Featured Article

Outcomes of robotic and endoscopic combined aortic and mitral valve surgery: experience from National Taiwan University Hospital

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Background: Minimally invasive approaches in cardiac surgery have transformed the field by reducing surgical trauma and improving recovery outcomes. The lateral approach, using robotic and endoscopic technologies, offers superior visualization for complex procedures, such as combined aortic and mitral valve surgery. Addressing concurrent pathologies in the aortic and mitral valves increases procedural complexity, requiring precise techniques and optimal patient selection.

Methods: This retrospective, single-center study evaluated adult patients who underwent robotic or endoscopic combined aortic and mitral valve surgery between January 2015 and November 2024. Data on patient demographics, perioperative details, and postoperative outcomes including complications, mortality rates, and improvements in New York Heart Association (NYHA) functional status were analyzed.

Results: A total of 67 patients were included, with 8 undergoing robotic and 59 endoscopic procedures. No mortality or conversion to open surgery was observed. Postoperative complications were minimal, with a low infection rate of 1.5% and an atrial fibrillation rate of 26.8%. Over 85% of patients experienced significant improvement in NYHA functional status.

Conclusions: Robotic and endoscopic combined aortic and mitral valve surgery using the lateral approach is safe and effective, yielding excellent outcomes in a well-selected patient population.

Keywords: Robotic valve surgery; endoscopic cardiac surgery; combined aortic and mitral valve surgery; minimally invasive cardiac surgery; lateral approach

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Introduction

Minimally invasive approaches in cardiac surgery have revolutionized the field by reducing surgical trauma, improving recovery times, and enhancing cosmetic outcomes compared to traditional sternotomy. Among these advancements, the lateral approach, facilitated by robotic and endoscopic technologies, has emerged as a leading technique. This approach offers superior visualization of the aortic and mitral valves, ensuring precision in surgical procedures. The use of high-definition endoscopic imaging allows for enhanced clarity, while the lateral thoracotomy provides direct access to the cardiac structures without the need for extensive disruption to surrounding tissues (1-3).

While robotic and endoscopic techniques are well established for single-valve procedures, particularly for mitral or aortic valve surgeries (1-6), combined aortic and mitral valve surgery introduces additional complexity. The need to address pathologies in both the aortic and mitral valves during a single procedure requires meticulous planning, enhanced technical precision, and an optimal surgical approach. Double valve surgery demands precise synchronization of procedural steps to avoid prolonged cardiopulmonary bypass (CPB) times and minimize the risk of complications. Furthermore, the proximity of the valves and their interrelated functional dynamics necessitate exceptional visualization and surgical dexterity (6-8).

Robotic systems are particularly advantageous in this setting, offering unmatched endoscopic visualization and the multidirectional wrist function of robotic instruments. These features enable surgeons to navigate complex anatomies and perform intricate repairs or replacements with exceptional accuracy (7-10). In double valve surgeries, where simultaneous interventions on the aortic and mitral valves are required, the robotic platform enhances dexterity and minimizes limitations traditionally associated with minimally invasive approaches (8,11).

This study evaluates the outcomes of robotic and endoscopic combined aortic and mitral valve surgery at National Taiwan University Hospital (NTUH). Emphasis is placed on the benefits of the lateral approach, the critical role of patient selection, and the unique advantages provided by robotic systems in managing the increased complexity of double valve procedures.

Methods

Ethics statement and study design

This observational, single-center, retrospective study was approved by the Institutional Review Board and adhered to the ethical principles of the 1964 Declaration of Helsinki and its subsequent amendments. The Institutional Review Board waived the need for informed consent owing to the retrospective nature of the study (IRB NTUH 202012072RIND, 202401213RINC).

Study population

This study involved patients who underwent robotic or endoscopic combined aortic and mitral valve surgery at NTUH from January 2015 to November 2024. The inclusion criteria were adult patients (aged 18 years and older) diagnosed with concurrent aortic and mitral valve diseases requiring surgical intervention. The surgeries were performed using robotic or endoscopic equipment, adhering to the protocols established by the cardiovascular surgery department at NTUH. The surgical team comprised experienced surgeons, anesthesiologists, and perioperative nursing staff, all specialized in minimally invasive cardiac procedures. Data from the surgeries, including operative details, perioperative care, and postoperative outcomes, were collected from the hospital's electronic health records system.

