Comparison of the Surgical Effect and the Long-term Clinical Outcomes Between Robotic and Sternotomy Mitral Valve Replacement

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Research article

Keywords: minimally invasive surgery, robotic, mitral valve surgery

Posted Date: October 28th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-96898/v1

Abstract

Background

Robot-assisted mitral valve surgery has been increasingly used by surgeons to achieve better results. This study was to assess the safety and effectiveness of totally endoscopic robotic mitral valve replacement (TE-MVR) and to provide evidence that it is a reasonable surgical choice by analyzing the clinical experience, surgical efficacy, and follow-up outcomes of this procedure.

Method

Between October 2008 and October 2015, 47 patients underwent da Vinci TE-MVR. From March 2002 to June 2014, 293 patients underwent conventional sternotomy mitral valve replacement (CS-MVR), of whom 47 patients were selected to match the TE-MVR group (1:1). We performed a retrospective study by collecting perioperative data and assessed TE-MVR efficacy by comparing clinical outcomes and echocardiography with CS-MVR in a 10-year follow-up period.

Results

All cases were conducted successfully. No operative deaths were observed, and the complications were not significantly different between the groups. The cardiopulmonary bypass time (122.02±25.45 min) and aortic cross-clamping time (85.68±20.70 min) were longer in TE-MVR group ($P<0.001$). The perioperative complications are similar in two groups, but the drainage volume, blood product transfusion, ICU stay and postsurgical hospital stay are better in robotic group ($P<0.001$). During the follow-up period, 42 patients (89.4%) in TE-MVR group and 40 patients (87.0%) in CS-MVR group were followed. Long-term event-free survival is similar in both groups.

Conclusion

Robotic MVR is a feasible, effective and safe minimally-invasive alternative to sternotomy MVR, and the long-term clinical and echocardiographic results are comparable to sternotomy MVR in selected patients.

Introduction

With the continuous improvement in surgical quality and fewer complications, surgeons and patients are no longer satisfied with the traditional sternotomy cardiac surgery. Minimally invasive cardiac surgery techniques, including partial sternotomy, mini-anterolateral thoracotomy and thoracoscopic surgery, particularly with robot assistance, have dramatically improved the success rate of minimally invasive surgery. [1]

From 2007 to 2015, totally over 900 cases of cardiac surgery have been completed at our center, including 157 cases of mitral valve (MV) surgery (110 cases MV repair [2] and 47 cases MV replacement) [3]. Because of the advantages including a well-expanded operative field and operative dexterity, robotic

MV repair has become widely accepted following continuous multicenter trials that have shown the same safety and effectiveness between robotic and traditional sternotomy surgery [4-6]. However, in patients with severe MV calcification, especially with severe synechia after rheumatic heart disease, MV replacement (MVR) is the only surgical option [7], but comparative evidence of robotic MVR is still rare. The purpose of our study is to report the patients selection and surgical safety, of robotic MVR. After comparison with sternotomy, the long-term outcomes of robotic MVR were evaluated. The results of this work may provide evidence for surgical decision-making.

Patients And Methods

Patient selection

Between October 2008 and October 2015, 157 patients were scheduled to receive robotic mitral valve surgery. After evaluation and intraoperative repair tests, 110 patients successfully received MV repair. The other 47 patients with the poor reparative result or severe rheumatic calcification received robotically assisted totally endoscopic MVRs (TE-MVRs group). Exclusion criteria of robotic MV surgery were reduced left ventricular function (ejection fraction <30%), pulmonary arterial hypertension (Systolic pressure >70mmHg), severe tricuspid valve regurgitation, previous cardiac or right thoracic surgery, a severe lung disease with the inability to tolerate single-lung ventilation, aortic calcification, severe perivalvular disease, severe mitral annular calcification (MAC), and other severe cardiac disease needing concomitant procedure.
Forty-seven patients from 293 patients who underwent conventional MVR from March 2002 to June 2014 were matched as a conventional sternotomy MVR (CS-MVR) group. These criteria were used to match the participants to reduce discrepancies between two groups including age (difference within 10 years), sex, New York Heart Association (NYHA) classification, lesion type and extent, preoperative Euro-Score II score, left ventricular ejection fraction (LVEF), and type of prosthesis. We paired the participants strictly based on the degree of lesion type and preoperative heart function grade as the central pairing criteria and used the other factors as secondary features.

Robotic surgical techniques

The anesthesia and cannulation methods for robotic MVR was the same as we previously described [3]. In brief, after induction of general anesthesia, the patient underwent double-lumen endotracheal intubation.

After left lung ventilation, ports are created in the chest wall. After all ports were placed and cardiopulmonary bypass (CPB) was established through peripheral cannulation, the ascending aorta was cross-clamped with a Chitwood cross-clamp (Scanlon International, Minneapolis, Minn) from the fourth intercostal space at the midaxillary line. A trocar was used to enter the ascending aorta from the right chest wall, directly followed by perfusion of crystalloid cardioplegia.

After cardiac arrest, left atriotomy was performed with a parallel atrial septal incision. Mostly, the valve leaflets were stiff due to calcification, and the paravalvular structures were sometimes affected by calcification. In typical cases, calcified valve tissue was fixed with a grasper and removed with curved scissors. The anterior valve leaflets were removed, and the posterior valve tissue was retained. Perivalvular tissue with severe calcification was also simultaneously excised. The attached papillary muscles and chordae tendineae were preserved and fixed to the annulus with artificial chordae.

