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Clinical Experience of Robot-Assisted Minimally Invasive Cardiac Surgery and Perioperative Management in Patients with Structural Heart Disease: A Single-Center Case Series

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Abstract: This study aimed to summarize the clinical experience and evaluate the feasibility, perioperative management, and early outcomes of robot-assisted minimally invasive cardiac surgery in patients with structural heart disease. In this retrospective single-center case series, ten consecutive patients (six women and four men; median age 47.5 years, range 23–58 years) with structural heart disease—including mitral valve disease (n=7), tricuspid valve disease (n=1), atrial or atrioventricular septal defect (n=2), and mixed valvular disease—underwent robot-assisted thoracoscopic cardiac surgery between March and April 2026. All procedures were successfully completed under cardiopulmonary bypass without conversion to median sternotomy; notably, one operation was performed as a cross-border remote live-broadcast surgery between Guangzhou and Chinese Macau. Surgical procedures comprised mitral valve replacement or repair, tricuspid valve repair, atrial septal defect repair, atrioventricular septal defect repair, and patent foramen ovale closure. No perioperative mortality occurred. All patients required postoperative mechanical ventilation and vasoactive support, while two patients (20%) required intra-aortic balloon pump support due to low cardiac output syndrome. Postoperative inflammatory responses and electrolyte disturbances were observed in all patients, and coagulation dysfunction and hematologic abnormalities were also common. Several high-risk patients developed postoperative complications, including infection, hepatic dysfunction, pleural complications, and prolonged intensive care unit stay; nevertheless, all patients survived to discharge or showed clinical improvement during hospitalization. Follow-up echocardiography demonstrated satisfactory valve function and successful defect closure in most patients. In conclusion, robot-assisted minimally invasive cardiac surgery is feasible and safe in selected patients with structural heart disease, including those with complex valvular and congenital lesions, and favorable short-term outcomes can be achieved with comprehensive perioperative management, although postoperative systemic complications remain relatively common in high-risk patients.

1. Introduction

Structural heart diseases, including valvular heart disease and congenital cardiac defects, remain a major cause of morbidity worldwide and often require surgical intervention when symptoms progress or cardiac function deteriorates [1]. Conventional cardiac surgery via median sternotomy has long been the standard approach; however, it is associated with substantial surgical trauma, prolonged recovery, and potential complications, particularly in patients with advanced cardiac dysfunction or multiple comorbidities [2].

In recent years, minimally invasive cardiac surgery has been increasingly adopted as an alternative to conventional approaches, aiming to reduce surgical trauma and improve postoperative recovery [2]. Among these techniques, robot-assisted cardiac surgery has emerged as an advanced modality that offers enhanced visualization, improved instrument dexterity, and greater precision in complex intracardiac procedures [3]. Previous studies have demonstrated that robot-assisted approaches can achieve comparable surgical outcomes to traditional surgery while potentially providing benefits such as reduced blood loss, shorter hospital stay, and faster recovery [4].

Despite these advantages, the application of robot-assisted cardiac surgery in patients with heterogeneous structural heart diseases remains challenging. These patients often present with varying degrees of cardiac dysfunction, hemodynamic instability, and systemic complications, which may increase perioperative risk [5]. Furthermore, while the technical feasibility of robotic cardiac surgery has been increasingly reported, real-world clinical experience—particularly regarding perioperative management and short-term outcomes in small, heterogeneous patient populations—remains limited [4].

Effective perioperative management is critical to optimizing outcomes in this setting. Factors such as hemodynamic support, anticoagulation management, infection control, and correction of metabolic disturbances play essential roles in postoperative recovery, especially in patients undergoing complex valve procedures or presenting with heart failure [2,4]. However, detailed descriptions of perioperative management strategies in the context of robot-assisted cardiac surgery are still relatively scarce in the literature [6].

Therefore, the present study aims to summarize our single-center clinical experience with robot-assisted minimally invasive cardiac surgery in patients with structural heart disease. We focus on procedural feasibility, perioperative management, and early clinical outcomes, with the goal of providing practical insights into the application of this technique in real-world clinical practice.