Patient selection

Adult patients aged 18 years and older who were diagnosed with concurrent aortic and mitral valve diseases requiring surgical intervention were included in this study. Exclusion criteria were strictly adhered to in order to mitigate surgical risks and complications. Patients with any evidence of thoracic adhesions were excluded to ensure unimpeded access for robotic or endoscopic instruments. Additionally, individuals with peripheral artery occlusive disease, which could complicate CPB, were not considered suitable for inclusion. The definition of an inoperable situation due to peripheral artery disease was based on preoperative imaging. If the screening computed tomography (CT) scan revealed heavy calcification of the aortoiliac vessels and vascular duplex ultrasound demonstrated a monophasic waveform in the femoral arteries, the patient was deemed unsuitable for peripheral cannulation and subsequently excluded from minimally invasive surgery. Severe aortic calcification necessitating aortic root enlargement procedures and severe heart failure [left ventricular ejection fraction (LVEF) <40%] were also grounds for exclusion. Moreover, patients requiring emergency surgery were excluded to maintain the study's focus on elective procedures. The aim was to select patients who were ideal candidates for minimally invasive combined aortic and mitral valve surgery, devoid of complicating factors commonly encountered in our practice. Those excluded from the study were typically managed through conventional sternotomy.

Robotic setting (*Figure 1A*)

The setting for the robotic surgery was the same as that reported previously for mitral valve surgery. After general anesthesia was administered via a single-lumen endotracheal tube, the patient was positioned supine with the right chest elevated. A 3-cm working port, safeguarded by a soft-tissue protector, was created in the fourth intercostal space around the right anterior axillary line. The third and sixth intercostal spaces served as sites for insertion of the left and right robotic arm ports, respectively. The atrial retractor was positioned in the fourth intercostal space, while the camera port was situated just above the working port and the sub-working port to vent below it.

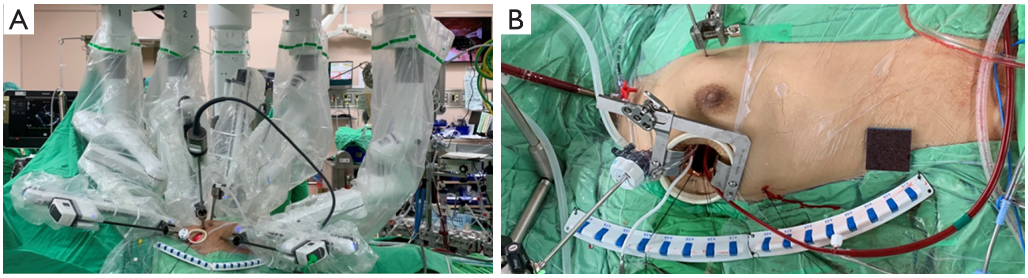

Figure 1 Surgery set-up. (A) The robotic setup demonstrates the placement of the working port, robotic arm ports, and camera port. The patient is positioned supine with the right chest elevated, and the ports are arranged to optimize access to the aortic and mitral valves via the lateral thoracic approach. (B) The endoscopic setup illustrates the arrangement of the working port and camera port in the right anterior thoracic space, with patient positioning and anesthesia protocols similar to the robotic setup. This configuration facilitates minimally invasive access for combined aortic and mitral valve surgeries.

