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A totally endoscopic approach for aortic valve surgery

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Graphical abstract

Key question: What are the outcomes of a new totally endoscopic technique for aortic valve surgery?

Key findings: The hospital mortality was 1.50%. Major adverse cardiac and cerebral events occurred in five patients within 30 days.

Take-home message: Our experience with totally endoscopic aortic valve replacement demonstrated satisfactory results, with low mortality and morbidity rates.

Abstract

Objective: A new approach for totally endoscopic aortic valve replacement is described.

Methods: From October 2017 through December 2020, 266 consecutive patients underwent totally endoscopic aortic valve replacement. Reoperations and combinations were excluded.

Results: A total of 266 patients with a median age of 72 [64, 79] years underwent totally endoscopic aortic valve replacement, of which 250 (93.98%) patients were indicated to undergo surgery because of aortic valve stenosis. The median follow-up index was 0.69 (0.30, 0.90). Major adverse cardiac and cerebrovascular events occurred in five (1.88%) patients within 30 days. Overall hospital mortality was 1.50%. Twenty additional deaths (7.52%) occurred during the three-year follow-up. An early thoracoscopic revision was needed in seven patients due to signs of bleeding or cardiac tamponade. Fourteen patients required permanent pacemaker implantation.

Conclusions: Retrospective analysis of our early experience with totally endoscopic aortic valve replacement in 266 consecutive patients demonstrated satisfactory results, with low mortality and acceptable morbidity rates.

Keywords: endoscopic, valvular surgery, aortic valve

Glossary of abbreviations

AVR: aortic valve replacement
AV: atrioventricular
CPB: cardiopulmonary bypass
CT: Computed Tomography
CVA: cerebrovascular accident
ECMO: extracorporeal membrane oxygenation
EuroSCORE: European System for Cardiac Operative Risk Evaluation
ICU: intensive care unit
LOS: length of stay
LVEF: left ventricular ejection fraction
MACCE: major adverse cardiac and cerebrovascular events
MiECC: minimally invasive extracorporeal circulation
OR: operating room
RALT: right anterolateral mini-thoracotomy
RAMT: right anterior mini-thoracotomy
TEAVR: totally endoscopic aortic valve replacement
TEE: transesophageal echocardiography
TIA: transient ischemic attack
TTE: transthoracic echocardiography
VATS: video-assisted thoracoscopic surgery

Introduction

Minimally invasive cardiac surgery is progressively evolving. Cosgrove *et al.* described the first minimally invasive aortic valve replacement (AVR) via a mini-sternotomy(1). Nowadays, mini-sternotomy is the preferred surgical approach in many cardiac centres for isolated aortic valve pathology. The idea of a non-full sternotomy approach resulted in new minimally invasive techniques for aortic valve replacement like the right anterolateral mini-thoracotomy (RALT) and right anterior mini-thoracotomy (RAMT)(2-4). Current European guidelines advocate transcatheter aortic valve implantation (TAVI) for patients above 75 years of age or low-risk patients (5). However, evidence for the long-term durability and the application in different anatomical situations in younger patients is sparse.

Further efforts resulted in the first totally endoscopic approach for AVR (TEAVR) reported by Vola *et al.* in 2014(6). Despite the acceptable initial clinical results, this technique did not evolve as expected due to limited indications and longer clamping and cardiopulmonary bypass (CPB) times(6). Since then, only several sporadic reports or small cohorts of endoscopic AVR have been reported(7-9).

In our centre, the Jessa Hospital, Hasselt, Belgium, a non-university tertiary institution, elective AVR has been performed through mini-sternotomy since 2005. Thanks to the knowledge and skills built up in totally endoscopic mitral valve surgery and endoscopic bypass surgery, the first steps to TEAVR were set(10). This report describes our initial experience of TEAVR in the first 266 patients.

Patients and Methods

Ethical statement

This retrospective cohort study was approved by the local ethics committee of the Jessa Hospital Belgium (20.88-carchir20.01) on September 8, 2020. No written informed consent was needed due to the retrospective nature of the study.

Patients

From October 2017 through December 2020, an unselected group of consecutive surgical AVR was included in this study. These were all patients operated on by the leading surgeon A.Y. In his absence, 20 urgent mini-sternotomies were performed. Previous cardiac surgery, mini-sternotomy, or combination surgeries were excluded.

Procedure

All procedures were performed under general anaesthesia. Patients were in a supine position and received a single-lumen endotracheal tube, a central venous catheter, a radial artery catheter, a peripheral intravenous line, and external defibrillating pads. Near-infrared oxygenation monitoring pads were placed at the patient's forehead, and a transesophageal echocardiography (TEE) probe was inserted.

