Received: 31 October 2020 | Revised: 3 December 2020 | Accepted: 21 December 2020

DOI: 10.1111/jocs.15281

ORIGINAL ARTICLE

JOURNAL OF CARDIAC SURGERY WILEY

An analysis of the learning curve for robotic-assisted mitral valve repair

Ahmet Ü. Güllü MD[1] | Sahin Senay MD[1] | Muharrem Kocyigit MD[2] | Ertugrul Zencirci MD[3] | Ahmet Akyol MD[3] | Aleks Degirmencioglu MD[3] | Gultekin Karakus MD[3] | Egemen Ersin MSc[4] | Alara Karabiber MD[1] | Cem Alhan MD[1]

[1]Department of Cardiovascular Surgery, Acibadem Mehmet Ali Aydınlar University School of Medicine, Istanbul, Turkey

[2]Department of Anesthesiology, Acibadem Mehmet Ali Aydınlar University School of Medicine, Istanbul, Turkey

[3]Department of Cardiology, Acibadem Mehmet Ali Aydınlar University School of Medicine, Istanbul, Turkey

[4]Department of Cardiovascular Surgery, Programme of Perfusion, Acibadem Mehmet Ali Aydınlar University School of Medicine, Istanbul, Turkey

Correspondence
Egemen Ersin, MSc, Department of Cardiovascular Surgery, Programme of Perfusion, Acibadem Mehmet Ali Aydınlar University School of Medicine, Istanbul, Turkey.
Email: egemn.ersin@gmail.com

Abstract

Background: Many cardiac surgeons receive training for sternotomy-based cardiac surgical operations in residency programs and only a few education programs offer training specifically in minimally invasive cardiac surgery. In this report, we aimed to search and analyze the learning curve for robotic-assisted mitral valve (MV) repair in cardiac surgeons.

Method: Between January 2010 and July 2019, 60 robotic-assisted isolated MV repair surgeries were performed with DaVinci Robotic Systems in our center. Different kinds of surgical techniques were used. The assessment of the learning curve was based on cardiopulmonary bypass (CPB) and transthoracic aortic clamp (CC) times.

Result: There were 23 (38.3%) men and 37 (61.7%) women with a mean age of 48.3 years. The lesions of the MV were posterior leaflet prolapsus ($n = 42$, 70.0%), anterior leaflet prolapsus ($n = 8$, 13.3%), Barlow disease ($n = 3$, 5%), and annular dilatation ($n = 7$, 11.6%). The patients underwent notochordal implantation ($n = 27$, 45%), quadrangular or triangular resection ($n = 23$, 38.3%), isolated ring annuloplasty ($n = 7$, 11.7%), resection, and leaflet reduction ($n = 2$, 3.3%) or edge to edge repair ($n = 1$, 1.7%). The maturation of the learning curve appeared to be about 30 cases. The statistical analysis showed that the mean CPB and CC times for the first 30 cases were greater compared with the 30 after learning curve (155.3 vs. 118.9 min [$p = .00$], 102.3 vs. 80 min [$p = .00$], respectively). There was no case of conversion to open surgery. No perioperative mortality was observed.

Conclusion: The maturation of the learning curve for robotic-assisted MV repair appeared to be about 30 cases in our group of patients. This study had encouraging results for surgeons who desire to start a robotic mitral surgery program.

KEYWORDS
learning curve, robotic surgery, valve repair

1 | INTRODUCTION

Minimally invasive mitral valve (MV) surgery began by using a right anterolateral thoracotomy approach. Further advances in instrumentation, visualization, and techniques were developed which enabled peripheral cannulation, myocardial protection, and improved exposure. Finally, the introduction of the robotic approach to MV brought an era of potentially better outcomes such as less pain, decreased transfusion requirements, decreased length of stay in intensive care and hospital, and shorter recovery time.[1,2] However, this established benefit with robotic assistance comes at a cost of a steep learning curve. This is because cardiac surgeons receive training for conventional sternotomy-based cardiac surgical operations in residency programs and only a few education programs offer training specifically in minimally invasive cardiac surgery. Additionally, these programs generally do not provide enough practice duration for robotic-assisted surgery.

