Technique and early outcomes of total thoracoscopic double-valve replacement

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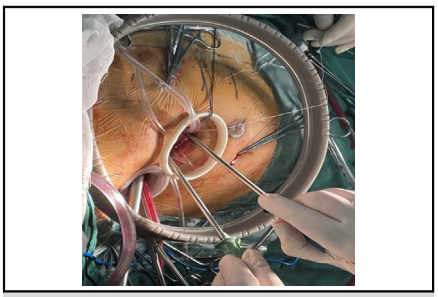
ABSTRACT

Objective: Reports on aortic and mitral double-valve replacement through total thoracoscopy are scarce, with surgical techniques constantly evolving. We aimed to compare the feasibility and safety between total thoracoscopic double-valve replacement and median sternotomy double-valve replacement.

Methods: From November 2021 to March 2023, we performed double-valve replacements in 76 patients using the total thoracoscopic double-valve replacement. The control group comprised 77 patients who underwent median sternotomy double-valve replacement. We analyzed data on baseline characteristics, perioperative events, and early postoperative outcomes.

Results: In the total thoracoscopic double-valve replacement group, the cardiopulmonary bypass and aortic crossclamping times were 174.20 ± 38.87 minutes and 120.20 ± 19.54 minutes, respectively; both were significantly longer compared with those in the median sternotomy double-valve replacement group (cardiopulmonary bypass: 123.65 ± 15.33 minutes; aortic crossclamping: 82.86 ± 9.51 minutes, $P < .001$). The total thoracoscopic double-valve replacement group exhibited an extended operative duration, with a mean of 4.40 ± 0.76 hours, in contrast to 3.21 ± 0.68 hours in the median sternotomy double-valve replacement group ($P < .001$). Postoperatively, the total thoracoscopic double-valve replacement group demonstrated a significantly shorter mechanical ventilation duration (9.29 ± 3.12 hours) and reduced intensive care unit stay time (24.31 ± 7.29 hours) than the median sternotomy double-valve replacement group (11.49 ± 4.27 hours and 26.76 ± 5.89 hours, respectively; P values of .019 and .040, respectively). Furthermore, the total thoracoscopic double-valve replacement group experienced a shorter postoperative hospitalization time, averaging 6.21 ± 1.58 days, than the median sternotomy double-valve replacement group (8.35 ± 1.07 days, $P < .001$). The total thoracoscopic double-valve replacement group also exhibited significantly lower chest drainage volume (average 223.91 ± 53.93 mL) than the median sternotomy double-valve replacement group (382.56 ± 61.87 mL, $P < .001$). In terms of transfusion rates, the total thoracoscopic double-valve replacement group (9.21%) showed a marked reduction compared with the median sternotomy double-valve replacement group (36.36%, $P < .001$). Both groups had similar major complications.

Conclusions: The initial results of the total thoracoscopic double-valve replacement underscore its safety and efficacy. This approach extends the applicability of total thoracoscopic cardiac surgery and warrants deeper exploration. (JTCVS Techniques 2024;24:41-9)



Total thoracoscopic double-valve replacement.

CENTRAL MESSAGE

TTDVR is a promising, minimally invasive cardiac surgery technique with favorable early outcomes and a reduced incidence of complications.

PERSPECTIVE

TTDVR presents a promising avenue in minimally invasive cardiac surgery. With a reduced incidence of complications and favorable early outcomes, this technique may revolutionize double-valve surgeries, offering safer and more efficient options for patients.

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Abbreviations and Acronyms

ACC = aortic crossclamping
CPB = cardiopulmonary bypass
MSDVR = median sternotomy double-valve replacement
NYHA = New York Heart Association
TEE = transesophageal echocardiography
TTDVR = total thoracoscopic double-valve replacement

▶ Video clip is available online.

Cardiac surgeons have made progress in the field of cardiac surgery to ensure safety, reduce trauma, accelerate rehabilitation, and improve cosmetic outcomes.[1] This has led to significant advancements in the development of minimally invasive procedures over the past few decades. Minimally invasive heart surgery techniques include partial sternotomies, small incisions on the right side of the chest, video-assisted procedures, total thoracoscopy, and robot-assisted methods.[2] Compared with traditional median sternotomy, these procedures have been proven minimally invasive, safe, and feasible and decrease the need for blood transfusions. Among these, thoracoscopy and robot-assisted procedures are the least invasive, with the smallest incisions. However, robot-assisted heart surgery faces costs that may require surgeons to seek alternatives. In contrast, total thoracoscopic cardiac surgery, offering both excellent visibility and minimal invasiveness, has gained interest in many centers, primarily due to its comparatively lower cost.[3]

Reports on total thoracoscopic cardiac procedures have included cases involving congenital heart defects, the mitral valve, or the aortic valve.[3-5] However, the confined space of the aorta and involvement of multiple valves add complexity to the procedure, resulting in an extended learning curve. Only double-valve replacement surgeries performed with right anterolateral mini-thoracotomy or video-assisted thoracotomy have been reported.[6,7] Reports on double-valve replacement surgeries that involve total thoracoscopy are notably lacking, and surgical techniques are still under constant exploration. Our team initiated total thoracoscopic double-valve replacement (TTDVR) to address this gap in expertise in November 2021. We aimed to compile the technical surgical details and evaluate the clinical outcomes in patients undergoing TTDVR.

