;
- right robotic arm port—sixth intercostal space laterally;
- left atrial retractor port—fourth intercostal space medially.

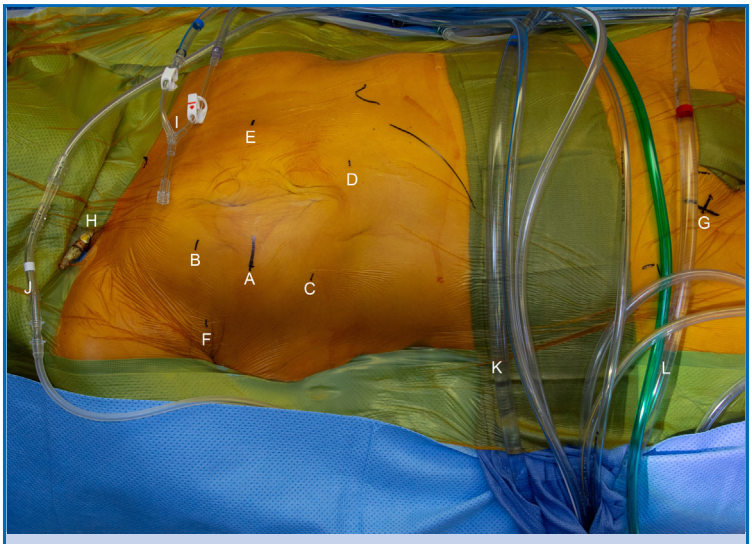

FIGURE 1. Surgical setup for robotic PFE excision. The patient is placed in supine position, with right side of the elevated by 30 degrees: (A) working port incision site; (B) left robotic arm port site; (C) right robotic arm port site; (D) atrial retractor port site; (E) cardioplegia line site; (F) aortic clamp site; (G) femoral artery and vein cut down or percutaneous cannulation site; (H) small cannula placed percutaneously in the right internal jugular vein for future cannulation site; (I) cardioplegia line with attached suction; (J) internal sump sucker; (K) venous CPB line; and (L) arterial CPB line.

Port positioning was adjusted to patient anatomy. The right pleural space was insufflated with carbon dioxide throughout the procedures, with the right lung deflated. Before initiating the CPB, the pericardium was opened longitudinally anterior to the phrenic nerve, which was identified and protected. A DaVinci Si/Xi robotic surgery system (Intuitive Surgical) was used in all cases. The aorta was cross-clamped with a Chitwood clamp (second intercostal space, right anterior axillary line), and cold blood del Nido antegrade cardioplegia was administered through a separate stab wound (second or third intercostal space, right parasternal line). Standard left atriotomy through the Sondegaard plane was performed in all cases. Then, the masses were identified and grasped using robotic forceps and sharply dissected with scissors (2 cases had additional cryoablation of the tumor base after excision for 7 and 15 seconds, respectively). The left atriotomy was closed using running 3.0 Prolene suture, and the heart was allowed to fill after the suture line was completed. The left side of the heart was deaired, and the cross-clamp was released. Postoperative TEE was performed in all cases to ensure the absence of residual PFE mass and assess MV function.

RESULTS

Over the study period, 12 consecutive patients underwent a minimally invasive robotic procedure for the excision of PFE. The mean age was 55±8 years, and 6 (50%) patients were women. PFE was the primary indication for the procedure in 10 of the 12 patients, with the other 2 cases primarily performed for MV repair for symptomatic severe primary mitral regurgitation (in addition to possible tricuspid repair in the tricuspid PFE case). There was a total of 9 preoperative cerebrovascular events, leading to diagnosis and excision in 3 patients. The remaining patients with a primary indication (n=7) were operated on for primary prevention of embolic events. PFE was incidental to perioperative TEE in 2 of the patients who underwent robotic MV repair. The PFE in those patients was discovered using echocardiography performed before other planned cardiac intervention (maze for atrial fibrillation) (n=2) or a different cardiac reason, such as

Mayo Clin Proc Inn Qual Out ■ April 2024;8(2):143-150 ■ https://doi.org/10.1016/j.mayocpiqo.2024.01.001
www.mcpiqojournal.org