A prosthetic valve generally needs 10 to 12-needle 2-0 double-armed Ti-Cron sutures (Covidien Inc., Dublin, Ireland) to be anchored to the native annulus with Teflon pledgets (Figure 1). First, the prosthetic valve was removed from the holder and positioned in the chest cavity via a 2.5-3cm working port. Then, it was fixed vertically through a small incision. There are two methods for suturing. First, all the knots can be tied using a knotting device, and then the knot is sent through the incision. Prosthesis with a plasty ring is suitable for this method because it is effective. Additionally, the knot can be buried deeper into the soft plasty ring and tissue to prevent it from loosening easily. Alternatively, knotting can be accomplished using the COR-KNOT device (LSI SOLUTIONS, Victor, NY, USA). The advantage of this system is that it makes every knot very uniform, so each knot has the same tension and quality. Additionally, the replacement process for each prosthesis can be reduced by 10 to 15 min. The left atrial appendage was closed with 4-0 polytetrafluoroethylene running suture (W.L. Gore and Assoc, Inc. Flagstaff, AZ, USA). After de-airing, the Chitwood cross-clamp was released. The pacing lead was routinely placed on the surface of the right ventricle. TEE was conducted to evaluate the function of the prosthetic valve after weaning from CPB. The operation was completed once no regurgitation or paravalvular leak confirming. A chest drainage tube was placed after meticulous hemostasis.

Post-operative treatments

Antibiotics should be used in patients with infective endocarditis for a sufficient amount of time. After the extubation patients received Vitamin K antagonists treatment. The international normalized ratio (INR) was adjusted according to the type of the artificial valve. Mechanical valve needs long-term anticoagulation and timely detection of INR values while the biovalve need to be anticoagulated for six months. The predischarge thoracic echocardiography was performed to observe the function of the prosthetic valve.

Follow-up data

Follow-up of patients was conducted by regular outpatient review and telephone interview in a systematic manner. The follow-up outcomes assessed included postsurgical overall survival, stroke, reoperation, and readmission for worsening heart function and other major cardiovascular and cerebrovascular events, and postoperative TTE findings. MACCEs include all medical events with cardiovascular and cerebral vascular origins that had caused death or required hospitalization and medical attention including stroke, thromboembolic events, deteriorating heart function, prosthetic dysfunction, infective endocarditis.

Statistical methods

Categorical data were statistically described as frequencies (%). The rates of the two samples were compared using the χ2 test, and ordered count data were compared using the rank-sum test. Continuous data were described as the mean ± standard deviation (SD), and continuous variables in the two groups were compared using Student's t-tests. The Kaplan-Meier plot and two-sample log-rank test were generated to reveal visual and statistical differences in late period complications between groups. CPB and ACC time were deal with a nonlinear regression analysis model (r2) to evaluate the effect of the learning curve. Euro-Score II was calculated with the special calculator online [8]. Significance was set at $P<0.05$. All data were statistically analyzed with SPSS 22.0 statistical software (IBM, Armonk, NY, USA).

Results

Demographic information and valve status

There were 47 patients in both groups after 1:1 matching. No significant difference was found in patient demographics, MV pathology and co-morbidity of other diseases. Preoperative and echocardiography data of two groups are shown in Tables 1.

Operative data

Surgery was completed successfully and no conversion to sternotomy surgery was noted in both groups. Thirty-five (74.5%) mechanical valves and 12 (25.5%) bioprosthetic valves were implanted in TE-MVR group. While 33 patients (70.2%) received mechanical and 14 patients (29.8%) received bioprosthetic valves in CS-MVR group (Figure 2). TE-MVR had a CPB time of 122.02±25.45 min and an ACC time of 85.68±20.70 min. CS-MVR had a CPB time of 90.70±26.258 min and an ACC time of 63.77±21.248 min. The CPB and ACC times associated with robotic surgery were significantly longer than those associated with median sternotomy ($P<0.001$). The size distribution of the mechanical prosthesis or bioprosthesis is presented in Table2. Approximately 2.1% (1/47) and 29.8% (14/47) patients received concomitant cardiac procedures in two groups respectively, and left atrial appendage obliteration in CS-MVR were more likely to be performed ($P=0.003$). Intraoperative TTE confirmed satisfactory prosthesis function in all patients. The operative data are summarized in Table 2.

Postoperative data

No death, stroke, new onset of atrial fibrillation or severe infection occurred during hospitalization in TE-MVR. In CS-MVR, one patient (2.1%) underwent re-exploration for bleeding due to excessive chest drainage. One patient (2.1%) suffered multiple organ failure after septic shock and died on the sixth postoperative day. The other patients in CS-MVR recovered well. Differences between groups became indistinguishable in terms of postsurgical complications. Regarding the postoperative drainage volume, it was significantly higher in CS-MVR ($P<0.001$) and the difference in transfusion of red blood cells and plasma was statistically significant between two groups. The robotics group recovered well after surgery, and there was no prosthetic valve dysfunction in the predischarge TTE. The EF was slightly lower than before surgery in TE-MVR group, but this difference between two groups was not significant (Table 3).

Follow-up data

Patients were followed up by outpatient and telephone interviews. Forty-two (89.4%) patients were followed up in TE-MVR group with an average duration of 71.68±23.62 months TE-MVR group(range from 28 to 110 months) . In CS-MVR group, 40 (87.0%) patients were followed up for 136.47±43.55 months (range from 69 to 218 months). During the long-term follow-up, 2.1% (1/47) of patient in TE-MVR had reoperation because of infective endocarditis three weeks after discharge and this patient died of acute pancreatitis after another two years. In CS-MVR group, 12.8% (6/47) of the patients died, 14.9% (7/47) of the patients had stroke, 4.3% of the patients had redo-MVR due to paravalvular leakage and infective endocarditis and 12.8% (6/47) of the patients were readmitted because of recurrent heart failure and 6.4% (3/47) with paravalvular leakage. Kaplan-Maier analysis showed equivalent 10-year rates of death, stroke, redo-operation and re-admission between TE-MVR and CS-MVR (all P>0.05). However, the cumulative major adverse cardiac and cerebrovascular events (MACCE) was 5.7fold more common in CS-MVR than in TE-MVR, although not reaching statistical significance (6.4% vs. 36.2%, odd ratio =5.7, P=0.10). (Figure 3).