2. Methods

2.1 Study Design

This study was designed as a retrospective, single-center clinical experience study to evaluate the feasibility, perioperative management, safety, and early outcomes of robot-assisted minimally invasive cardiac surgery in patients with structural heart disease. Institutional approval was obtained in accordance with local ethical standards, and the requirement for informed consent was waived due to the retrospective nature of the study.

2.2 Participant Inclusion Process

Patients were consecutively screened from the institutional cardiac surgery database between March and April 2026. Individuals who underwent robot-assisted thoracoscopic cardiac surgery during this period were assessed for eligibility. A total of ten patients who met the inclusion criteria were included in the final analysis. All patients underwent standardized preoperative assessment, intraoperative management, and postoperative intensive care according to institutional protocols.

2.3 Inclusion and Exclusion Criteria

Patients were included if they met the following criteria: (1) diagnosis of structural heart disease requiring surgical intervention, including valvular heart disease or congenital cardiac defects; (2) underwent robot-assisted minimally invasive cardiac surgery under cardiopulmonary bypass; and (3) availability of essential clinical, operative, and perioperative data.

Patients were excluded if they: (1) underwent conventional median sternotomy; (2) had incomplete key clinical data precluding outcome assessment; or (3) required emergency surgery without standard perioperative evaluation.

2.4 Data Collection

Clinical data were retrospectively collected from electronic medical records. Baseline variables included age, sex, primary diagnosis, presenting symptoms, New York Heart Association (NYHA) functional class, atrial fibrillation, pulmonary hypertension, pleural effusion, natriuretic peptide levels, and major comorbidities.

Operative variables included type of robotic procedure, use of cardiopulmonary bypass, intraoperative findings, need for repeat valve repair or intraoperative correction, and requirement for intra-aortic balloon pump (IABP) support.

Perioperative variables included postoperative mechanical ventilation, vasoactive support, inflammatory response, infection, coagulation dysfunction, hematologic abnormalities, electrolyte imbalance, hepatic dysfunction, pleural complications, intensive care unit (ICU) stay, and postoperative length of hospitalization.

Postoperative outcomes included in-hospital mortality, postoperative echocardiographic findings, and clinical status at discharge.

Missing data were reported as “not available,” and no data imputation was performed.

2.5 Statistical Analysis

Given the limited sample size, statistical analysis was primarily descriptive. Continuous variables were summarized as median with range, while categorical variables were expressed as counts and percentages. No inferential statistical analyses were performed.

3. Results

3.1 Patient Characteristics

A total of ten patients were included in this study, comprising six women and four men, with a median age of 47.5 years (range: 23–58 years). Baseline characteristics are summarized in Table 1.

The primary diagnoses included rheumatic mitral stenosis (n = 2), severe mitral regurgitation or mitral valve prolapse (n = 5), severe tricuspid regurgitation (n = 1), atrial septal defect (n = 1), and atrioventricular septal defect (n = 1). At presentation, the most common symptoms were dyspnea or chest tightness (n = 7, 70%), edema or abdominal distension (n = 3, 30%), palpitations (n = 2, 20%), chest pain (n = 1, 10%), and chronic cough (n = 1, 10%).

Four patients (40%) were classified as NYHA class III, one patient (10%) had NYHA class IV heart failure, and one patient presented with borderline class II–III symptoms. Atrial fibrillation or atrial flutter was present in four patients (40%). Pulmonary hypertension was documented in eight patients (80%). Pleural effusion was identified in five patients (50%). Elevated BNP or NT-proBNP levels were observed in most patients, indicating increased cardiac burden.