PATIENTS AND METHODS

Patient Selection

This study was approved by the Ethics Committee of Fujian Medical University Union Hospital (2023KY198, May 10, 2023); patients provided informed written consent for publication of study data. From November 2021 to March 2023, 76 consecutive patients underwent TTDVR surgery performed by Dr Dai.

The patients selected met the following inclusion criteria: (1) aged 18 to 70 years; (2) requiring double-valve replacement therapy for aortic valve and mitral valve degenerative valvular disease or rheumatic combined valvular disease; (3) aortic root diameter 25 mm or greater and aortic valve annulus diameter 20 mm or greater; and (4) provided full informed consent and signed the informed consent form.

Conversely, we excluded patients based on the following criteria: (1) ascending aorta with severe calcification, aneurysm, or diameter 45 mm or greater; (2) necessity for concurrent atrial fibrillation ablation or coronary bypass grafting surgery; (3) history of surgery in the right thoracic cavity or severe adhesions in the right thoracic cavity; (4) previous cardiac surgery; (5) emergency surgery; and (6) femoral or abdominal aorta with severe stenosis, calcification, tortuosity, or other factors, challenging the establishment of peripheral cardiopulmonary bypass (CPB).

Anesthesia

General intravenous anesthesia was administered for the procedure. A double-lumen endotracheal tube facilitated ventilation of the left lung while collapsing the right lung to expose the surgical field. The patient was in a supine position, with defibrillator pads attached to the anterior lower left thorax and right scapular region. The right side of the body was elevated by 15 to 30 degrees, and the right upper limb extended downward and outward with a slight elbow bend (Figure 1). After the confirmation of successful anesthesia, a transesophageal ultrasound probe was inserted to assess prosthetic valve function and cardiac function postcardiac resuscitation. Subsequently, the anesthesiologist performed percutaneous catheterization of the right jugular vein (16F-18F) to access the superior vena cava, a crucial step in enabling upper vena cava blood drainage during CPB. Throughout the surgery, vital parameters, including heart rhythm, blood pressure, oxygen saturation, and heart rate, were continuously monitored to ensure stable anesthesia.

Surgical Techniques

After successful anesthesia, the right femoral artery and vein were dissected. This allowed for direct visualization of the catheters (18F-21F in the artery and 22F-26F in the vein), establishing peripheral CPB. During surgery, negative-pressure drainage was used for good drainage, and the depth of the femoral vein catheter was adjusted.

The TTDVR uses a 2-port method on the right chest wall. This method incorporates both the main and auxiliary ports. The main port was situated in the third intercostal space between the anterior axillary line and the midclavicular line on the right chest wall, with a length of approximately 3 to 4 cm, intended for intraoperative instrument manipulation, insertion of delivery tubes for myocardial protection fluid, CO_2 delivery, and intraoperative thoracic smoke suction. The auxiliary port, located in the same intercostal space but 2 cm lateral to the main port, was approximately 1.5 to 2 cm long, serving as the site for thoracoscope insertion, CHITWOOD aortic crossclamp, left heart drainage tube, and pericardial traction wires (Figure 1).

After the skin incision, a disposable incision spreader was used to safeguard the skin, subcutaneous tissue, and muscles, as well as to enable hemostasis via pressure application and to expand the incision (Figure E1).

After initiating CPB, mechanical ventilation ceased, and a 1- to 2-cm incision was made in the pericardium just above the phrenic nerve. The pericardium was suspended on both sides with traction sutures to expose the aorta and heart effectively. A myocardial protection solution perfusion catheter was inserted into the aorta and secured with a 3-0 Prolene line. Subsequently, the aorta was clamped using a CHITWOOD clamp, and antegrade perfusion of histidine-tryptophan-ketoglutarate cardioplegia was initiated through the perfusion tube for myocardial protection fluid,