Arrangement of the access ports or trocars is crucial for endoscopic surgery. Only the 2nd and 3rd intercostal spaces were used. The first 5mm air-sealed trocar was introduced approximately 2 cm below the anterior axillary line in the 3rd intercostal space and was used for the 0-degree endoscope (5mm, Karl Storz, Tuttlingen, Germany) (figure 1). This initial trocar was introduced during a short period of apnea followed by CO2-insufflation using the trocar's side-port, creating a pneumothorax of 6-8 mmHg to facilitate adequate working space and avoid selective lung ventilation.

The location for the larger access port was selected by simple transthoracic needle insertion through the 2nd intercostal space under endoscopic vision, avoiding lesions of the right internal mammary artery. A 15-20 mm skin incision was made through the 2nd intercostal space, large enough for the index finger's width (figure 1). The pectoral muscle was divided in line with the muscle fibres, and an extra small soft tissue retractor (Shanghai International Holding Corporation GmbH, Hamburg, Germany) was placed.

Subsequently, heparin was administered. The common femoral artery and vein were exposed and cannulated using the Seldinger method under TEE guidance. CPB with retrograde perfusion was achieved using a minimally invasive extracorporeal circulation (MiECC) system [the mini-Inspire JESSA MiECC (Sorin S.p.A., Mirandola, Italy)](11). Ventilation is stopped after full MiECC flow.

Two additional 5 mm ports were inserted. One port in the 3rd intercostal space was placed directly caudal to the larger access port and one in the 2nd intercostal space at the anterior axillary line, lateral to the larger access port, as illustrated in Figure 1. From this point on, the procedure is continued totally thoracoscopically using the endoscope and the screen. The pericardium was opened laterally in a horizontal fashion at least 2 cm from the phrenic nerve to get maximum exposure to the ascending aorta. Three transthoracic pericardial traction sutures were placed. A left ventricular venting catheter (16 Fr Medtronic, Minneapolis, USA) is inserted in the right superior pulmonary vein via the lateral 5mm access point in the 2nd intercostal space. Through this same incision, transthoracic aortic cross-clamping was obtained (Chitwood aortic clamp Tuttlingen, Germany), immediately being followed by injection of an antegrade single shot of cold (8°C) mixed cardioplegia (blood: crystalloid 3:1, Fresenius Kabi, Schelle, Belgium) using a 14G aortic root vent (Argon Secalon-TTM, Plano, USA) inserted directly in the aorta through the large access port.

After cardioplegic arrest, a transverse aortotomy was realised at the point of the cardioplegia needle. Two traction sutures were placed to keep the aortotomy open. Next, complete excision of the diseased aortic valvular leaflets and annular decalcification was realised. Sizing of the aortic annulus was done with conventional sizers through the large utility port. Approximately 12 pledged sutures (Ethibond 2-0 (Johnson&Johnson, Somerville, NJ, USA)) were placed in an inversed manner in the aortic annulus using long-shafted endoscopic instruments. Subsequently, these sutures were put through the sewing ring of the extracorporeal prosthetic valve and introduced transversely intra-corporeally through the larger utility port without the holder. The prosthetic valve was gently parachuted and positioned to the aortic annulus with forceps (figure 2), being secured using the Cor-Knot system (LSI Solutions, NY, USA). After determining the function of the prosthetic valve and checking the free coronary ostia, the ascending aorta was closed using a double-layered suture Prolene 4-0. Epicardial ventricular pacing wires were positioned on the right ventricle before removing the aortic cross-clamp. De-airing was achieved by the left ventricular venting catheter, which was removed only in the absence of free air on TEE. Once the patient was hemodynamically stable, and TEE confirmation showed a good valve function without paravalvular leakage, weaning from CPB was initiated. In all cases, the pericardium was approximated using Vicryl 2-0 sutures and a chest tube (Blake drain 19Fr., Johnson&Johnson, Somerville, NJ, USA) introduced through a trocar incision into the right pleural space. All patients were transferred to the intensive care unit (ICU) postoperatively.

Outcomes

The primary objectives are the occurrence of major adverse cardiac and cerebrovascular events (MACCE) and mortality at 30 days, one year, and three years. MACCE includes cardiac death, myocardial infarction, stroke, and prosthetic degeneration. Prosthetic degeneration is defined as "intrinsic permanent changes of the prosthetic valve (i.e., calcification, leaflet fibrosis, tear or flail) leading to degeneration and/or hemodynamic dysfunction" (12). Additionally, peri-operative bleeding is defined as the amount (mL) of blood collected during the surgery via suction, while postoperative bleeding is measured 24h through the thorax drains. Moreover, hospital and intensive care unit lengths of stay (LOS) and complications, including surgical revisions, neurological complications, new-onset atrial fibrillation, and pacemaker implantation, are secondary endpoints.