Table 1. Baseline Characteristics of the Patients

Variable	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6	Patient 7	Patient 8	Patient 9	Patient 10
Age (years)	41	56	56	36	44	29	51	56	58	23
Sex	Female	Male	Female	Female	Female	Female	Female	Male	Male	Male
Primary diagnosis	Rheumatic mitral stenosis	Severe MR with chordal rupture	Severe MR	Severe TR	ASD	AVSD/ASD	Rheumatic mitral stenosis	MVP with severe MR	MVP with severe MR	MVP
NYHA class	II	III	IV	III	II	II	II–III	III	III	II
Main symptoms	Cough	Dyspnea, edema	Acute heart failure	Edema, abdominal distension	Chest pain, dyspnea	Chest tightness	Palpitations, chest tightness	Palpitations, dyspnea	Chest tightness, dyspnea	Chest tightness
Atrial fibrillation/ flutter	No	Yes	Yes	No	No	No	Yes	Yes	No	No
Pulmonary hypertension	Mild–moderate	Moderate–severe	Not specified	Mild	Moderate	Mild	Mild	Moderate	Mild	No
Pleural effusion	No	Yes	Yes	Yes	No	No	Right pleural effusion	Yes	Right pleural effusion	No
BNP / NT-proBNP elevation	Not reported	Yes	Yes	Yes	Yes	Not reported	Not reported	Yes	Yes	Not reported
Major comorbidities	Rheumatic heart disease	CAD, renal insufficiency, diabetes	Pneumonia	History of thymoma	Hypertension, cerebral artery stenosis	Liver dysfunction	Gallstones	Orthopedic implants	Coronary atherosclerosis	Previous sympathectomy

Comorbidities included coronary artery disease, renal insufficiency, diabetes mellitus, pneumonia, hypertension, liver dysfunction, previous thymoma, cerebral artery stenosis, and prior orthopedic surgery.

3.2 Surgical Procedures

All patients underwent robot-assisted thoracoscopic cardiac surgery under general anesthesia with cardiopulmonary bypass (Table 2). Surgical procedures included mitral valve replacement (n = 4), mitral valve repair (n = 5), tricuspid valve repair (n = 8), atrial septal defect repair (n = 1), atrioventricular septal defect repair (n = 1), and patent foramen ovale closure (n = 1).

All procedures were successfully completed without conversion to median sternotomy. Intraoperative findings were generally consistent with preoperative imaging assessments. Two patients required additional intraoperative valve correction or repeat repair because of residual regurgitation identified on transesophageal echocardiography. Two patients developed postoperative low cardiac output syndrome requiring intra-aortic balloon pump (IABP) support.

One patient underwent emergency postoperative re-exploration because of increased thoracic drainage caused by chest wall bleeding, which was successfully controlled without major sequelae.

Table 2. Surgical Procedures and Perioperative Outcomes

Variable	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6	Patient 7	Patient 8	Patient 9	Patient 10
Procedure	MVR + TV repair	MVR + TV repair + PFO closure	MV repair + TV repair	MV repair + TV repair	ASD repair + TV repair	AVSD/ASD repair + MV/TV repair	MVR + TV repair	MVR + TV repair	MV repair	MV repair
Cardiopulmonary bypass	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Conversion to sternotomy	No	No	No	No	No	No	No	No	No	No
Major perioperative complication	Residual regurgitation corrected	None	Repeat repair required	None	None	Re-exploration for bleeding	None	Low cardiac output syndrome	None	None
IABP support	No	No	Yes	No	No	No	No	Yes	No	No
Mechanical ventilation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Vasoactive support	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inflammatory response/ infection	Mild	Moderate	Severe	Mild	Moderate	Moderate	Moderate	Severe	Moderate	Mild
Hematologic abnormality	Mild anemia	Anemia	Anemia + thrombocytopenia	Mild	Mild anemia	Postoperative bleeding/anemia	Mild anemia	Severe coagulopathy/anemia	Severe anemia	Mild
Coagulation dysfunction	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Mild
Electrolyte imbalance	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Mild
ICU stay	Not specified	Not specified	Prolonged	Short	Short	Prolonged	Short	Prolonged	Short	Ongoing
Length of stay (days)	20	12	18	17	17	20	25	15	15	Ongoing
Mortality	No	No	No	No	No	No	No	No	No	No
Outcome at discharge	Good	Improved	Stabilized	Good	Good	Improved	Good	Improving	Good	Recovering

3.3 Perioperative Outcomes

All patients required postoperative ICU admission, mechanical ventilation, and vasoactive drug support in the early postoperative period. Two patients (20%) required IABP support because of impaired cardiac function after surgery.

Postoperative inflammatory activation or transient inflammatory marker elevation was commonly observed. Several patients developed postoperative infection or significant inflammatory responses, with elevated white blood cell counts, C-reactive protein, and procalcitonin levels. Hematologic abnormalities, including anemia and thrombocytopenia, occurred frequently, particularly in critically ill patients. Coagulation dysfunction was observed in most patients and required dynamic adjustment of anticoagulation therapy.