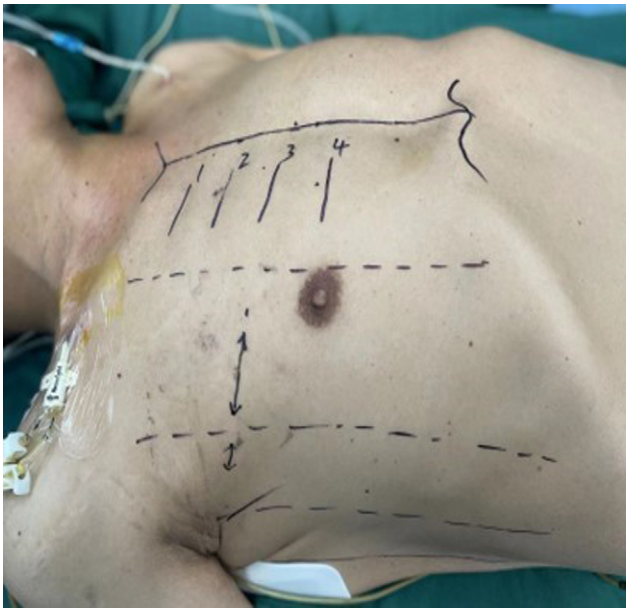
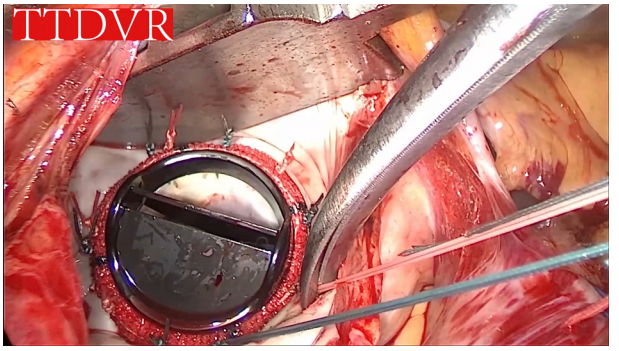


FIGURE 1. The patient's right side is elevated 15° to 30°. The main operative port, approximately 3 to 4 cm long, is located in the third intercostal space between the anterior axillary and midclavicular lines on the right chest wall. The auxiliary port is located 2 cm lateral to the main operative hole within the same intercostal space and was approximately 1.5 to 2 cm long.

minimizing the need for frequent perfusions during the procedure. This approach allows cardiac arrest in patients with aortic valve stenosis without significant aortic valve regurgitation. However, we adapted our approach in cases where the patient had aortic valve regurgitation. After partial perfusion to the point of myocardial fibrillation, we made an aortic incision. We directly administered a cardioplegic solution through the coronary ostia. Once cardiac arrest was confirmed, an aortic incision was positioned 1 to 1.5 cm above the root of the noncoronary sinus. The distal end of the aortic incision was sutured and knotted to either the left side of the aorta or the pericardium beside the thymus for traction. The aortic valve was exposed by tracing the incisions on the left and right sides of the aorta. Different surgical teams may have different practices regarding the sequence of aortic and mitral valve replacements. However, in our practice, we typically proceed with mitral valve replacement, followed by aortic valve replacement.

During mitral valve replacement, an incision was made in the atrioventricular groove. Polyester sutures with pledgets were used to retract the right atrium, exposing the mitral valve. This exposure was achieved by inserting a left atrial retractor through a puncture in the third intercostal space near the sternum. Subsequently, the anterior leaflet of the diseased mitral valve was excised, and the preservation of the posterior leaflet depended on specific circumstances. The annulus was sutured using 2/0 pledgeted polyester sutures with a double-armed needle, using the interrupted mattress technique (Video 1). Once the prosthetic valve was securely in place, the incision in the atrioventricular groove was closed.

Our team enhanced aortic valve exposure and streamlined the procedure by applying traction at 3 points on the aortic valve. To avoid overburdening the incision with excessive traction sutures, we chose a percutaneous puncture method for their removal. These traction sutures were strategically placed at the junction of the left and noncoronary sinuses via the auxiliary port. Meanwhile, the traction sutures at the left and right coronary sinus junctions were secured to the skin through a second intercostal space puncture, and the traction sutures at the right and noncoronary sinus junctions were fixed to the skin through a fifth intercostal space puncture (Figure 2). After excision of the valve leaflets, meticulous debridement



VIDEO 1. Surgical procedure. Video available at: https://www.jtcvs.org/article/S2666-2507(24)00047-6/fulltext.

was performed if aortic valve calcification was observed. Interrupted mattress sutures were performed using 2/0 pledgeted polyester sutures along the aortic annulus with a double-armed needle. The pledget was positioned beneath the aortic valve, and suturing commenced from the right coronary annulus, proceeding sequentially to the non⧹coronary annulus and finally to the left coronary annulus. After aortic valve replacement, a nerve hook was used to inspect the coronary ostia through thoracoscopy. Closure of the aortic incision used 5-0 Prolene sutures, with the ascending aorta being opened to vent air through the cannula. Before discontinuing CPB, each patient underwent a transesophageal echocardiography (TEE) examination, followed by meticulous inspection to confirm the absence of active bleeding from the incision (Figure 3).

Simultaneously, a cohort of 77 patients presented with equal suitability for either median sternotomy or TTDVR procedures. However, after a comprehensive consideration of the merits and demerits of both surgical methods, as well as their individual value assessments, the patients opted for the traditional approach of median sternotomy double-valve replacement (MSDVR), performed by Dr Dai. We also explored the feasibility and safety of TTDVR.