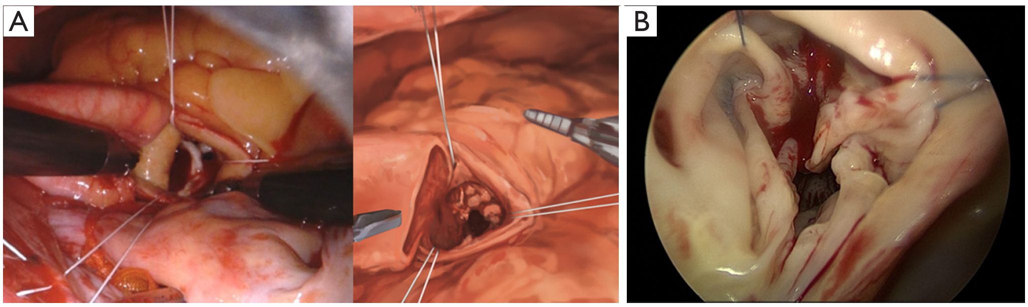

Figure 2 Aortic valve exposure using traction sutures. (A) The robotic approach. (B) Endoscopic approach. The three-suture traction technique optimizes exposure for aortic valve surgery. Upward traction: a suture placed at the left-right commissure is directed upward and secured to the upper pericardium. Rightward traction: a suture at the right-noncoronary commissure is pulled towards the diaphragm, improving lateral exposure. Downward traction: a suture at the left-noncoronary commissure is directed downward toward the working port.

Endoscopic setting (*Figure 1B*)

Patient positioning and anesthesia protocols for the endoscopic approach mirrored those used in the robotic platform. The incision was made over the fourth intercostal space around the right anterior axillary line. The camera port was positioned in the second or third intercostal space, employing a 5-mm, 30-degree endoscopic camera.

CPB setting

Two suture-mediated closure system devices (ProGlide™; Abbott, North Chicago, IL, USA) were used for right common femoral arterial cannulation. Venous cannulations were performed in the right jugular and right femoral veins under transesophageal echocardiographic guidance. After heparin administration, CPB was initiated, and the patient's cart was docked. After the pericardium was opened, a long-shaft cardioplegic needle was used on the aortic root, and a detachable aortic clamper (Glauber clamp; Cardio Medical GmbH, Langenhagen, Germany) was inserted through the working port into the thoracic cage. Antegrade cardioplegia (St. Thomas Hospital No. 2, HTK, and adenosine) was administered.

Aortic valve exposure method (*Figure 2*)

The aortic valve exposure is primarily achieved through the strategic placement of three traction sutures, each designed to optimize visibility and accessibility during surgery.

(I) *Upward traction*: The suture at the left-right commissure is secured to the upper part of the pericardium and directed upward. This positioning elevates the valve, enhancing the surgeon's view

Table 1 Patient's characteristics

Characteristics	Total (n=67)	Robotic double valve (n=8)	Endoscopic double valve (n=59)
Age (years)	63.9±8.9	63.2±6.8	64.1±9.2
Male	36 (53.7)	3 (37.5)	33 (55.9)
Female	31 (46.3)	5 (62.5)	26 (44.1)
BSA (m^2)	1.72±0.20	1.69±0.13	2.1±0.16
CAD	4 (6.0)	1 (12.5)	3 (5.1)
CKD	7 (10.4)	1 (12.5)	6 (10.2)
NYHA class			
I–II	49 (73.1)	6 (75.0)	43 (72.9)
III–IV	18 (26.9)	2 (25.0)	16 (27.1)
Stroke history	11 (16.4)	2 (25.0)	9 (15.3)
Peripheral vascular disease (mild)	8 (11.9)	0 (0.0)	8 (13.6)
Chronic lung disease	4 (6.0)	0 (0.0)	4 (6.8)
Current smokers	13 (19.4)	2 (25.0)	11 (18.6)
Preoperative beta blockers	32 (47.8)	3 (37.5)	29 (49.2)
Preoperative anticoagulation	30 (44.8)	3 (37.5)	27 (45.8)
LVEF <50%	9 (13.4)	0 (0.0)	9 (15.3)
Euroscore II	8.0±3.9	8.2±4.8	8.0±3.8

Data are expressed as mean ± standard deviation or number (%). BSA, body surface area; CAD, coronary artery disease; CKD, chronic kidney disease; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association.

of the superior aspects and facilitating precise interventions.