A special report from the task force on robotic surgery of the STS/AATS warns hospital administrators that they should be aware of the necessity of surgeon and team learning curves, which in some complex procedures can reach three-digit numbers.[3] However, this comment relies on an expert consensus, not any analysis according to our literature search. In this study, we aimed to analyze and evaluate the learning curve results during robotic-assisted MV repair using a stepwise approach.

2 | MATERIALS AND METHODS

This report is a retrospective review of a prospectively designed database of consecutive patients who underwent robotic-assisted isolated MV repair at our clinic between January 2010 and July 2019. Informed consent was obtained from all individual participants included in the study and the study was approved by the cardiovascular surgical committee of our university. In this period, 60 robotic-assisted isolated MV repair surgeries were performed with Da Vinci Systems (Intuitive Surgical, Inc.). The assessment of the learning curve was based on cardiopulmonary bypass (CPB) and transthoracic aortic clamp (CC) times.

All patients had severe mitral insufficiency according to transthoracic or transesophageal echocardiography (TEE), preoperatively. Data for this report, including medical histories, demographic characteristics, comorbidities, operative and laboratory results, electrocardiogram analysis, early postoperative outcomes were all retrospectively retrieved from the institutional database. Both techniques, robot-assisted surgery, and the conventional approach via sternotomy were described in detail to all patients before the operation and surgical technique was determined according to patient request. This program did not have systematic exclusion criteria for robotic-assisted MV repair. However, intensive pleural adhesions may complicate the procedure during pleural dissection. Symptomatic coronary artery disease, aortic valve insufficiency, and pectus excavatum may also be other contraindications for this procedure. All patients above 40 years of age or with multiple risk factors for coronary disease underwent a coronary angiogram before the operation.

2.1 | Surgical technique

We have described our technique for robotic-assisted MV surgery elsewhere previously.[4] But briefly, after double-lumen tube intubation, for selective single lung ventilation, a TEE probe is inserted and used liberally in all steps of operation. The pathological function of the MV leaflets and eventually other segments are evaluated with TEE. TEE not only guides a suitable technique of valve repair but also shows probable postoperative residual mitral regurgitation, iatrogenic mitral stenosis, or other potential complications (i.e., systolic anterior motion [SAM], distortion of the circumflex artery, new onset of aortic regurgitation or aortic dissection). A chest roll is placed under the right shoulder, the right arm is placed at the side of the operation table and the table is rotated 15–20° right-side-up position. Intubation is achieved with a double-lumen endotracheal tube. Central venous and other cannulation sites are marked and the diameters of the vessels are measured by the aid of ultrasound. A venous cannula is inserted for venous drainage via the right internal jugular vein with TEE guidance. The arterial cannulation side was decided with the help of Doppler USG and a non-calcified artery was selected. In case of severe atherosclerosis at femoral arteries, the right axillary artery was used as another option. A soft tissue retractor is placed following a 3 cm incision between the anterior axillary and midclavicular line at the fourth intercostal space. The port for the robotic right arm is placed through the first or second intercostal spaces inferior to the soft tissue retractor, and the left arm port is placed in one intercostal space superiorly. After the positioning of the trocars, the robotic system is docked. Following CPB institution, the pericardium is opened 2–3 cm anteriorly to the phrenic nerve, pulled through the lateral chest wall inferior to the thoracotomy, and fixed externally. The heart is arrested with a CC which is inserted through the chest wall in the direction of the transverse sinus. A cardioplegia needle is placed temporarily into the aortic root through the working port and single-shot cold crystalloid cardioplegia is delivered (1500 ml). Aortic cross-clamping and cardioplegia delivery should be checked by TEE. The inferior and superior vena cava are occluded with bulldog clamps.[5] For left atrial exposure, the interatrial approach is used after dissection of the interatrial groove. After left atriotomy, the exposure of the MV is established by properly placing the left atrial retractor via the robotic 4th arm. MV was assessed using hydrostatic testing with a suction irrigator. Each leaflet segment was analyzed via endoscope and the pathologies, anatomic variations, or malformations of the subvalvular apparatus were evaluated. Triangular or quadrangular resection techniques were preferred when the leaflets were oversized and myxoid. Neochordae implantation was performed when the leaflets flailed but were sized normally, while existing chordal rupture or elongation. Some variations of neochord techniques were used. In the Loop Neochord technique, prefabricated commercial loops were also available on the shelf, but we created loops at the time of operation with Gore-Tex 4-0 CV (W.L. Gore and Associates) and pledgets. The length of loops was 12 mm for the posterior mitral leaflet and 22 mm for anterior mitral leaflet in normal left ventricular dimensions and 14 and 24 mm, respectively in patients with enlarged left ventricles. The needles of the GORE-TEX® sutures were passed through the respective papillary muscle in such a way that the loops arising towards the prolapsing segment were then passed through a second pledget and tied down. Next, the four separate Goretex sutures were used to fix each loop to the free edge of the prolapsing segment, with the knots placed on the atrial surface of the leaflet. In another neochord technique using a Memo 3D Rechord ring ($n = 17$), the artificial chords made of Goretex sutures were passed from the papillary muscle to the prolapsing leaflet, then the reference element of the Memo 3D Rechord ring (Sorin) and finally tied at the annular level without chord length measurement. The sizing of the ring is based on the surface area of the anterior mitral leaflet and implanted with standard techniques. Pledgeted sutures were implanted with robotic assistance for the ring implantation. Different kinds of annular rings were used during this study period. Once all the sutures were completed, they were passed through the annulus of the valve or ring prosthesis outside the thoracic cavity. The ring was removed from its holder and deployed through the soft tissue retractor. The pledgeted sutures of the ring were secured with an automatic mechanical knot fastening system (Cor-Knot; LSI Solution). This automatic system was used to save time, but alternatively, the sutures could be secured via the knot pusher. The left atrium was closed following the completion of MV repair using a premade loop suture. Both bulldog clamps are released. After deairing, the aortic cross-clamp is also released. TEE examination is performed to check any abnormal situation or air trap. The surgical team is to ensure that no more than trace-to-mild mitral regurgitation is present at the completion of the repair. The patient is then weaned from CPB, cannulae are removed and protamine is administered.