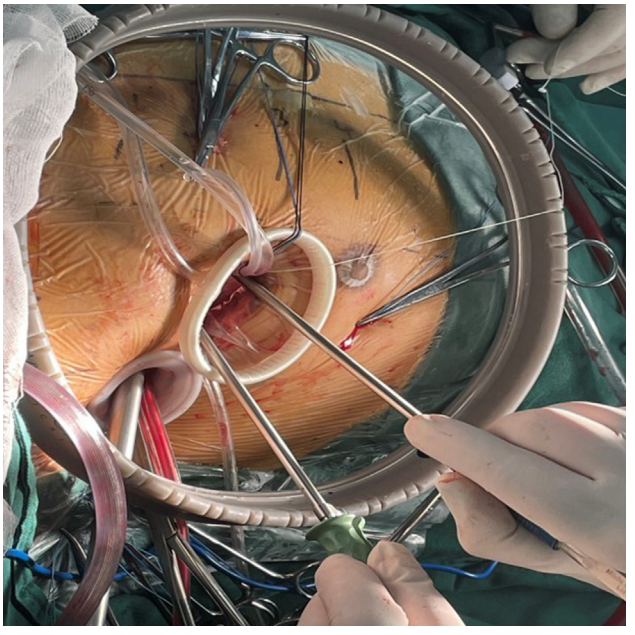


FIGURE 2. The functions of the main operative and auxiliary ports. The traction lines of the aortic junction are fixed at the skin surfaces of the second and fifth intercostal spaces.