Discussion

Carpentier completed the world's first robot-assisted MV surgery in 1998 [9]. After two decades of development, robotic technology has rapidly evolved and aided in the remarkable advancements witnessed in mitral valve surgery with some apparent advantages which outperform thoracoscopic techniques [10,11]. From our experience with TE-MVR, robotic surgical system can provide a good view of the surgical field. With 10-fold magnification, subtle lesions can be accurately located and removed during the operation; accurate localization is vital in the removal and repair of calcified or adherent valve annulus structures. Meanwhile, the glass-free three-dimensional visual effects can aid the surgeon in accurately distinguishing tissue structures and performing procedures, including excision and suturing. Likewise, the LA approach can obviate the right atrial-atrial septal approach used in the traditional way. By minimizing the retraction of the atrial tissue, mitral valve structure is exposed more precisely. Nonetheless, robotic technology is more reliable intraoperatively given that the serpentine structure of the front part of the robotic arm can flexibly perform seven-dimensional activities, greatly expanding its range of movement. Therefore, this technique makes it possible to accomplish complex actions, in addition to other unique features. The gradual elimination of micro tremors in the hands also leads to smoother and more accurate surgical procedures.

Compared with CS-MVR, the CPB and ACC times of TE-MVR were significantly longer than CS-MVR, which was reported previously [12,13] and the process of operative time shortening was similar to the learning curve reported in Kuo’s study [14]. However, shorter CPB and ACC durations were seen in our study than in Kuo’s report (122.02±25.45 min vs. 217.1 ± 42.0 and 85.68±20.70 min vs. 141.3 ± 34.3min), mainly because of rapid development of a robotic surgical regimen by intense practice of concurrent multiple varieties of robotic cardiac procedures with a fixed specialist team. Thus, the learning curve of TE-MVR

operation became level when robotic mitral valve surgery reached a total of 50-60 cases among which about only 15 were TE-MVR (see figure 3).

In our series of consecutive TE-MVR cases, no perioperative complications such as reoperation, postoperative new onset of atrial fibrillation, low cardiac output syndrome, cerebrovascular events, and postsurgical renal failure was observed. In CS-MVR group, only one patient experienced re-exploration for bleeding, and one patient suffered from renal failure. Notably, no new cases of atrial fibrillation were observed in TE-MVR group, while 4 cases were observed in the CS-MVR group (0% vs. 8.52%, P=0.117). Although no significant differences were noted herein, the results of previous studies have suggested that the incidence of AF is lower than that associated with traditional surgery [15] . Similar results were also shown by Suri *et al*. in patients undergoing MV repair [16] . Two main reasons can explain this finding. First, robotic MVR is performed from the interatrial sulcus into the left atrium. Because the mitral annulus is parallel to the sagittal plane of the human body, the manipulator can be conveniently directed through the right chest wall to the MV tissue. Atrial tissue retraction is avoided with an atrial retractor. A median thoracotomy often requires a right atrial and an atrial septal incision. During the process, the right atrium and atrial septum undergo forceful retraction, which injures atrial structures. Second, robotic surgery can be performed under 10 times magnification in 3D to diminish the possibility of inappropriate operation of normal tissues, resulting in lower arrhythmia rates.

The tracheal intubation time, length of ICU stay, and postsurgical hospital stay were significantly shorter in TE-MVR than in CS-MVR, which is consistent with the findings reported by Suri *et al*. [17]. Hawkins reported a shorter ICU stay and postoperative length of hospital stay and obtained similar conclusions when comparing robotic MVR with minimally invasive and conventional MVR [10]. Considering the obvious clinical effects, the main reason for these findings is that robotic surgery obviates the need to disrupt the sternum and reduces complications associated with sternotomy. In addition to pain relief during postoperative recovery, robotic surgery is associated with considerable reduced blood loss and blood product transfusion, which can also minimize the possibility of transfusion-related acute lung injury, infection and allergy [18]. In principle, the use of blood products should be minimized to ensure clinical safety. Our center adopts strict indications for blood transfusion. In addition, the reason for the lower number of robotic blood transfusions is attributed to three phrases. First, sternum-sparing approach with punctures in the lateral chest wall prevents possible blood loss from the marrow cavity in the sternum. Second, the adoption of closed-type extracorporeal circulation technology decreases the need for intubation and the perturbation of great vessels and the heart so that perioperative bleeding is reduced. Third, the surgical field in robotic surgery is clear, and the magnification is sufficient for convenient and comprehensive hemostasis. In addition, accumulated robotic surgical experience would further facilitated reduction of surgical blood loss, which was in agreement with results from Coyan and colleagues [19].

Besides, the negative impact of transfusions is also curial and detrimental to long-term survival. Although nonsignificant difference was found between the two groups regarding the long-term survival and serious late complications such as thromboembolic events, redo MVR, and readmission for worsening heart

function, TE-MVR has a tendency of lower rates of serious events. Nevertheless, patients are more satisfied with the surgical wounds and more likely to collaborate with physicians during postoperative rehabilitation, which could further speed recovery [17,20].