3 | RESULTS

The preoperative demographics of the patients were presented in Table 1. There were 23 (38.3%) men and 37 (61.7%) women with a mean age of 48.3 years (range 16.1–79.1). Most patients were in New York Heart Association class I or II (90.0%) and the mean LV ejection fraction was 62.1%. The lesions of the MV were posterior leaflet prolapsus ($n = 42$, 70.0%), anterior leaflet prolapsus ($n = 8$, 13.3%), Barlow disease ($n = 3$, 5%), and annular dilatation ($n = 7$, 11.6%). The patients underwent notochordal implantation ($n = 27$, 45%), quadrangular or triangular resection ($n = 23$, 38.3%), isolated ring annuloplasty ($n = 7$, 11.7%), resection, and leaflet reduction ($n = 2$, 3.3%) or edge to edge repair ($n = 1$, 1.7%) (Table 2). CC and CPB duration were analyzed consecutively to detect improvements in performance over time. The maturation of the learning curve for robotic-assisted MV repair appeared to be about 30 cases. Figures 1 and 2 show the steady decrease of ischemic time and extracorporeal circulation period during the course of experience. The mean CPB and CC times for the first 30 cases were greater compared with the 30 post-learning curve cases (155.3 vs. 118.9 min [$p = .00$], 102.3 vs. 80 min [$p = .00$], respectively). Perioperative complications are presented in Table 3. A decrease in postoperative hemorrhage after the learning curve was found (318.0 ± 241 ml vs. 214 ± 123 ml), however, this was not statistically significant. Two cases needed revision related to bleeding which was encountered at the early times of experience (3rd and 12th cases). ICU stay was longer in early phases, rather than after the learning curve (23.2 vs. 19.5 $p = .004$). There was no case of conversion to open thoracotomy or sternotomy. The comparison of postoperative outcomes of the first 30 cases and the later course did not reveal any obvious differences in morbidity. No perioperative mortality was observed.