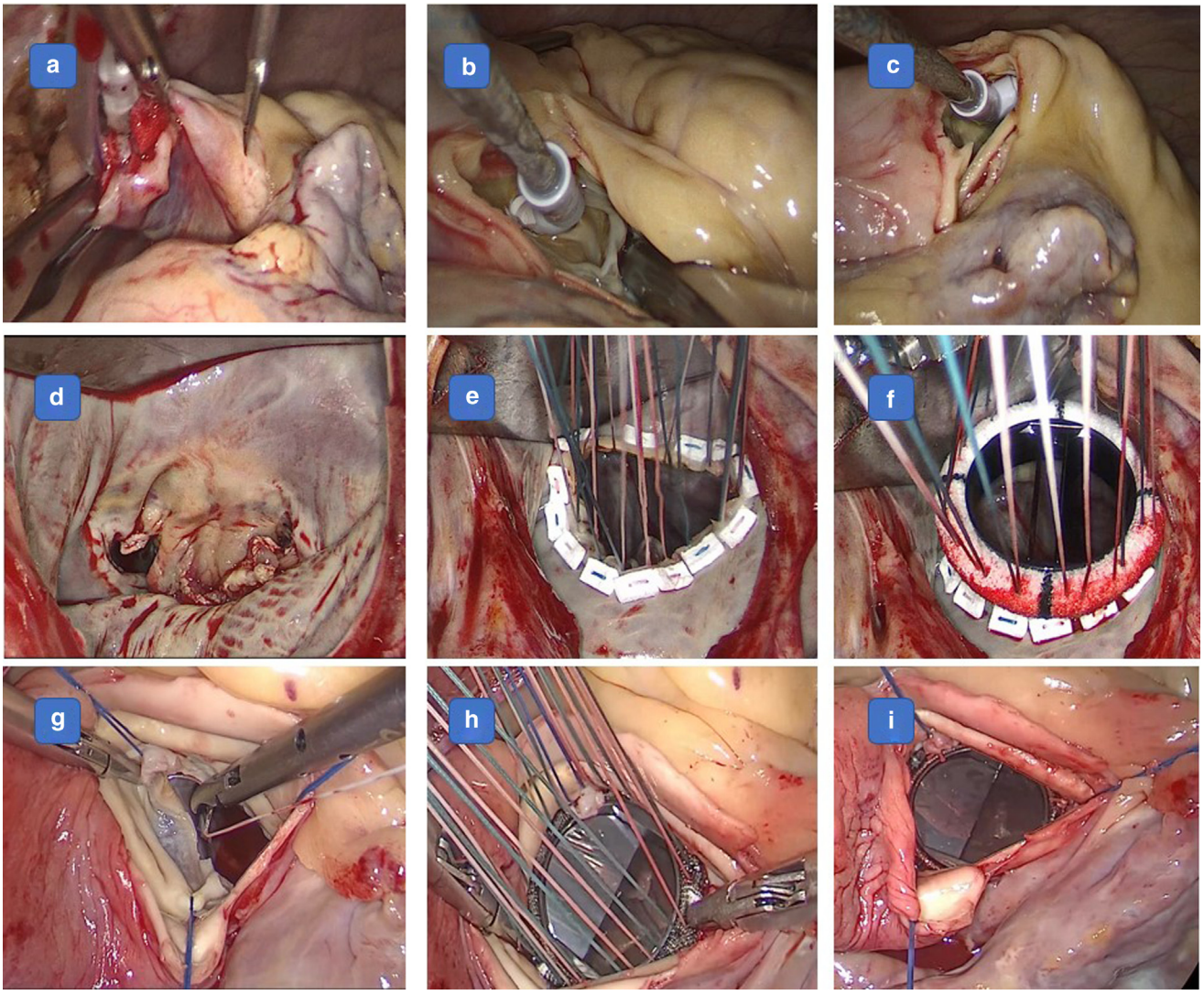


FIGURE 3. The thoracoscopic double-valve replacement surgical process. A, CHITWOOD occlusion clamp blocks the aorta before opening the aortic wall. B, After the aortic incision, the myocardial protection solution histidine-tryptophan-ketoglutarate is antegrade directly perfused through the left coronary artery opening. C, Histidine-tryptophan-ketoglutarate myocardial protection solution is also directly perfused through the opening of the right coronary artery. D, Left atrial retractor is used to expose the mitral valves completely. E, The mitral valve is sutured with a 2/0 mattress polytetrafluoroethylene thread, including a pledget, along the valve annulus. F, A mechanical mitral valve is implanted. G, The aortic valve junction is pulled to achieve good exposure of the aortic valve. H, A mechanical valve is implanted after suturing the aortic valve. I, After the mechanical aortic valve is implanted, the junction traction line is removed, and the coronary artery openings are checked and sutured to close the aortic incision.

Statistical Analysis

Data were analyzed using SPSS (version 21.0; IBM Corp). Continuous data are represented as mean ± SD ($\bar{x} \pm s$), with independent sample comparison conducted through the t test. Categorical data are denoted as numbers (n) or percentages (%), with comparisons made using the chi-square test.

RESULTS

The study group comprised 76 patients (43 male and 33 female). The average age of patients was 55.21 ± 9.04 years, and the body mass index was 23.42 ± 2.85 kg/m^2. The group included 13 patients with coexisting hypertension, 7 with diabetes, and 2 with chronic obstructive pulmonary disease. The New York Heart Association (NYHA) class distribution was as follows: Nine cases were classified as NYHA class II, 66 cases were classified as NYHA class III, and a single case was categorized as NYHA class IV. A surgical risk assessment was conducted for all patients using the European System for Cardiac Operative Risk Evaluation II (%), averaging 1.77% ± 0.73%. Preoperative transthoracic echocardiography revealed that the ascending aortic diameter was 33.85 ± 5.47 mm, left atrial diameter was 42.47 ± 9.50 mm, left ventricular end-diastolic diameter

was 55.95 ± 10.59 mm, left ventricular end-systolic diameter was 38.50 ± 10.44 mm, and left ventricular ejection fraction was 58.18% ± 13.01%. No significant differences were observed in age, sex, body mass index, prevalence of hypertension and chronic obstructive pulmonary disease, NYHA classification, ascending aortic diameter, left atrial diameter, left ventricular end-diastolic diameter, left ventricular end-systolic diameter, left ventricular ejection fraction, or European System for Cardiac Operative Risk Evaluation II% between the 2 groups (Table 1).

All patients successfully underwent TTDVR surgery. In the TTDVR group, the CPB time was 174.20 ± 38.87 minutes, and the aortic crossclamping (ACC) time was 120.20 ± 19.54 minutes, both of which were significantly longer than those in the MSDVR group (123.65 ± 15.33 minutes for CPB and 82.86 ± 9.51 minutes for ACC, $P < .001$). Additionally, the TTDVR group exhibited an extended operative time, with a mean of 4.40 ± 0.76 hours, compared with that in the MSDVR group at 3.21 ± 0.68 hours ($P < .001$). Postoperatively, the TTDVR group demonstrated a shorter mechanical ventilation duration (9.29 ± 3.12 hours) and reduced intensive care unit stay time (24.31 ± 7.29 hours) than the MSDVR group at 11.49 ± 4.27 hours and 26.76 ± 5.89 hours, respectively (P values of .019 and .040, respectively). Furthermore, the TTDVR group experienced a shorter postoperative hospitalization time, averaging 6.21 ± 1.58 days, than the MSDVR group (8.35 ± 1.07 days) ($P < .001$). The TTDVR group also exhibited significantly lower chest drainage volume (average 223.91 ± 53.93 mL) than the MSDVR group (382.56 ± 61.87 mL) ($P < .001$). Regarding transfusion rates, the TTDVR group (9.21%) showed a marked reduction compared with the MSDVR group (36.36%, $P < .001$). Regarding major complications, there were no significant differences between the 2 groups in terms of mortality, bleeding reoperation, or complete atrioventricular block occurrence rates. However, the TTDVR group presented with 3 cases of paravalvular leaks, which were absent in the MSDVR group (Table 2). In the early stage, 1 patient experienced bleeding from the aortic incision, necessitating reoperation. The original incision was reused, and the aortic incision was sutured using thoracoscopy. Among the first 10 patients who underwent TTDVR, 3 experienced paravalvular leakage, 2 of whom had biologic valves and 1 had a mechanical valve. TEE found moderate paravalvular leakage in the noncoronary sinus in 1 patient with bioprosthetic valve replacement during the operation. No specific treatment was implemented for the mild paravalvular leakage, and follow-up transthoracic echocardiography at 1 and 3 months postoperatively indicated that the paravalvular leakage had resolved. Repair was performed after cardiac arrest in cases of moderate paravalvular leakage.

Data analysis revealed that the CPB, ACC, and operation times were gradually decreased as the number of cases increased (Figure 4). The CPB, ACC, and operation times were significantly higher in the first 25 cases than in the subsequent ones, suggesting that the team's proficiency was improved and operations became more stable after completing 25 surgeries. A comparison of the first 25 cases (group 1) with the subsequent 51 cases (group 2) revealed statistically significant differences ($P < .05$) (Table 3).