We have performed more than 150 robotic MV operations, and 30% of them are MVRs. The ratio of replacement is higher than that in centers in developed countries [10,21]. It is believed that the etiological difference between China and developed countries may explain the higher proportion of MVR in MV surgery. The living and nutrition condition of most Chinese residents was unfavorable three to four decades before, and rheumatic fever was common among children, which could lead to rheumatic calcification of the heart valves. Mitral valve repair is quite tricky for severe rheumatic valvular pathology [22] and MVR is inevitable among these rheumatic patients. Moreover, the majority of patients opted for a mechanical valve rather than a bioprosthetic valve [14]. But surgeons and patients in developed countries are more willing to choose biological valves. We believe two main reasons may be contributing to this. First, with the decreasing technical difficulty and more mature robotic surgical skills, the condition for redo robotic surgery turns relatively mature. Spiller and colleagues [23] even reported the third-time redo robotic MVR recently. Second, due to more favorable economic condition in developed regions, increasing patients incline to receive a biological valve rather than slightly cheaper mechanical prosthesis with long-term intaking anticoagulants and blood tests [24].

However, robotic MV surgery is still an evolving technology. Therefore, with consideration for its safety and effectiveness, we should be more rigorous in selecting patients for the best possible long-term outcomes. Patients requiring isolated MV surgery are generally preferred. However, with continual advancements in technology, these contraindications are gradually being eliminated. Onan reported robotic MVR in a patient with pectus excavatum [25], confirming the possibility of using robots in patients with thoracic deformity. Although infective endocarditis is not a contraindication for robotic surgery, valves with complex structural lesions can cause many difficulties intraoperatively. Gillinov and colleagues [11] reported the outcomes of patients with infective endocarditis receiving robotic MV surgery and showed the results of the operation were satisfactory. In our TE-MVR group, 3 of 47 patients had infective endocarditis and recovered well after robotic MVR. A history of previous cardiac surgery or severe pulmonary hypertension was also a contraindication for robotic surgery, but Murphy [21] also reported patients who underwent a redo robotic MVR, as well as patients with preoperative COPD. In his report, no complication was noted, such as paravalvular leakage or obstruction of the left ventricular outflow tract postoperatively. The follow-up outcomes were acceptable, and the cardiac function was class 1 and 2. Recently, the range of patient selection has been gradually expanded, reflecting these improvements.

Limitations

This retrospective study has some limitations, including a relatively small population from a single center. It is largely since TE-MVR is more expensive, with an average increase of $5,000 per case (unpublished data). Thus, during the same period, most patients in China selected the CS-MVR rather than TE-MVR.

Considering that this is a nonrandomized control study, surgeon bias is still a challenge. All TE-MVRs were performed by a single surgeon, while CS-MVRs were performed by several surgeons. Although all patients were paired, we believe that the patients in TE-MVR were milder, highly selected cases given that a large LA diameter was noted in CS-MVR.

Conclusion

Robotic MVR is safe and reliable, and it is associated with less trauma, bleeding, and blood product transfusion than median sternotomy. In addition, the long-term outcomes are excellent and beneficial to selected patients; thus, robotic MVR can be considered an alternative option of minimally invasive surgery.

Abbreviations

ACC: Aortic cross-clamping; BMI: Body Mass Index; CPB: Cardiopulmonary Bypass; CS-MVR: Conventional Sternotomy Mitral Valve Replacement; EF: Ejection Fraction; ICU: Intensive Care Unit; LA: Left Atrium; LV: Left Ventricle; LVED: Left Ventricle End-Diastolic; MACCE: Major adverse cardiac and cerebrovascular events; MV: Mitral valve; MVR: Mitral valve replacement; NYHA: New York Heart Association heart failure classification; PH: Pulmonary Hypertension; TE-MVR: Totally Endoscopic Robotic Mitral Valve Replacement; TTE: Transthoracic Echocardiography

Declarations

Acknowledgements

We thank American Journal Experts (www.aje.com) for its linguistic assistance during the preparation of this manuscript.

Authors' contributions

CQG, HJZ, HZZ designed the study; HZZ, WBK, YW, MY collected the data; HJZ, HZZ analyzed and interpreted the results; CQG, RW support and encourage the study; HZZ wrote this article; All the authors have read and reviewed this manuscript. The author(s) read and approved the final manuscript.

Funding

This work was funded by the National Natural Science Foundation of China (2012AA021104).

Availability of data and materials

The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study was assessed by the site's ethical committee of PLA General Hospital, which stated that no approval and no patient informed consent was necessary because of the retrospective nature.

Consent for publication

Consent was obtained from the patients or their relatives

Competing interests

The authors have declared that no interest.

References

1 Modi P, Hassan A, Chitwood WR, Jr. Minimally invasive mitral valve surgery: a systematic review and meta-analysis. Eur J Cardiothorac Surg. 2008;34:943-52.

2 Liu G, Zhang H, Yang M, Wang R, Xiao C, Wang G et al. Robotic mitral valve repair: 7-year surgical experience and mid-term follow-up results. J Cardiovasc Surg (Torino). 2019;60:406-12.

3 Gao C, Yang M, Xiao C, Wang G, Wu Y, Wang J et al. Robotically assisted mitral valve replacement. J Thorac Cardiovasc Surg. 2012;143: S64-7.

4 Folliguet T, Vanhuyse F, Constantino X, Realli M, Laborde F. Mitral valve repair robotic versus sternotomy. Eur J Cardiothorac Surg. 2006;29:362-6.