TABLE 1 Perioperative characteristics of patients

Demographics	Min-Max	Mean-St
Age	16–79	48.3 ± 15
Euroscore	2–9	3.1 ± 1.45
EF (%)	40–72	62.4 ± 5.38
LVEDD (mm)	43–63	6.6 ± 7.4
CPB Duration (min)	73–275	137.3 ± 46.8
CC Time (min)	47–200	92.0 ± 31.2
ICU Stay (h)	13–120	21.4 ± 13.5
	n	%
NYHA Class 3-4	6	10
COPD	4	6.7
Hypertension	6	10

Abbreviations: CC time, cross-clamp time; COPD, chronic obstructive pulmonary disease; CPB duration, cardiopulmonary bypass duration; EF, ejection fraction; ICU Stay, intensive care unit stay; LVEDD, left ventricle end-diastolic dimension; NYHA Class, New York Heart Association Classification.

TABLE 2 Types of mitral repair techniques

Repair techniques	*n* =60 (patients)	%
Leaflet resection (triangular/quadrangular)	23	38.3
Leaflet resection and reduction	2	3.3
Neochordae implantation		
• Anterior	8	13.3
• Posterior	17	28.3
• Anterior and posterior	2	3.3
Edge to edge repair	1	1.7
Just ring annuloplasty	7	11.7

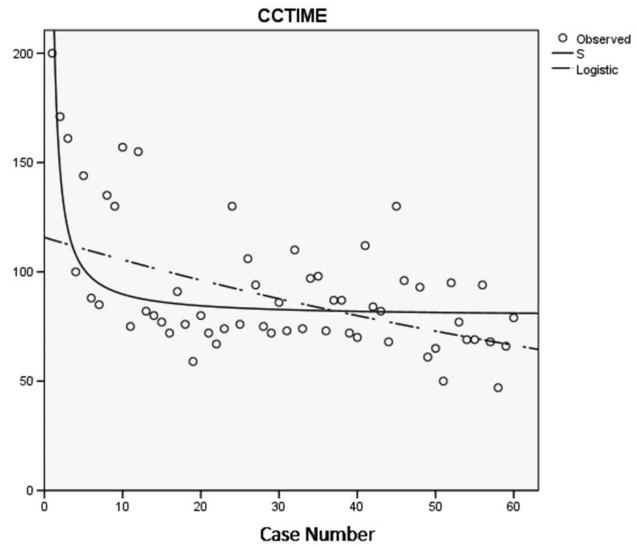

FIGURE 1 Cross clamp time by learning curve

TABLE 3 Perioperative complications during robotic-assisted mitral valve repair

Perioperative complications	n = 60 (patients)	%
Neurological deficit		
• Permanent	0	0
• Transient	1	1.7
Bleeding	2	3.3
Coronary stenosis needs stenting	1	1.7
New-onset AF	5	8.3
Postpericardiotomy syndrome	2	3.3
Pleural efusion needs drainage	1	1.7
Intraoperative SAM and recross clamping	1	1.7
Renal failure needs dialysis	1	1.7
Infective endocarditis	0	0
Mortality	0	0

Abbreviation: SAM, systolic anterior motion.

4 | DISCUSSION

Robotic technology was generally adopted very slowly in MV repair surgery for many reasons, including cost, need for dedicated nursing, anesthesia, perfusionists and more importantly, lack of proper training. The training of MV repair is still through conventional sternotomy in many institutions during residency programs. Although the repair technique of MV is the same through sternotomy and robotic assistance, the setup and challenges of these two approaches are highly different. The combination of all these factors resulted in only a few centers worldwide being able to establish successful and enduring robotic-assisted MV repair programs. This study presents the learning curve and early results of robotic-assisted MV repair. The maturation of the learning curve for robotic-assisted MV repair appeared to be about 30 cases. The comparison of the first 30 cases to the rest of the study group showed a significant decrease in CC and CPB times. This is consistent with the experimental and clinical experience of other groups with regard to robotically assisted totally endoscopic coronary artery bypass grafting and ASD closure.[3,6] In a study of Bonaros in which the ASD repair was performed with robotic assistance, the learning curves were extremely steep, however, this might be related to ASD closure being a more straight forward operation.[6] The number of procedures being performed by robotic surgery has been constantly increasing in numerous specialties, however, there are conflicting curricula for the basic training and certification programs to establish a successful robotic program especially for cardiac surgery. On the other side, in a special report from the Task Force on robotic cardiac surgery of STS/AATS, it was advised that hospital administrators and physician leaders should be aware of learning curves, causing some complex procedures to reach three-digit numbers in terms of expenses.[3] Keeping in mind that the learning curve of some complicated cases may become extensively long, or necessitate conversion to an alternative approach. Therefore it is highly important to start a robotic program by selecting low operative risk patients with simple pathology. Our team was experienced in techniques for minimally invasive cardiac surgery before starting the robotic program. In addition, mammarian artery harvesting and ASD closure cases were selected as the initial cases with robotic assistance. Moreover, having conventional MV repair experience can be considered as one of the factors that have a positive effect on the learning curve in our study.