TABLE 1. Baseline Characteristics of All Patients

	1	2	3	4	5	6	7	8	9	10	11	12
Demographics												
Age (y)	59	59	50	48	42	69	61	69	49	49	58	43
Sex	F	F	M	M	F	M	M	F	F	M	F	M
Body mass index (kg/m^2)	23	21	31	37	26	26	26	26	24	20	32	32
Hypertension	X		X		X	X	X	X				
Diabetes mellitus						X						
Arrhythmia				X (AF)			X (AF)					X (AF)
Coronary artery disease			X									
History of cancer	X (Breast stage II)					X (Prostate)		X (Breast early stage)				
History of chest radiation	X											
History of cardiac intervention			X (PCI)									
Presentation												
Stroke					X					X		
TIA								X		X		
PFE primary indication for intervention	X	X	X	X	X	X	X	X	X	X		
Size TEE (mm)	8 × 2	11 × 8	10 × 2	1 × 2	4 × 3	8 × 5	7 × 6	7 × 1	6 × 1	8 × 7	10 × 2	6 × 5
PFE location	MV (P2)	MV (A2 scallop)	MV (anterior chordae)	LA	MV (AL)	MV (P2)	MV (AL)	MV (anterior chordae)	MV (AL)	MV (chordae)	MV (PL)	TV (P2)

AL, anterior leaflet; LA, left atrium; MV, mitral valve; PCI, percutaneous coronary intervention; PL, posterior leaflet; TIA, transient ischemic attack; TEE, transesophageal echocardiography; TV, tricuspid valve.

FIGURE 2. Visualization of PFE on the tricuspid valve before excision.

prechemotherapy initiation (n=1), postmyocardial infarction chest pain (n=1), and shortness of breath or palpitation workup (n=3). Furthermore, 3 patients presented with a history of atrial fibrillation and 3 with a history of cancer (2 with breast cancer and 1 with prostate cancer). Moreover, only 1 patient showed a history of chest radiation, whereas 1 had undergone a previous cardiac intervention (percutaneous coronary intervention to the right coronary artery). Other cardiovascular risk factors are summarized in Table 1.

The PFE was located on the MV in 10 of the 12 (91%) patients, the left atrium (LA; atrial appendage) in 1 patient, and the posterior tricuspid valve leaflet in 1 patient (Figure 2; Clip 1, available online at http://www.mcpiqojournal.org). For patients with PFE in MV, 4 were present on the anterior leaflet, 3 were present on the posterior leaflet, and 3 were attached to the chordae. The average length and width of the mass on TEE were 7±3 mm and 4±2 mm, respectively.

The mean bypass was 57±25 minutes, and the cross-clamp times were 30±16 minutes. Six patients underwent a concomitant procedure (MV repair, maze, patent foramen ovale closures, pulmonary vein isolation, and left atrial appendage exclusion) along with the excision of the PFE (Table 2). One patient experienced prolonged bypass time owing to decannulation-associated hypotension requiring fluid support, and 1 patient required packed red blood cell transfusion. There were no conversions to sternotomy.

All patients were extubated in the operating room. The average length of stay at the hospital was 4±2 days. There were no cases of excessive postoperative drainage, and all chest tubes were removed on postoperative day 2. Two patients experienced atelectasis postoperatively, which responded to pulmonary toilet, and 1 showed mild drainage from the chest tube insertion site that resolved spontaneously, but there were no cases of late pleural effusions or pneumothorax. The median length of follow-up of the patients was 4 months (IQR, 2-33 months). One patient experienced pericarditis postoperatively, which was diagnosed 84 days after the surgery, where he was treated with prednisone (Table 2).

DISCUSSION

This series describes the Mayo Clinic experience with PFE excision using robot-assisted surgery in 12 consecutive patients, which expands our previous case series.[12] All procedures were technically effective and characterized by a short hospital stay. Previously published experience with PFE robotically assisted excision has been limited to 18 cases,[10,12-20] with 15 unique patients (3 patients were published twice by the same institution[10,18]). The published patient data information from those reports are summarized in Table 3.