5 Suri RM, Burkhart HM, Daly RC, Dearani JA, Park SJ, Sundt TM, 3rd et al. Robotic mitral valve repair for all prolapse subsets using techniques identical to open valvuloplasty: establishing the benchmark against which percutaneous interventions should be judged. J Thorac Cardiovasc Surg. 2011;142:970-9.

6 Wei B, D'Amico TA. Thoracoscopic versus robotic approaches: advantages and disadvantages. Thorac Surg Clin. 2014;24:177-88, vi.

7 Senay S, Gullu AU, Kocyigit M, Degirmencioglu A, Kilic L, Karabulut H et al. Robotic mitral valve replacement for severe rheumatic mitral disease: perioperative technique, outcomes, and early results. Innovations (Phila). 2014;9:292-6.

8 Leahey PA, LaSalvia MT, Rosenthal ES, Karchmer AW, Rowley CF. High Morbidity and Mortality Among Patients With Sentinel Admission for Injection Drug Use-Related Infective Endocarditis. Open Forum Infect Dis. 2019;6: ofz089.

9 Carpentier A, Loulmet D, Aupecle B, Kieffer JP, Tournay D, Guibourt P et al. Computer assisted open heart surgery. First case operated on with success. C R Acad Sci III. 1998;321:437-42.

10 Hawkins RB, Mehaffey JH, Mullen MG, Nifong WL, Chitwood WR, Katz MR et al. A propensity matched analysis of robotic, minimally invasive, and conventional mitral valve surgery. Heart. 2018;104:1970-75.

11 Gillinov AM, Mihaljevic T, Javadikasgari H, Suri RM, Mick SL, Navia JL et al. Early results of robotically assisted mitral valve surgery: Analysis of the first 1000 cases. J Thorac Cardiovasc Surg. 2018;155:82-91.e2.

12 Yanagawa F, Perez M, Bell T, Grim R, Martin J, Ahuja V. Critical Outcomes in Nonrobotic vs Robotic-Assisted Cardiac Surgery. JAMA Surg. 2015;150:771-7.

13 Westhofen S, Conradi L, Deuse T, Detter C, Vettorazzi E, Treede H et al. A matched pairs analysis of non-rib-spreading, fully endoscopic, mini-incision technique versus conventional mini-thoracotomy for mitral valve repair. Eur J Cardiothorac Surg. 2016;50:1181-87.

14 Kuo CC, Chang HH, Hsing CH, Hii HP, Wu NC, Hsu CM et al. Robotic mitral valve replacements with bioprosthetic valves in 52 patients: experience from a tertiary referral hospital. Eur J Cardiothorac Surg. 2018;54:853-59.

15 Mihaljevic T, Jarrett CM, Gillinov AM, Williams SJ, DeVilliers PA, Stewart WJ et al. Robotic repair of posterior mitral valve prolapse versus conventional approaches: potential realized. J Thorac Cardiovasc Surg. 2011;141:72-80. e1-4.

16 Suri RM, Dearani JA, Mihaljevic T, Chitwood WR, Jr., Murphy DA, Trento A et al. Mitral valve repair using robotic technology: Safe, effective, and durable. J Thorac Cardiovasc Surg. 2016;151:1450-4.

17 Suri RM, Antiel RM, Burkhart HM, Huebner M, Li Z, Eton DT et al. Quality of life after early mitral valve repair using conventional and robotic approaches. Ann Thorac Surg. 2012;93:761-9.

18 Grau JB, Fortier JH, Kuschner C, Ferrari G, Brizzio ME, Zapolanski A et al. Implementing a protocol to optimize blood use in a cardiac surgery service: results of a pre-post analysis and the impact of high-volume blood users. Transfusion. 2017;57:2483-89.

19 Coyan G, Wei LM, Althouse A, Roberts HG, Schauble D, Murashita T et al. Robotic mitral valve operations by experienced surgeons are cost-neutral and durable at 1 year. J Thorac Cardiovasc Surg. 2018;156:1040-47.

20 Yang M, Yao M, Wang G, Xiao C, Wu Y, Zhang H et al. Comparison of postoperative quality of life for patients who undergo atrial myxoma excision with robotically assisted versus conventional surgery. J Thorac Cardiovasc Surg. 2015;150:152-7.

21 Murphy DA, Moss E, Binongo J, Miller JS, Macheers SK, Sarin EL et al. The Expanding Role of Endoscopic Robotics in Mitral Valve Surgery: 1,257 Consecutive Procedures. Ann Thorac Surg. 2015;100:1675-81; discussion 81-2.

22 Zhai J, Wei L, Huang B, Wang C, Zhang H, Yin K. Minimally invasive mitral valve replacement is a safe and effective surgery for patients with rheumatic valve disease: A retrospective study. Medicine (Baltimore). 2017;96: e7193.

23 Spiller R, Symalla T, McCrorey M, Balkhy HH. Robotic-Assisted Third-Time Redo Mitral Valve Replacement. Ann Thorac Surg. 2019;108: e245-e47.

24 Labaf A, Svensson PJ, Renlund H, Jeppsson A, Sjalander A. Incidence and risk factors for thromboembolism and major bleeding in patients with mechanical valve prosthesis: A nationwide population-based study. Am Heart J. 2016; 181:1-9.