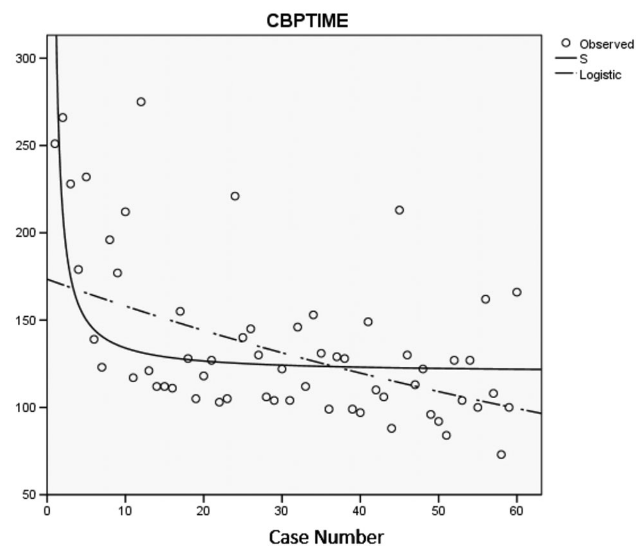

FIGURE 2 Cardiopulmonary bypass time by learning curve

In this article, only CPB and CC times were taken as a basis during the learning curve analysis. However, the learning curve does not comprise only the surgeon but also the whole team because it is well recognized that a coordinated surgical team, which includes cardiac surgeons, anesthesiologists, scrub nurses and perfusionists is critical to establish a successful robot-assisted cardiac surgical program. Members of the robotic team were shifted or exchanged very rarely, as we believe that the existence of a stable team is also another factor that may affect the outcomes. The learning curve period may be longer in educational centers where the team members shift more often. In a study of Kesavuori et al.[7] they reported their experience with robotic MV repair ($n = 142$) comparing the mentioned group to those undergoing sternotomy. Valve-related outcomes were similar between the groups, but early major complications occurred significantly more often in the robotic group. These included conversions to sternotomy, low cardiac output states, circumflex artery occlusions, and femoral artery occlusion. They attributed these complications principally to the initial use of endoaortic balloon occlusion. We used a transthoracic clamp instead of an endoaortic balloon for aortic occlusion, however, the aorta was investigated carefully in terms of calcification through TEE. Also, in case of suspicion of ascending aortic calcification at chest X-ray, the patient was investigated via tomography preoperatively. Moreover, in patients with the highly calcified aorta, arterial cannulation was performed with the right axillary artery to avoid calcification related complications. Despite taking all kinds of precautions, temporary hemiparesis occurred in one patient in our study group. As another major complication, one patient had coronary occlusion and needed stenting right after the operation.

Despite good long-term results of the "triangular or quadrangular resection," Perier et al.[8] proposed an alternative technique for localized prolapse of PL using only artificial chordae without any leaflet resection. The objective of the "respect rather than resect" approach was to promote a larger surface of coaptation zone deep in the ventricle and the free edge of the posterior leaflet which acts as a buttress for the anterior leaflet. This concept may be an effective strategy in preventing SAM. However, it may compromise posterior leaflet mobility and results need to be confirmed in the very long-term.[9] In our patient group, there was no standard surgical technique for mitral repair at any time; but the learning curve provided us to perform more complex valve repair techniques in patients including with Barlow disease or anterior leaflet prolapsus.