(II) *Rightward traction*: Positioned at the right-noncoronary commissure, this suture is pulled rightward toward the diaphragm. The lateral traction effectively aligns the valve horizontally, broadening the surgical field laterally and improving access to the lateral components of the valve structure.

(III) *Downward traction*: The third suture, attached to the left-noncoronary commissure, is directed downward towards the working port. This downward force opens the lower part of the valve, ensuring the inferior aspects are well exposed.

The careful arrangement of these sutures is crucial for fully opening the aortic root and valve, thereby presenting them prominently within the surgeon's field of view and to the operating camera. This method not only enhances the visibility of the valve structures but also facilitates a safer and more effective surgical procedure by allowing precise manipulation of the valve components.

Results

Patient demographics and baseline characteristics (*Table 1*)

A total of 67 patients underwent combined aortic and mitral valve surgery, with 8 receiving the robotic approach and 59 undergoing the endoscopic approach. The average age of the participants was 63.9±8.9 years. Those in the robotic group were 63.2±6.8 years on average compared to those in the endoscopic group 64.1±9.2 years). The cohort consisted of 46.3% females and 53.7% males.

The prevalence of coronary artery disease (CAD) was low across the cohort, affecting 6.0% of all patients, with all cases being non-significant in terms of surgical impact. Chronic kidney disease (CKD) was observed in 11.9% of

Table 2 Aortic valve and mitral procedures

Procedures	Biological valve	Mechanical valve
Aortic valve procedures	52 (77.6%)	15 (22.4%)
Intuity Elite	10	
Perceval	8	
Others	34	
Size distribution		
19 mm	3	2
21 mm	6	8
23 mm	26	5
25 mm	17	0
Mitral valve procedures	34 (50.7%)	22 (32.8%)
Size distribution		
27 mm	12	5
29 mm	17	11
31 mm	5	6

Data are expressed as number (%) or number.

the total patient population, with a similar incidence in the robotic group (12.5%). The majority of patients were classified as New York Heart Association (NYHA) class II (73.1%).

A history of stroke was noted in 16.4% of total patients, and 25.0% in robotic group. Mild peripheral vascular disease was exclusively noted in 13.6% of the endoscopic patients. Mild chronic lung disease was present in 6.0% of the total cohort, with no cases reported in the robotic group. The average body surface area was consistently 1.72±0.20 m^2 across both groups.

Preoperative use of beta blockers (47.8%) and anticoagulation (44.8%) was common. A low percentage (13.4%) of patients had a LVEF below 50%. The average Euroscore II was 8.0±3.9, categorizing the patient group as non-high risk for adverse cardiac events.

Surgical valve details (*Table 2*, Figure S1A-S1C)

For the aortic valve replacements, biological valves were predominantly used, accounting for 78% of the procedures, with specific models including Perceval (Corcym, Burnady, Canada) (11.9%) and Intuity Elite (Edwards Lifesciences, Irvine, USA) (14.9%) (Figure S1A,S1B).

Mitral valve interventions were equally divided between replacements and repairs. Mitral valve replacement predominantly utilized biological valves (50.7%), with mechanical valves used in 32.8% of patients undergoing mitral valve replacement. For mitral valve repairs, the majority (54.5%) involved the annuloplasty ring only, while 24.2% included artificial chordae, and 21.2% involved commissure closure (Figure S1C).

Postoperative outcomes (*Table 3*)

The outcomes were successful with a mortality rate of 0% and no instances of conversion to open surgery. The operative time varied slightly between techniques; the average for all surgeries was 296±102 minutes, with robotic surgeries averaging slightly longer at 302±108 minutes compared to 288±100 minutes for endoscopic procedures.

The CPB time was consistent across procedures, lasting an average of 199±28 minutes. The duration of aortic cross-clamping averaged 151±22 minutes, with robotic procedures exhibiting marginally longer durations of 155±23 minutes.