All previously published procedures used the DaVinci Si or Xi robot, except one that used AESOP 3000.[15] Reported procedures have been performed on AV (7/15), MV (4/15), LA (1/15), left ventricle (1/15), and right ventricle (1/15). Our institution has extensive experience with robotic MV surgery; thus, left-sided atrial and MV lesions are the natural target. Ten of our cases were PFE excised on the MV with only 1 on the LA. With robotic AV surgery being less refined and popular than MV surgery, the majority of reported AV PFE excisions come mainly from 1 institution (5/7).[16]

Most patients with PFE are asymptomatic with the majority identified incidentally.[8]

Mayo Clin Proc Inn Qual Out ■ April 2024;8(2):143-150 ■ https://doi.org/10.1016/j.mayocpiqo.2024.01.001
www.mcpiqojournal.org

TABLE 2. Operative Details for Patients

	1	2	3	4	5	6	7	8	9	10	11	12
Operative												
Bypass time (min)	40	22	63	88	39	49	81	41	80	24	84	145
Cross-clamp time (min)	20	16	20	55	20	30	52	17	32	13	52	101
Concomitant procedure	—	—	—	Maze cryoprobe	PFO closure	—	Maze, PFO closure	PFO closure	—	—	MV annuloplasty	MV repair, PVI, app ligation
Postoperative												
Time to extubation	OR	OR	OR	OR	OR	OR	OR	OR	OR	OR	OR	OR
Total chest tube drainage (mL)	1 (60)	2 (504)	1 (~1 L)	1 (354)	2 (651)	1 (612)	2 (864)	1 (220)	1 (minimal)	2 (minimal)	2 (290)	2 (minimal)
Days in hospital	3	3	9	7	3	5	4	4	5	5	4	3
Complications	—	—	Atelectasis	Atelectasis	—	—	Drainage from tube insertion	—	Intraoperative hypotension	—	—	—
Length of follow-up (mo)	84	1	1	2	18	3	48	4	168	4	3	1

MV, mitral valve; OR, operating room; PFO, patent foramen ovale; PVI, pulmonary vein isolation.

TABLE 3. Summary List of Robotically Excised PFE Publications[a]

Reference, year	Age (y)/Sex	Location	Size (mm)	Working port	Cross clamping time (min)	Complication	LOS
Woo et al,[20] 2005	50/M	AV	10[b]	Second ICS, 5 cm	48	—	3
Je et al,[15] 2007	39/M	LV	13[c]	Second ICS, 5 cm	24	—	NA
Bonnichsen et al,[12] 2012	49/F	MV	6 × 6[c]	Fifth ICS, 2.5 cm	NA	—	3
	49/M	MV	9[c]	Fifth ICS, 2.5 cm	NA	—	4
Murphy,[16] 2012	58/F	AV	6 × 7[c]	Fourth ICS, 5 cm	NA	Fall	11
Hua et al,[14] 2014	89/F	LA	8 × 7, 6 × 9[c]	Fourth ICS	NA	AF	11
Arsalan et al,[13] 2016	47/F	MV	11 × 11[b]	NA	31	—	3
Stone et al,[19] 2016	84/F	RA	18 × 17[b]	NA	NA	—	NA
Gillinov et al,[9] 2018	NA	MV	NA	NA	NA	NA	NA
Balkhy et al,[10] 2018, and Nisivaco et al,[18] 2018	46/F	AV	2[d]	First ICS, 5 cm	75	—	4
	61/F	AV	10[d]	Second ICS, 2 cm	49	—	4
	72/F	AV	5[d]	Second ICS, 2 cm	88	—	3
Nisivaco et al,[18] 2018	66/M	AV	3.5[d]	Second ICS, 2 cm	43	—	2
	80/F	AV	8[d]	Second ICS, 2 cm	66	—	3
Nisivaco et al,[19] 2019	56/F	RV	13 × 12[b]	Second ICS, 1.5 cm (right)	NA	—	2

[a]AF, atrial fibrillation; AV, aortic valve; F, female; LA, left atrium; ICS, intercostal space; LOS, length of hospital stay, M, male; MV, mitral valve; NA, not available; —, uncomplicated.
[b]Size measured using transesophageal echocardiography.
[c]Size measured using transthoracic echocardiography.
[d]Size measured after excision.

Nonetheless, symptoms due to PFE could be catastrophic and are usually attributed to systemic embolization. The presenting symptoms in published cases varied from transient ischemic attack,[12] recurrent syncope,[14] chest pain[13] (attributed to cardiac embolization), and palpitations[19] (due to arrhythmia). In patients with echocardiographically suspected PFE who are not treated surgically, both cerebrovascular accidents and mortality are more frequent.[8] In this series, 3 of the 8 patients presented with transient ischemic attack/stroke symptoms.