The present report comprised the patients who underwent isolated MV repair ($n = 60$) in our center from the beginning of the robotic-assisted cardiac surgery program until the time of this study. As we mentioned previously, mammarian artery harvesting and ASD closure procedures were selected as the initial cases with robotic assistance. The fact that there were not only isolated mitral repair cases in all cohorts ($n = 275$), and the presence of concomitant mitral procedures, ASD closure or coronary bypass operations can be considered as a limitation of the study.

In conclusion, the maturation of the learning curve for robotic-assisted MV repair appeared to be about 30 cases in our group of patients. This study had encouraging results for surgeons who desire to start a robotic mitral surgery program.

The data that support the findings of this study are available from the corresponding author (EE), upon reasonable request.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

ORCID

Ahmet Ü. Güllü http://orcid.org/0000-0002-7160-6427
Sahin Senay http://orcid.org/0000-0001-5692-6927
Muharrem Kocyigit http://orcid.org/0000-0003-0615-6025
Ertugrul Zencirci http://orcid.org/0000-0001-6316-9696
Aleks Degirmencioglu http://orcid.org/0000-0002-5844-3213
Gultekin Karakus http://orcid.org/0000-0002-0705-8243
Egemen Ersin http://orcid.org/0000-0003-4555-0869
Alara Karabiber http://orcid.org/0000-0002-0653-4121

REFERENCES

1. Carpentier A, Loulmet D, Aupècle B, et al. Chirurgie à coeur ouvert assistée par ordinateur. Premier cas opéré avec succès [Computer assisted open heart surgery. First case operated on with success]. *C R Acad Sci III*. 1998;321(5):437-442. https://doi.org/10.1016/s0764-4469(98)80309-0
2. Bush B, Nifong LW, Alwair H, Chitwood WR, Jr.Robotic mitral valve surgery-current status and future directions. *Ann Cardiothorac Surg*. 2013;2(6):814-817. https://doi.org/10.3978/j.issn.2225-319X.2013.10.04
3. Rodriguez E, Nifong LW, Bonatti J, et al. Pathway for surgeons and programs to establish and maintain a successful robot-assisted adult cardiac surgery program. *J Thorac Cardiovasc Surg*. 2016;152(1):9-13. https://doi.org/10.1016/j.jtcvs.2016.05.018
4. Senay S, Gullu AU, Kocyigit M, Degirmencioglu A, Karabulut H, Alhan C. Robotic mitral valve replacement. *Multimed Man Cardiothorac Surg*. 2014;2014:mmu016. https://doi.org/10.1093/mmcts/mmu016
5. Gullu AU, Senay S, Kocyigit M, Alhan C. A simple method for occlusion of both venae cavae in total cardiopulmonary bypass for robotic surgery. *Interact Cardiovasc Thorac Surg*. 2012;14(2):138-139. https://doi.org/10.1093/icvts/ivr057
6. Bonaros N, Schachner T, Oehlinger A, et al. Robotically assisted totally endoscopic atrial septal defect repair: insights from operative times, learning curves, and clinical outcome. *Ann Thorac Surg*. 2006;82(2):687-693. https://doi.org/10.1016/j.athoracsur.2006.03.024
7. Kesävuori R, Raivio P, Jokinen JJ, Sahlman A, Teittinen K, Vento A. Early experience with robotic mitral valve repair with intra-aortic occlusion. *J Thorac Cardiovasc Surg*. 2018;155(4):1463-1471. https://doi.org/10.1016/j.jtcvs.2017.10.076
8. Perier P, Hohenberger W, Lakew F, Diegeler A. Prolapse of the posterior leaflet: resect or respect. *Ann Cardiothorac Surg*. 2015;4(3):273-277. https://doi.org/10.3978/j.issn.2225-319X.2014.11.16
9. Jouan J. Mitral valve repair over five decades. *Ann Cardiothorac Surg*. 2015;4(4):322-334. https://doi.org/10.3978/j.issn.2225-319X.2015.01.07

How to cite this article: Güllü AÜ, Senay S, Kocyigit M, et al. An analysis of the learning curve for robotic-assisted mitral valve repair. *J Card Surg*. 2021;36:624–628. https://doi.org/10.1111/jocs.15281