25 Onan B, Bakir I. Robotic Mitral Valve Replacement in Pectus Excavatum. J Card Surg. 2016;31:306-8.

Tables

Table 1. Baseline characteristics and presurgical echocardiography data of patients

	TE-MVR(n=47)	CS-MVR(n=47)	P
Age (years), mean ± SD	47.5±10.8	50.5±9.2	0.160
Gender Male, n(%)	26 (55.3)	26 (55.3)	1.000
BMI (kg/m^2), mean ± SD	24.5±3.2	24.2±4.4	0.722
Euro-ScoreII(%), mean ± SD	0.8±0.3	0.8±0.4	0.442
Comorbidities, n (%)			
Heart disease history	2(4.3)	0(0)	0.495
Diabetes mellitus	1(2.1)	2(4.3)	1.000
Hypertension	8(17.0)	8(17.0)	1.000
Hyperlipemia	2(4.3)	1(2.1)	1.000
Stroke	3(6.4)	2(4.3)	0.617
COPD	0(0)	0(0)	NA
Atrial fibrillation	20(44.7)	23(48.9)	0.836
NYHA class, n (%)			1.000
I	2(4.3)	2(4.3)	
II	25(53.2)	25(53.2)	
III	20(42.6)	20(42.6)	
IV	0(0)	0(0)	
MV pathologies, n (%)			0.306
Degenerative (Barlow's)	6(12.8)	8(17.0)	
Rheumatic	36(76.6)	36(76.6)	
Infective endocarditis	2(4.3)	2(4.3)	
Congenital	3(6.4)	1(2.1)	
Echocardiographic data			
LA (mm)	46.8±6.7	54.1±15.1	0.003
LVED (mm)	45.2±6.3	46.4±8.2	0.476
EF (%)	64.0±7.4	61.3±8.7	0.141
Moderate/severe MR, n (%)	18(38.3)	23(49.0)	0.298
Moderate/severe MS, n (%)	33(70.2)	30(63.8)	0.510

Moderate/severe TR, n (%)	5(10.6)	3(6.4)	0.712
Moderate/severe PH, n (%)	3(6.4)	7(14.9)	0.316

Abbreviations: BMI: Body mass index; COPD: Chronic obstructive pulmonary disease; MR: Mitral regurgitation; MS: Mitral Stenosis; PH: Pulmonary hypertension; TR: Tricuspid regurgitation; NYHA: New York heart association classification; EF: Ejection fraction; LA: Left atrium; LVED: Left Ventricle End-Diastolic; SD: Standard deviation.

Table 2. Operative data

	TE-MVR (n=47)	CS-MVR (n=47)	P
Perfusion time (min), mean ± SD			
CPB	122.0±25.5	90.7±26.3	<.001
Aortic Crossclamp	85.7±20.7	63.8±21.2	<.001
Prosthesis type, n (%)			0.645
Mechanical valve	35(74.5)	33(70.2)	
Biovalve	12(25.5)	14(29.8)	
Prosthesis size, n (%)			0.019
22	0(0)	1(2.1)	
25	25(53.2)	17(36.2)	
27	20(42.6)	17(36.2)	
29	2(4.3)	7(14.9)	
31	0(0)	5(10.6)	
Concomitant procedure, n (%)			
ASD closure	1(2.1)	0(0)	1.000
LAA obliteration	0(0)	9(19.1)	0.003
Left atrial thrombectomy	0(0)	5(10.6)	0.056

Abbreviations :AF: Atrial fibrillation; CPB: Cardiopulmonary bypass; LAA: left atrial appendage; SD: Standard deviation.

Table 3.Postoperative complications in the two groups

	TE-MVR (n=47)	CS-MVR (n=47)	P
Ventilation time(h)	7.5±3.3	20.0±20.0	0.001
ICU stay(h)	46.7±16.3	89.1±32.2	<.001
Postsurgical hospital stay (d)	6.8±2.5	13.00±5.3	<.001
Complications, (n, %)			
Sternotomy conversion	0(0)	0(0)	NA
Re-exploration for bleeding	0(0)	1(2.1)	1.000
Prolonged ventilation time(>24h)	1 (2.1)	5(10.6)	0.203
Low cardiac output	0(0)	0(0)	NA
New-onset AF†	0(0)	4(8.5)	0.117
Stroke	0(0)	0(0)	NA
Acute Renal Failure	0(0)	1(2.1)	1.000
30-Day mortality	0(0)	1(2.1)	1.000
Pleural effusion	1 (2.1)	1(2.1)	1.000
Drainage volume (ml)	349.2±152.6	514.4±76.7	<.001
Blood product infusion (units)			
RBCs	1.2±1.5	2.4±1.2	<.001
Plasma	3.1±1.8	4.3±2.3	0.007
Post echocardiographic data	(n=47)	(n=46)	
LA (mm)	38.4±5.3	42.3±11.9	0.006
LVED (mm)	41.3±3.8	44.4±6.5	0.002
LVEF (%)	62.3±7.0	59.6±7.5	0.066

Abbreviations :AF: Atrial fibrillation; †New-onset AF: 1) AF treated during any time during the perioperative period; 2) AF continuing for ≥20 min; and 3) accumulated AF time >60 mins over 24 hours. EF: Ejection fraction; LA: Left atrium; LVED: Left Ventricle End-Diastolic; SD: Standard deviation.