Comparing this series of short-term outcomes with published cases, the study had a similar length of stay (days): 5±2 vs 4±3. Postoperatively, 2 patients from this case series experienced atelectasis, which led to a longer stay than the rest of the series: 7 and 9 days, respectively. In other reports, the cause of a prolonged postoperative length of stay (both 11 days) was due to a fall leading to periorbital hematoma[16] and new-onset atrial fibrillation with rapid ventricular rate.[14]

Robotic-assisted cardiac surgery was introduced in the 1990s. Presenting as one of the least-invasive surgical approaches, robotic-assisted cardiac procedures include mitral and tricuspid valve repairs or replacement, AV replacement, coronary revascularizations, atrial fibrillation ablations, intracardiac tumor resections, and selected congenital heart surgery procedures, for example, atrial septal defect and partial atrioventricular septal defect.[10,21] In this case series, 4 patients underwent concomitant procedures (patent foramen ovale closure and maze). In the literature, concomitant procedures were reported with PFE excision in 3 cases: biatrial maze,[16] lung adhesiolysis, and left atrial maze.[18] It is conceivable that with the growing popularity of robotic MV repair, some incidental PFEs will be removed during MV surgery. In addition, several studies compared robotic surgery with conventional sternotomy approach, especially in MV surgeries. Minimally invasive surgery is proven to provide equal outcomes as the sternotomy approach, with improved

Mayo Clin Proc Inn Qual Out ■ April 2024;8(2):143-150 ■ https://doi.org/10.1016/j.mayocpiqo.2024.01.001
www.mcpiqojournal.org

recovery, less transfusions, less pain, reduced hospital stays, and improved patient satisfaction with avoidance of sternotomy.[22,23] Robotic approach in mitral surgery has equivalent outcomes to classical minimally invasive MV surgery.[24] In high-volume centers, robotic MV repair has excellent short-term and long-term results.[11] Further studies will be needed to investigate the benefit of robotic surgeries in PFE resection compared with that of conventional approach.

The future role of robotic-assisted removal of PFE and other cardiac tumors remains unknown. As robotic technology continues to advance, we anticipate that the robotic approach will gain more popularity, especially when the excellent results of robotic MV surgery are considered. Multiple benefits include shorter length of stay, earlier return to preoperative baseline functional level, less transfusion, improved cosmesis, and reduced pain.[21] Its widespread application has been restricted by technical challenges, economic cost, and institutional availability, limiting robot-assisted cardiac procedures to specialized cardiac centers.[25] Future studies should also consider the economic value of performing robotic excision of cardiac tumors compared with that of conventional surgical techniques.

CONCLUSION

In conclusion, this is the largest case series describing the experience of robotic surgery in the excision of PFE from a single institution. Robot-assisted surgery is an excellent approach for PFE excision in selected patients.

POTENTIAL COMPETING INTERESTS

The authors declare no conflicts of interest.

ACKNOWLEDGMENTS

Drs Ahmad and El-Am contributed equally to this work.

SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://www.mcpiqojournal.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **AV**, aortic valve; **CPB**, cardiopulmonary bypass; **MV**, mitral valve; **PFE**, papillary fibroelastoma

Grant support: This study was funded by Mayo Foundation.

Correspondence: Address to Kyle W. Klarich, MD, Department of Cardiovascular Medicine, Mayo Clinic, 200 First Street SW, Rochester, MN 55905 (klarich.kyle@mayo.edu; Twitter: @KyleWKlarich).