Postoperative ventilation was an average of 4.7±2.2 hours. Intensive care unit (ICU) stays were averaging 1.92±1.14 days, with robotic patients experiencing slightly longer stays at 2.14±1.05 days. The infection rate was notably low at 1.5%, and the incidence of postoperative atrial fibrillation was 26.8%. The average hospital stay was 10.0±2.7 days. Importantly, there was significant improvement in NYHA functional status post-surgery, with over 85% of patients showing improvement (*Figure 3*).

Discussion

Principal findings

This study highlights the effectiveness and safety of robotic and endoscopic combined aortic and mitral valve surgeries, marked by zero mortality and conversion rates. Key to these outcomes was the rigorous patient selection process, which ensured that only candidates suitable for minimally invasive approaches were chosen. These findings align with those of Rao *et al.* (2022) (2), who reported similar outcomes in robotic mitral valve surgeries. The results also parallel the experiences documented by Chou *et al.* (2022) (4), highlighting the efficacy of robotic systems in achieving significant improvements in functional status.

Average operative times were manageable at 296±102 minutes, with comparable CPB and aortic cross-clamp

Table 3 Perioperative outcomes

Parameter	Total patients	Robotic procedures	Endoscopic procedures
Mortality	0 (0.0)	0 (0.0)	0 (0.0)
Conversion	0 (0.0)	0 (0.0)	0 (0.0)
Operative time (min)	296±102	302±108	288±100
Cardiopulmonary bypass time (min)	199±28	194±28	199±28
Cross clamp time (min)	151±22	155±23	150±22
Ventilation time (h)	4.7±2.2	5.6±2.3	4.7±2.3
Infection	1 (1.5)	0 (0.0)	1 (1.7)
Post-op atrial fibrillation	18 (26.9)	3 (37.5)	15 (25.4)
ICU stay (days)	1.9±1.1	2.1±1.0	1.9±1.1
Hospital stay (days)	10.0±2.7	12.3±1.9	9.6±2.6
Post-op NYHA	1.5±0.7	1.6±0.9	1.5±0.7

Data are expressed as mean ± standard deviation or number (%). ICU, intensive care unit; NYHA, New York Heart Association.

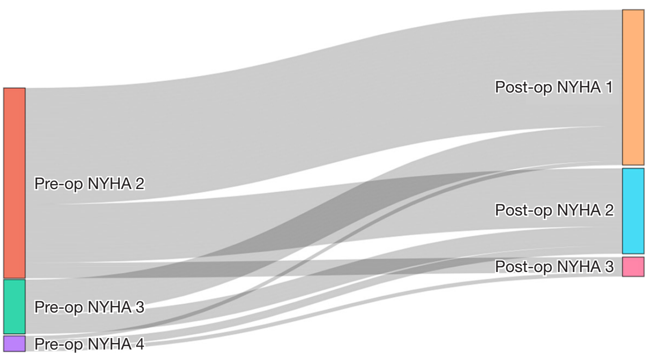

Figure 3 NYHA Sankey diagram. This diagram visually represents the transitions in NYHA functional class for patients following robotic and endoscopic double valve surgery. Each pathway's width corresponds to the number of patients experiencing that transition, emphasizing the improvement or consistency in functional outcomes postoperatively. NYHA, New York Heart Association.

durations across both surgical techniques. These stringent criteria contributed to excellent outcomes, including over 85% of patients achieving significant improvements in NYHA functional status, reflecting enhanced mobility and quality of life post-surgery. The low complication rates, with an infection rate of just 1.5% and one minor bleeding incident, further underscore the procedural safety and efficacy (7,10).

The longer hospital stay observed in this study compared to reports from Western countries can be attributed to differences in healthcare systems. In Taiwan, the government-funded medical insurance system provides comprehensive coverage for hospitalization costs. This allows patients to remain in the hospital until they feel fully recovered and comfortable returning home without incurring additional financial burdens. Consequently, patients tend to stay longer for continued observation and rehabilitation, ensuring satisfaction and confidence in their recovery before discharge.