Figures

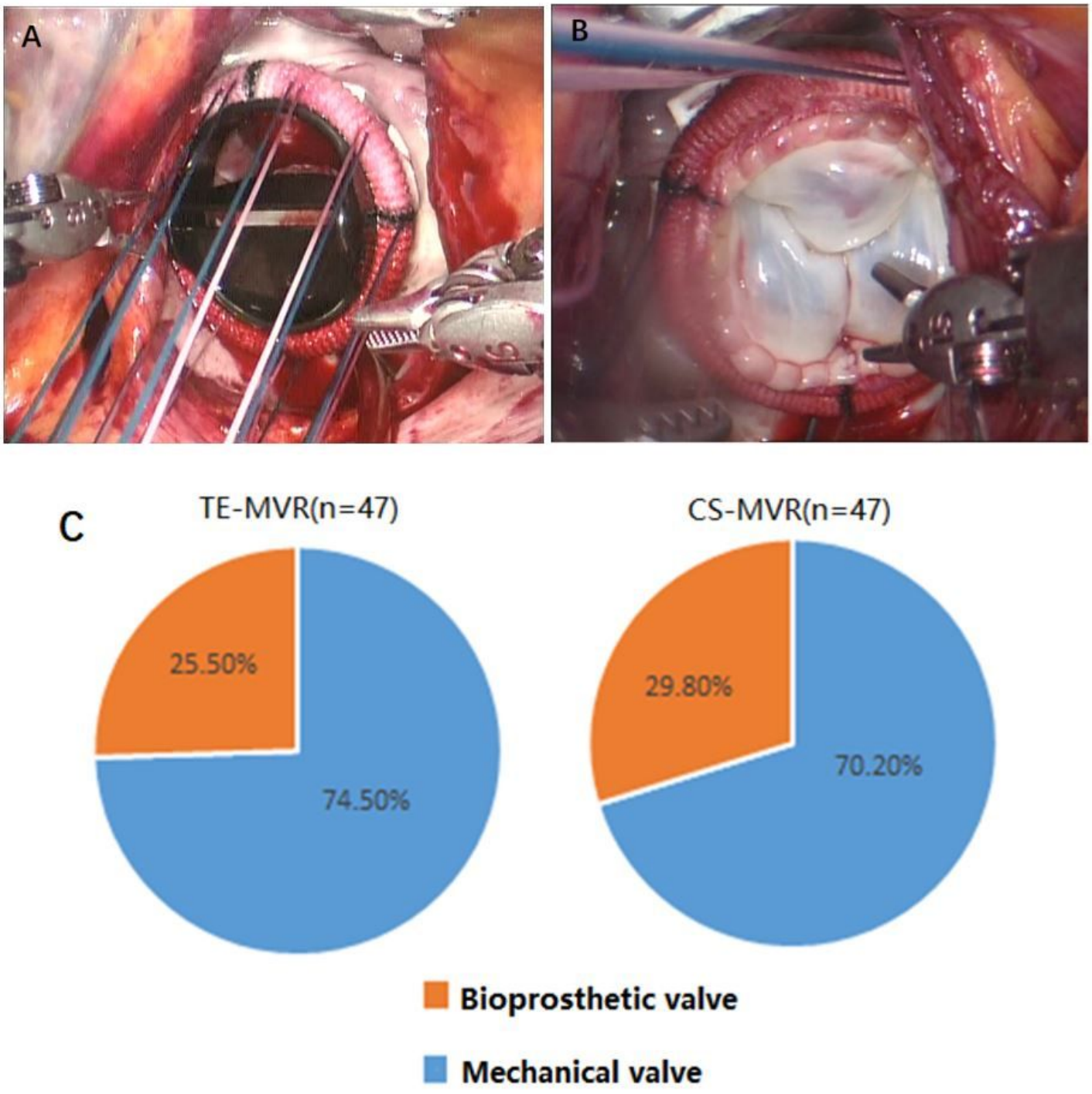

Figure 1

Endoscopic view of (A) mechanical and (B) bioprosthetic valves during TE-MVR and the proportion of prosthesis types used in TE-MVR and CS-MVR (C).