All patients were followed up postoperatively via outpatient visits or telephone calls. The patients underwent cardiac echocardiography, electrocardiography, and chest radiography at the clinic. The follow-up period ranged from 1 to 18 months, averaging 7.58 ± 2.33 months. No deaths, repeat surgeries, or adverse cardiovascular events occurred during the follow-up period.

DISCUSSION

Total thoracoscopic aortic valve replacement surgery is characterized by a narrow operating space at the root of the aortic valve, with an incision in the second or third intercostal space. In contrast, the total thoracoscopic mitral valve surgery incision is located in the fourth intercostal space of the right chest wall. Because the mitral and aortic valves are not located on the same plane, replacing both valves presents certain difficulties if either a total thoracoscopic aortic incision or mitral valve incision is used. Consequently, the current literature mainly focuses on small incisions in the second or third intercostal space on the right side or double-valve replacement surgeries aided by thoracoscopy. These surgeries typically require retractors between the ribs, creating large incisions and posing risks such as rib fractures and damage to the right internal thoracic artery.[8-12] Moreover, as reported by Lio and colleagues,[9] when using an anterior right minithoracotomy approach, ensuring the insertion of the ascending aortic cannula is facilitated by maintaining a distance of less than 10 cm between the patient's ascending aorta and the right chest wall. Notably, this consideration does not apply to TTDVR procedures, given the use of specialized elongated surgical instruments. TTDVR has not yet been documented in the literature.

Our team has experience with total thoracoscopic heart surgeries and has performed total thoracoscopic aortic valve replacement surgeries since January 2021.[13] Expanding on this foundation, we attempted TTDVR in November 2021 and established an effective procedural flow.[14]

To ensure the success of TTDVR, attention should be paid to the following points. (1) Strict patient selection and careful preoperative evaluation involve selecting appropriate patients according to the inclusion and exclusion criteria. In the early stages, it is advisable to avoid choosing patients with severe aortic valve calcification because it is often challenging to remove it during surgery. The primary pathology for selection should be aortic valve regurgitation. This facilitates direct perfusion of the cardioplegic solution through the coronary ostium under

TABLE 1. Preoperative baseline data of total thoracoscopic double-valve replacement and median sternotomy double-valve replacement

Variable	TTDVR (n = 76)	MSDVR (n = 77)	*P* value
Age (y)	55.21 ± 9.04	54.97 ± 11.69	.889
Sex (male/female)	43/33	45/32	.871
BMI	23.42 ± 2.85	23.54 ± 2.13	.790
Hypertension (n, %)	13 (17.11)	11 (14.29)	.663
Diabetes (n, %)	6 (7.89)	8 (10.39)	.780
COPD (n, %)	2 (2.63)	3 (3.89)	1.000
NYHA			.822
II (n, %)	9 (11.84)	8 (10.39)	
III (n, %)	66 (86.84)	67 (87.01)	
IV (n, %)	1 (1.32)	2 (2.60)	
AA (mm)	33.85 ± 5.47	34.17 ± 6.08	.891
LA (mm)	42.47 ± 9.50	42.39 ± 8.68	.962
LVDD (mm)	55.95 ± 10.59	56.55 ± 10.12	.720
LVEDS (mm)	38.50 ± 10.44	38.22 ± 11.39	.869
LVEF (%)	58.18 ± 13.01	58.94 ± 12.92	.715
euroSCORE II (%)	1.77 ± 0.73	1.88 ± 0.56	.362

TTDVR, Total thoracoscopic double-valve replacement; *MSDVR*, median sternotomy double-valve replacement; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disorder; *NYHA*, New York Heart Association; *AA*, ascending aorta; *LA*, left atrial; *LVDD*, left ventricular diastolic diameter; *LVEDS*, left ventricular end-systolic diameter; *LVEF*, left ventricular ejection fraction; *euroSCORE*, European System for Cardiac Operative Risk Evaluation.

thoracoscopy. The valve annulus should be greater than 20 mm to avoid aortic valve annulus enlargement during the operation. (2) Proficiency in thoracoscopic surgical skills is required. According to the principle of proceeding from easy to difficult, the key to TTDVR is the replacement of the aortic valve under thoracoscopy. This should be based on proficiency in total thoracoscopic mitral and tricuspid valve surgeries. After gaining further proficiency in total thoracoscopic aortic valve replacement, attempts can be made to perform TTDVR. (3) Adequate exposure to the operative field is required. Exposure to TTDVR begins with the choice of incision. The main incision is made

TABLE 2. Intraoperative data of total thoracoscopic double-valve replacement and median sternotomy double-valve replacement