Electrolyte imbalance was common after surgery and included hypokalemia, hypocalcemia, hypernatremia, and acid–base disturbances. Some patients also experienced postoperative liver dysfunction, pleural effusion, pneumothorax, pulmonary infiltrates, or subcutaneous emphysema.

One patient required prolonged intensive care management because of severe infection, respiratory complications, coagulation dysfunction, and persistent hemodynamic instability. Nevertheless, inflammatory markers and cardiac function gradually improved with comprehensive treatment.

No perioperative mortality, conversion to sternotomy, or catastrophic surgical failure occurred, although several patients experienced major postoperative complications requiring intensive management.

3.4 Postoperative Recovery and Outcomes

The postoperative length of hospital stay ranged from 12 to 25 days in patients with available data. Most patients demonstrated progressive improvement in cardiac symptoms and hemodynamic status during hospitalization. One patient remained hospitalized at the time of data cutoff and was reported according to the latest available clinical records.

Follow-up echocardiography showed satisfactory prosthetic valve function, successful valve repair, or complete closure of congenital defects without significant residual abnormalities in most cases. Patients receiving mechanical valve replacement were discharged with long-term anticoagulation therapy and regular INR monitoring recommendations.

At discharge or latest available inpatient assessment, most patients demonstrated good or improving clinical status. Two patients remained hospitalized at the time of data cutoff but showed gradual clinical improvement. No perioperative mortality occurred in this cohort.

4. Discussion

In this study, we summarized our single-center clinical experience with robot-assisted minimally invasive cardiac surgery in ten patients with heterogeneous structural heart diseases, including complex valvular lesions and congenital cardiac defects. Despite the diversity and complexity of the cases, all procedures were successfully completed without conversion to median sternotomy, and no perioperative mortality occurred. These findings support the technical feasibility and short-term safety of robot-assisted cardiac surgery in carefully selected patients.

From a technical perspective, the robotic platform enabled the successful completion of a broad range of intracardiac procedures, including mitral valve replacement and repair, tricuspid valve repair, atrial septal defect repair, atrioventricular septal defect repair, and patent foramen ovale closure. The absence of conversion to sternotomy in all cases is consistent with previous studies demonstrating the reliability, precision, and stability of robotic systems in structural cardiac surgery [7,8]. Intraoperative transesophageal echocardiography also played a critical role in surgical quality control. In two patients, residual valvular regurgitation detected intraoperatively prompted immediate repeat repair, ultimately resulting in satisfactory postoperative valve function.

Our findings further highlight the complexity of perioperative management in patients undergoing robotic cardiac surgery. Although minimally invasive approaches may reduce surgical trauma and improve postoperative recovery, substantial postoperative physiological disturbances remained common in our cohort. All patients required postoperative mechanical ventilation and vasoactive support, reflecting both the complexity of the procedures and the severity of the underlying cardiac disease. Inflammatory response, electrolyte disturbances, coagulation dysfunction, and hematologic abnormalities were frequently observed, particularly in patients with severe heart failure or prolonged cardiopulmonary bypass duration [9].

Importantly, two patients developed low cardiac output syndrome requiring intra-aortic balloon pump support. One patient with severe mitral regurgitation and acute heart failure experienced persistent postoperative circulatory instability despite multiple vasoactive agents, whereas another patient developed impaired left ventricular systolic function after valve replacement. Both patients gradually recovered following aggressive hemodynamic support and intensive care management. These findings suggest that robot-assisted cardiac surgery can still be safely implemented in selected high-risk patients when advanced perioperative circulatory support and multidisciplinary critical care are available [10].

Successful implementation of robotic cardiac surgery also depends heavily on the establishment of a dedicated multidisciplinary team. All personnel should undergo standardized robotic surgical training and certification before participating in clinical procedures. The robotic cardiac surgery team should include cardiac surgeons, anesthesiologists, perfusionists, operating room nurses, and intensive care specialists. Close collaboration among team members is essential to ensure procedural safety, optimize operative efficiency, and maximize the advantages of minimally invasive robotic techniques [11].