Among the 15% of patients who did not show improvement in NYHA functional class, the majority were in Class II preoperatively and remained in Class II after surgery. However, six patients experienced a decline from Class II to Class III. Notably, all of these patients were octogenarians with multiple pre-existing comorbidities, such as CKD, pulmonary hypertension, or impaired mobility. This subgroup may have had limited physiological reserve and reduced capacity for postoperative rehabilitation, contributing to their lack of improvement or functional deterioration. The combination of advanced age and baseline functional limitations likely played a significant role in their outcomes. These findings underscore the importance of careful patient selection and the need for tailored perioperative care strategies in elderly, comorbidity-burdened individuals undergoing complex valve surgery.

Integration of robotic and endoscopic views with traction suture techniques

The superior visualization provided by the lateral approach was critically enhanced by the use of both robotic and endoscopic scopes, which offered distinct visual advantages. The robotic scope's high-definition, three-dimensional imaging capabilities were particularly beneficial for precise aortic valve exposure (3,6), while the endoscopic scope offered flexibility and efficient access in the constrained surgical field (1). Combined with the strategic placement of traction sutures to position the aortic valve—upward, rightward, and downward—this approach allowed unobstructed visualization and access, enabling accurate surgical repairs and replacements.

Additionally, the matured positioning of the mitral valve in the lateral approach facilitated precise interventions, contributing to consistently positive outcomes. These findings support the conclusions of Wong *et al.* (2022) (3) and Hosoba *et al.* (2022) (1), who emphasized the importance of combining advanced imaging with refined surgical techniques.

Non-high risk patient selection

The success of these surgeries was closely tied to rigorous patient selection. Patients with conditions that elevated surgical risks, such as thoracic adhesions, severe aortic calcification, poor lung function, or moderate-to-severe peripheral artery occlusive disease, were excluded. Similarly, those requiring aortic root enlargement, presenting with severe CAD, or undergoing emergency surgeries were not included. This approach ensured that the study cohort primarily comprised non-high-risk patients, reflected by an average Euroscore II of 8.0±3.9. These criteria directly contributed to the observed outcomes, including zero mortality, no conversions, and significant functional recovery in over 85% of patients.

Robotic *vs.* endoscopic techniques

Robotic and endoscopic techniques offered unique advantages while achieving comparable clinical outcomes. Robotic surgeries provided superior three-dimensional visualization and enhanced dexterity, which were particularly advantageous in anatomically complex cases (7,8,10). However, they required longer operative times, averaging 302.3±108.4 minutes, compared to 288.57±100.1 minutes for endoscopic procedures (6,8). In contrast, the simpler setup and shorter durations of endoscopic techniques made them more time-efficient (1,11).

Both approaches resulted in low infection rates, similar incidences of postoperative atrial fibrillation, and significant improvements in NYHA class for the majority of patients, highlighting their effectiveness in suitable patient populations (2,6,7).

Multidisciplinary team

The success of these surgeries was heavily reliant on a skilled multidisciplinary team. Seamless collaboration among cardiac surgeons, anesthesiologists, perfusionists, and nursing staff was essential to ensure procedural efficiency, minimize complications, and stabilize outcomes. This teamwork was particularly crucial in managing the complexities inherent to robotic and endoscopic double valve surgeries.

Challenges and limitations of the lateral approach

Despite its advantages, the lateral approach has notable limitations. Anatomical challenges, such as heavily calcified aortic valves or very small aortic roots, can complicate exposure and manipulation, even with advanced tools (8). Furthermore, robotic systems demand substantial institutional investment and involve a significant learning curve, as emphasized by Badhwar *et al.* (2024) (12). These challenges highlight the importance of carefully selecting centers with adequate experience and resources to ensure successful implementation (13).

Future directions

Future studies should focus on expanding the sample size and exploring outcomes in patients with higher surgical risks or more complex conditions, such as those requiring emergency procedures. Multi-center collaborations will be critical to validate these findings and assess the broader applicability of robotic and endoscopic techniques. Additionally, the development of more accessible robotic systems and comprehensive training programs could facilitate wider adoption of these advanced surgical methods, ultimately improving patient outcomes

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Footnote

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