Variable	TTDVR (n = 76)	MSDVR (n = 77)	*P* value
CPB time (min)	174.20 ± 38.87	123.65 ± 15.33	<.001
ACC time (min)	120.20 ± 19.54	82.86 ± 9.51	<.001
Operation time (h)	4.40 ± 0.76	3.21 ± 0.68	<.001
Artificial valve type			.681
Biological valve (n, %)	15 (19.73)	13 (16.88)	
Mechanical valve (n, %)	61 (80.26)	64 (83.12)	
Mechanical ventilation time (h)	9.29 ± 3.12	11.49 ± 4.27	.019
ICU stay time (h)	24.31 ± 7.29	26.76 ± 5.89	.040
Postoperative hospital stay (d)	6.21 ± 1.58	8.35 ± 1.07	<.001
Chest drainage volume (mL)	223.91 ± 53.93	382.56 ± 61.87	<.001
Blood transfusion (n, %)	7 (9.21)	28 (36.36)	<.001
Major complications			
Death (n, %)	0 (0.00)	0 (0.00)	1.000
Paravalvular leak (n, %)	3 (3.96)	0 (0.00)	.120
Converted to median sternotomy	1 (1.32)	-	1.000
Reoperation for bleeding (n, %)	1 (1.32)	1 (1.30)	1.000
Complete atrioventricular block (n, %)	1 (1.32)	0 (0.00)	1.000

TTDVR, Total thoracoscopic double-valve replacement; *MSDVR*, median sternotomy double-valve replacement; *CPB*, cardiopulmonary bypass; *ACC*, aortic crossclamping; *ICU*, intensive care unit.

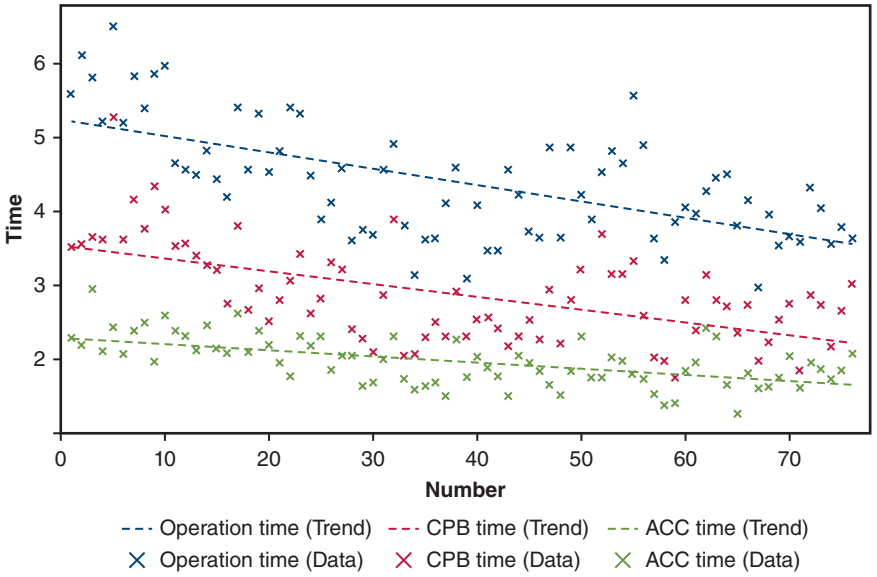


FIGURE 4. The surgical, CPB, and aortic crossclamp times are gradually decreased and tend to stabilize as the number of cases increase.

in the third intercostal space between the anterior axillary and midclavicular lines on the right chest wall, allowing for simultaneous exposure of the aortic and mitral valves. A left atrial retractor is used during the mitral valve surgery to enhance exposure further. During aortic valve surgery, after the aorta is crossclamped, it is retracted along the 3 aortic valve commissures. Retraction of the aortic valve commissure involves pulling the aortic valve annulus forward to expose it, which helps with suturing and assessing the seating of the artificial valve, thereby reducing perivalvular leakage. (4) Correct knot-tying technique should be implemented using instruments. Although there is literature on automated fastener devices or self-suturing devices such as the Cor-Knot, our team does not use them. (5) We found that knot-tying techniques vary between the mitral and aortic valve positions. In the mitral position, the primary surgeon can use his right hand to tie the knot and use a knot pusher with the left hand to tighten it directly on the artificial valve fabric. Because of the confined space in the aortic root, the knot pusher's maneuverability is limited. Therefore, it is advisable for the assistant to simultaneously pull the suture taut while assisting in knot tightening. After completing 76 procedures, we have confidence in the safety and feasibility of TTDVR.

TTDVR uses a soft incision protector, which serves dual functions: It protects the skin and muscle tissue and plays a crucial role in retracting and enlarging the operation hole. These features offer several advantages. Postoperatively, the right chest wall displayed only 2 incisions, measuring 3 to 4 cm and 1 cm. The procedure was successfully completed in all patients, with a short postoperative mechanical ventilation time, short intensive care unit stay, few postoperative hospitalization days, few blood transfusions, and lower postoperative pleural fluid accumulation. These results further substantiate that TTDVR is safe and achieves significant minimization.

Perivalvular aortic valve leakage is the most common complication of TTDVR. This complication arises from limited operational space at the root of the aortic valve. During the surgery, knotting and suturing may induce perivalvular leakage. However, TEE can accurately assess and promptly treat this condition. In this study, postoperative transesophageal ultrasonography detected 3 cases of perivalvular leakage.