In addition, operating room safety management is critically important during robotic cardiac surgery. Scrub nurses must be thoroughly familiar with the complete surgical workflow and capable of promptly identifying and resolving intraoperative technical issues or equipment malfunctions. Proper preparation before surgery—including sterile draping of robotic arms, accurate installation of robotic instruments, orderly cable arrangement, and camera white balancing and focusing—is essential for smooth procedural performance. During surgery, nurses and bedside assistants are responsible for establishing trocar ports, coordinating robotic instrument exchange, and continuously monitoring robotic arm stability and patient positioning to minimize the risk of inadvertent tissue injury [12].

The circulating nurse also plays an essential role in perioperative coordination and equipment management. Preoperative inspection of the robotic system, optimization of operating room layout, preparation of specialized consumables, and assistance with patient positioning are all necessary to ensure procedural efficiency and patient safety. Appropriate positioning of the patient, including elevation of the right hemithorax and careful protection of pressure-bearing areas, is particularly important for preventing pressure injury and nerve compression during prolonged procedures [13].

Intraoperatively, dynamic adjustment of imaging brightness, operating table angle, and carbon dioxide insufflation flow is required according to surgical demands. Cardiopulmonary bypass parameters and arterial blood gas results must be closely monitored, while the anesthesia team should carefully regulate body temperature, ventilation, and coagulation status. Moreover, contingency plans for emergency conversion to open surgery should always be established preoperatively. In the event of malignant arrhythmia or major intraoperative hemorrhage, immediate coordination among the bedside assistant, anesthesiologist, and perfusionist is essential to maintain patient stability and ensure uninterrupted cardiopulmonary bypass support [14].

Several patients in this study experienced postoperative complications, reflecting the systemic impact of complex cardiac surgery and cardiopulmonary bypass. Severe infection, pulmonary infiltrates, pleural complications, hepatic dysfunction, coagulation abnormalities, and anemia were observed mainly in critically ill patients. One patient required emergency re-exploration because of postoperative thoracic bleeding, whereas another developed pneumothorax and extensive subcutaneous emphysema requiring thoracic drainage and supportive treatment. Nevertheless, most complications gradually improved following comprehensive multidisciplinary management, including antimicrobial therapy, anticoagulation adjustment, nutritional support, respiratory care, and hemodynamic optimization.

Our results also demonstrate the applicability of robotic approaches in selected congenital structural heart diseases. In addition to adult valvular disease, robotic surgery was successfully performed in patients with atrial septal defect and atrioventricular septal defect. Postoperative echocardiography confirmed satisfactory defect closure and improved valvular function. These findings support the expanding role of robotic cardiac surgery in selected congenital lesions, particularly among younger patients who may benefit from reduced surgical trauma, shorter recovery time, and superior cosmetic outcomes [15].

From a broader perspective, this study reflects the increasing integration of robotic technology into modern cardiac surgery. Enhanced three-dimensional visualization and improved instrument dexterity provided by robotic systems may facilitate more precise intracardiac manipulation while avoiding the trauma associated with conventional median sternotomy [6,7,16]. However, robotic cardiac surgery remains technically demanding and resource-intensive, requiring careful patient selection, substantial surgical expertise, and highly coordinated perioperative management.

Several limitations should be acknowledged. First, this was a retrospective single-center study with a small sample size, limiting statistical analysis and generalizability. Second, the patient population was heterogeneous, including both congenital and acquired structural heart diseases with varying degrees of severity. Third, no control group undergoing conventional sternotomy or thoracoscopic surgery was included for comparison. Fourth, some perioperative variables and long-term follow-up data were incomplete. Finally, the present study primarily focused on early perioperative outcomes; therefore, larger multicenter studies with long-term follow-up are needed to further evaluate durability, quality of life, and long-term survival.

5. Conclusion

Robot-assisted minimally invasive cardiac surgery is a feasible and safe therapeutic approach for selected patients with structural heart disease, including complex valvular lesions and congenital cardiac defects. In this 10-patient single-center experience, all procedures were successfully completed without conversion to sternotomy or perioperative mortality. Favorable short-term outcomes were achieved despite substantial perioperative physiological disturbances and postoperative complications in several high-risk patients. Comprehensive perioperative monitoring and multidisciplinary management remain essential for optimizing recovery and surgical outcomes. Larger prospective studies with longer follow-up are warranted.

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