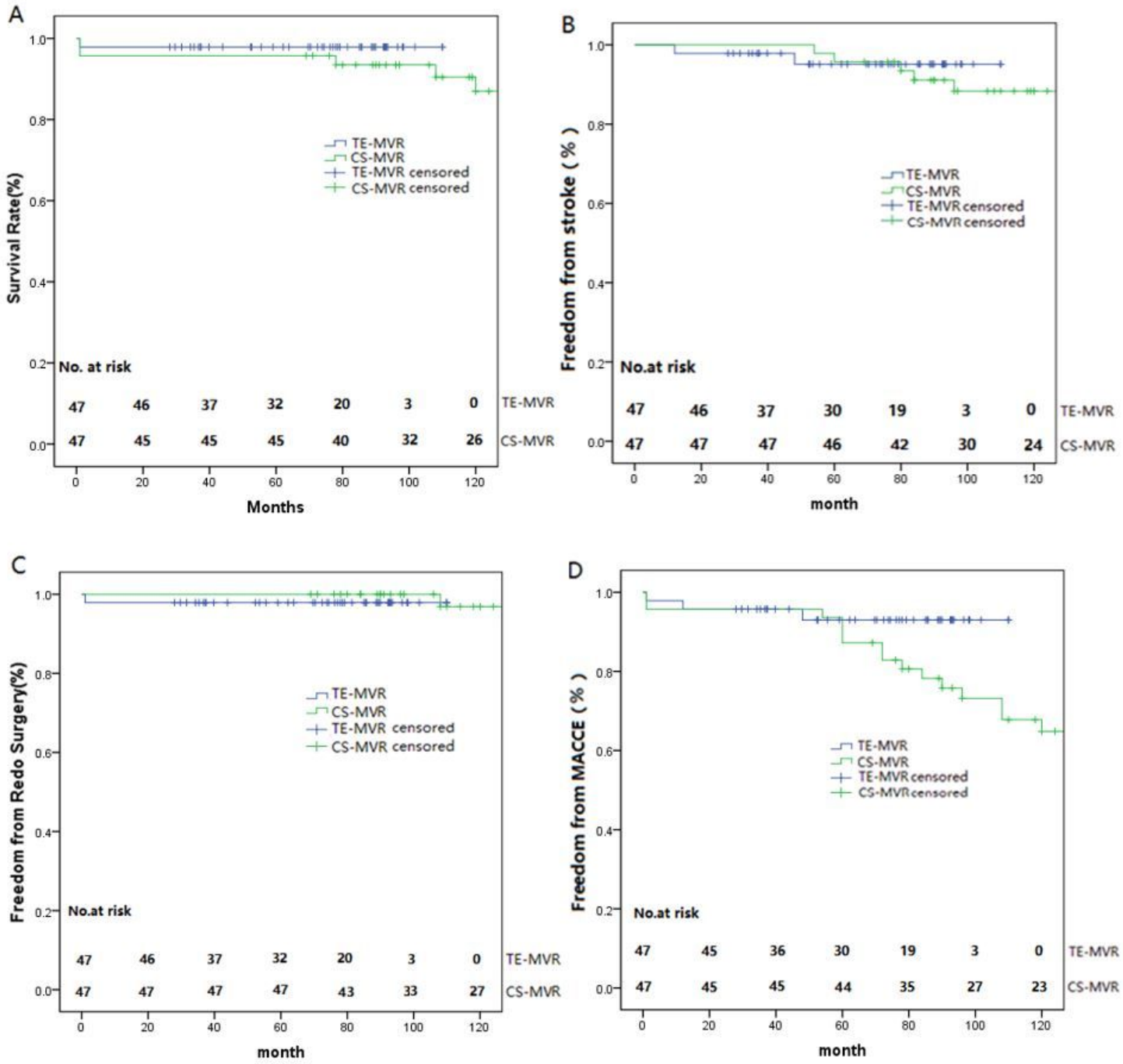

Figure 2

Comparison of the ten-year clinical outcomes after TE-MVR and CS-MVR with Kaplan-Meier cumulative incidence curves for (A)survival (P= 0.37), (B) freedom from stroke (P=0.68), (C) freedom from redo MVR (P= 0.43) and (D) freedom from MACCE (P =0.10).

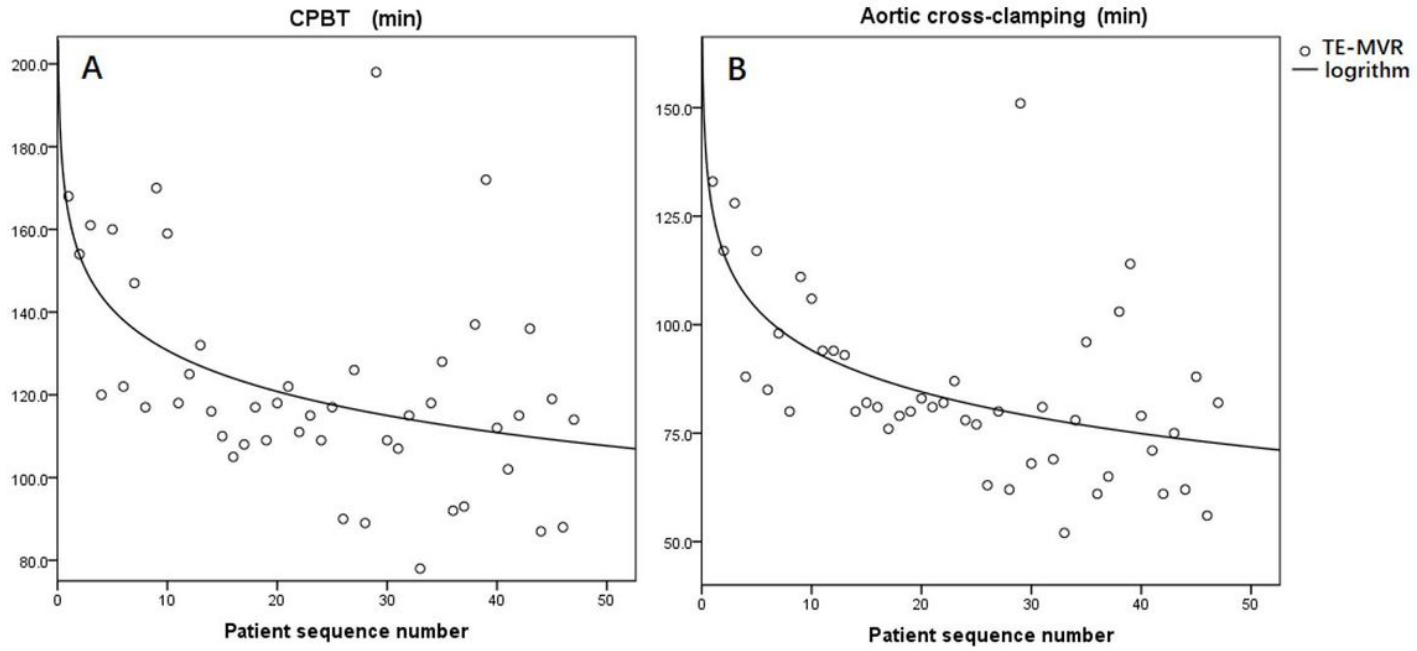

Figure 3

The learning curve of robotic surgical CPB time in (A) and Cross-clamp time in (B) for TE-MVR. The CPB time: y (min)= -14.323ln(x) + 163.712，r2=0.248; P<0.001. The Aortic cross-clamping time: y (min)= -13.852ln(x) + 126.00，r2=0.351; P<0.001.