ORCID

Elias Akiki: https://orcid.org/0009-0007-7261-7826

REFERENCES

1. Ahmad A, Arghami A, El-Am EA, Foley TA, Kurmann RD, Klarich KW. Case report: a tale of a cardiac mass: looks like a papillary fibroelastoma, acts like a non-bacterial thromboendocarditis. *Front Cardiovasc Med*. 2021;8:782926.
2. Ahmad A, El-Am EA, Kurmann RD, et al. Case report: a rare case of right-sided papillary fibroelastoma in a 1-year-old with congenital heart disease. *Front Cardiovasc Med*. 2020;7:624219.
3. Ahmad A, El-Am EA, Kurmann RD, et al. Clinical and echocardiographic characteristics of patients with pathology proven right-sided papillary fibroelastomas. *Int J Cardiol*. 2022;349:123-126.
4. Gowda RM, Khan IA, Nair CK, Mehta NJ, Vasavada BC, Sacchi TJ. Cardiac papillary fibroelastoma: a comprehensive analysis of 725 cases. *Am Heart J*. 2003;146(3):404-410.
5. Kurmann RD, El-Am EA, Sorour AA, et al. Papillary fibroelastoma growth: a retrospective follow-up study of patients with pathology-proven papillary fibroelastoma. *J Am Coll Cardiol*. 2021;77(16):2154-2155.
6. Maleszewski JJ, Bois MC, Bois JP, Young PM, Stulak JM, Klarich KW. Neoplasia and the heart: pathological review of effects with clinical and radiological correlation. *J Am Coll Cardiol*. 2018;72(2):202-227.
7. Mazur P, Kurmann R, Klarich KW, et al. Operative management of cardiac papillary fibroelastomas. J Thorac Cardiovasc Surg. Forthcoming.
8. Tamin SS, Maleszewski JJ, Scott CG, et al. Prognostic and bioepidemiologic implications of papillary fibroelastomas. *J Am Coll Cardiol*. 2015;65(22):2420-2429.
9. Gillinov AM, Mihaljevic T, Javadikasgari H, et al. Early results of robotically assisted mitral valve surgery: analysis of the first 1000 cases. *J Thorac Cardiovasc Surg*. 2018;155(1):82-91.e2.
10. Balkhy HH, Lewis CTP, Kitahara H. Robot-assisted aortic valve surgery: state of the art and challenges for the future. *Int J Med Robot*. 2018;14(4):e1913.
11. Arghami A, Jahanian S, Daly RC, et al. Robotic mitral valve repair: a decade of experience with echocardiographic follow-up. *Ann Thorac Surg*. 2021;114(5):1587-1595.
12. Bonnichsen CR, Burkhart HM, Klarich KW, Suri RM. Surgical resection of mitral valve papillary fibroelastoma: a robot-assisted, minimally invasive approach with three-dimensional transesophageal echocardiography imaging. *World J Cardiovasc Surg*. 2012;2(2):10-13.
13. Arsalan M, Smith RL, Squiers JJ, Wang A, DiMaio JM, Mack MJ. Robotic excision of a papillary fibroelastoma of the mitral chordae. *Ann Thorac Surg*. 2016;101(6):e187-e188.
14. Hua A, Shemin RJ, Gordon JP, Yang EH. Minimally invasive robotically assisted surgical resection of left atrial endocardial papillary fibroelastomas. *J Thorac Cardiovasc Surg*. 2014;148(6):3247-3249.
15. Je HG, Kim YS, Jung SH, Lee JW. Resection of left ventricular papillary fibroelastoma through thoracoscopic-assisted minithoracotomy. *Interact Cardiovasc Thorac Surg*. 2008;7(2):320-321.

16. Murphy ET. Robotic excision of aortic valve papillary fibroelastoma and concomitant maze procedure. *Glob Cardiol Sci Pract*. 2012;2012(2):93-100.
17. Nisivaco S, Henry M, Ward RP, Balkhy HH. Totally endoscopic robotic-assisted excision of right ventricular papillary fibroelastoma. *J Robot Surg*. 2019;13(6):779-782.
18. Nisivaco SM, Patel B, Balkhy HH. Robotic totally endoscopic excision of aortic valve papillary fibroelastoma: the least invasive approach. *J Card Surg*. 2019;34(12):1492-1497.
19. Stone J, Balkhy H, Ozcan C. Unique case of papillary fibroelastoma originating from the right interatrial septum. *Int J Cardiol*. 2016;223:251-253.
20. Woo YJ, Grand TJ, Weiss SJ. Robotic resection of an aortic valve papillary fibroelastoma. *Ann Thorac Surg*. 2005;80(3):1100-1102.
21. Bush B, Nifong LW, Chitwood WR Jr. Robotics in cardiac surgery: past, present, and future. *Rambam Maimonides Med J*. 2013;4(3):e0017.
22. Cheng DC, Martin J, Lal A, et al. Minimally invasive versus conventional open mitral valve surgery: a meta-analysis and systematic review. *Innovations (Phila)*. 2011;6(2):84-103.
23. Eqbal AJ, Gupta S, Basha A, et al. Minimally invasive mitral valve surgery versus conventional sternotomy mitral valve surgery: a systematic review and meta-analysis of 119 studies. *J Card Surg*. 2022;37(5):1319-1327.
24. Zheng CR, Mazur P, Arghami A, et al. Robotic vs. minimally invasive mitral valve repair: a 5-year comparison of surgical outcomes. *J Card Surg*. 2022;37(10):3267-3275.
25. Diodato MD Jr, Damiano RJ Jr. Robotic cardiac surgery: overview. ix. *Surg Clin North Am*. 2003;83(6):1351-1367.