Interestingly, all cases occurred in the first 10 cases during the early stage and were confined to the aortic valve position. Among these, 2 patients had mild perivalvular leakage, and 1 patient displayed moderate perivalvular leakage. Mild perivalvular leakage did not necessitate

TABLE 3. Comparison of intraoperative data between the first 25 cases and the subsequent 51 cases in total thoracoscopic double-valve replacement

Variable	Group 1 (n = 25)	Group 2 (n = 51)	*P* value
CPB time (min)	207.66 ± 36.99	157.80 ± 27.85	.001
ACC time (min)	138.14 ± 14.81	111.41 ± 15.08	.001
Operation time (h)	5.15 ± 0.66	4.03 ± 0.49	.001

CPB, Cardiopulmonary bypass; *ACC*, aortic crossclamping.

specific treatment, and subsequent chest color ultrasound examination revealed that the perivalvular leakage had resolved. Moderate perivalvular leakage was corrected using cardiac arrest and repair. Intraoperative TEE reexamination confirmed the absence of perivalvular leakage. By focusing on the depth of the aortic valve suture needle and placing a gasket under the aortic valve, the incidence of perivalvular leakage can be reduced.

TTDVR, a thoracoscopic mitral valve surgery type, has a particular learning curve. Approximately 40 to 50 cases are required for the valve replacement surgeon to achieve relative proficiency.[15] In our team's early stages of TTDVR, the CPB and aortic crossclamp times were both extended. However, after continuous refinement and perfection of the technique, we have remained relatively stable after only 25 cases. We propose that the learning curve for TTDVR should be between 20 and 30 cases. This learning curve was significantly shorter than that for thoracoscopic mitral valve replacement surgery, which could be due to the solid foundation of thoracoscopic cardiac surgery. However, this was the case for a single surgeon and the respective team experience, and we need to further evaluate similar experience in other surgeons.

Study Limitations

This retrospective study comprehensively analyzed the technical nuances and early results of TTDVR. Although the outcomes are promising, our study has some limitations. First, the small sample size implies that our results could be due to chance. Second, the brief follow-up period precluded us from appraising the long-term effects and safety of TTDVR. Consequently, future research should involve larger sample sizes and randomized controlled studies to corroborate the effectiveness and safety of TTDVR.

CONCLUSIONS

Continuous refinement of surgical techniques is vital for TTDVR. This approach presents significant challenges, involving a tight surgical space, long-distance procedures, and simultaneous aortic and mitral valve surgery. Physicians must undergo rigorous training to master the required surgical skills. Implementing total thoracoscopic double-valve surgery should prioritize patient well-being and the surgical team's technical proficiency. Encouraging preliminary results of TTDVR confirm its safety and effectiveness, warranting further investigations to expand the scope of thoracoscopic cardiac surgery.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: median sternotomy, minimally invasive, total thoracoscopic cardiac surgery, total thoracoscopic double-valve replacement

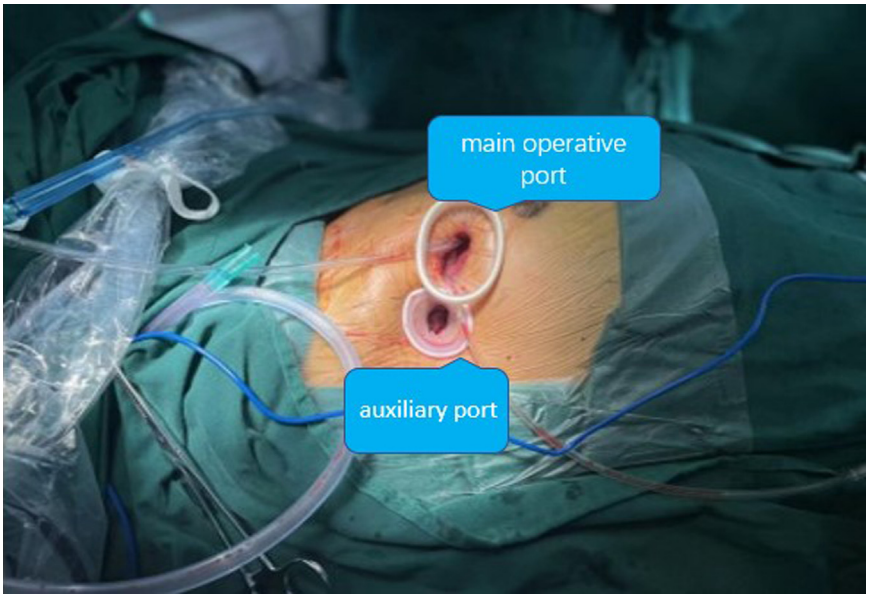

FIGURE E1. A disposable incision retractor is used to pull open and protect the skin, subcutaneous tissue, and muscles, as well as to provide hemostasis and enlarge the incision. The upper side of the main operative port is equipped with a negative-pressure suction tube, and the lower side has a carbon dioxide delivery tube.