Data Analysis

This retrospective review was performed on the data of all consecutive patients who underwent TEAVR. Data are expressed as frequencies (%), numbers (n), and median with interquartile range [p25,p75]. The survival was assessed using a Kaplan Meier analysis for the all-cause mortality and a cumulative incidence function for MACCE. All data was analysed based on an intention-to-treat principle using the R Core Team (2021).

Results

Patient demographics

A functional bicuspid aortic valve pathology was present in 61 patients (22.93%). Dyspnea was the most common symptom (56.77%), and 28.20% of the patients experienced no symptoms. The median European System for Cardiac Operative Risk Evaluation (EuroSCORE) II was 1.68 [1.07,2.52] %, corresponding to low peri-operative risk. Pertinent pre-operative patient characteristics are given in Table 1.

Early Results

TEAVR was successful in all cases except for one patient needing conversion to a partial upper sternotomy. Predominantly, a biological aortic valve prosthesis (99.62%) was implanted with a valve size of 25 mm (min 21, max 29 mm). All of the implanted valves were sutured valves. The median aortic cross-clamping and CPB times were 61.0 [54.0,71.8] and 91.0 [80.0,105.0] minutes, respectively. The operating room (OR) time was 139.0 [122.0,161.0] minutes. When comparing the OR time of the first and last ten patients (146 [136.5,162.5] and 146.5 [133.8,161.2]), no significant difference could be detected (p=0.91). There was no need for per-operative corrections or a second cardiopulmonary bypass run. Other intra-operative data are presented in Table 2.

The median ICU stay was 27.0 [22.0,51.75] hours, with a ventilation time of 4.0 [3.0,6.4] hours. Postoperative blood loss was limited to 187.5 [100.0,338.8] ml over 24h. A thoracoscopic re-exploration within 48 hours was performed in five patients (1.88%) due to signs of perpetual bleeding. In four cases, no active bleeding was found. Also, two patients, of which one on

Novel Oral Anticoagulants treatment, required revision surgery because of a tamponade. One patient developed a late bleeding one week postoperatively, for which thoracoscopic drainage was needed.

Postoperative neurological symptoms were observed in 14 patients (5.27%), of which five were considered a stroke. The symptoms were temporary in one patient, one passed away, and three did not fully recuperate.

Additionally, 14 (5.26%) patients developed a complete atrioventricular (AV) block requiring pacemaker implantation during the hospital stay. At discharge, in-hospital TTE showed a paravalvular leakage in one patient. The median hospital stay was 5 [4,7] days. Pertinent postoperative outcomes are given in Table 3.

Follow-up results

The median follow-up index was 0.69 (0.30,0.90) for a median follow-up of 679.0 [271.8,1073.8] days. Four cases of endocarditis were recorded during the follow-up period, for which two patients needed reoperation (Table 4). In two patients, reoperation was necessary because of a tamponade. Additionally, a pericardium fenestration led to reoperation in one patient. Early prosthetic degeneration was detected in one patient for which reoperation was required.

The referring cardiologist performed a follow-up TTE of the implanted valve when a clinical indication was found. More than 50% of all patients (57.52%) received a TTE, showing a paravalvular leakage in two (0.75%) patients but no structural valve deterioration (Table 4).

MACCE

MACCE occurred in five patients within 30 days (Figure 3A). Two patients suffered a cardiac death, while four had a stroke. Three more patients developed MACCE over the course of a year (Figure 3C). One suffered a cardiac death, while two endured a stroke. During the three-year follow-up, six other patients endured MACCE (Figure 3E). One experienced a cardiac death, and a stroke struck five individuals. No significant difference is present when comparing the occurrence of MACCE at one year between the first and last ten patients (0 vs 0).

All-cause mortality

Four in-hospital mortalities occurred. Within 30 days, no additional patients died (Figure 3B). Seven other patients died one year after their procedure (Figure 3D). Fifteen more individuals died during the three-year follow-up period (Figure 3F). The survival rate at 30 days, one year, and three years consisted of 98.4%, 95.1%, and 84.9%, respectively. No significant difference in mortality at one year is observed in the first and last ten patients (0 vs 0).

Discussion

Our experience with the first 266 patients treated with TEAVR at our hospital showed good results regarding our primary outcomes. The 30-day mortality was 1.50%. At the one-year mark, seven other patients passed away. Moreover, in the three-year follow-up, fifteen more patients died.

In 1.88%, 3.01%, and 5.26% of patients, a MACCE occurred at 30 days, one year, and three years, respectively. When comparing the first and last ten patients, there was no significant difference in one-year MACCE and mortality. Previous research regarding endoscopic surgery has shown a significant learning curve. There were longer operation, aortic clamping, and CPB times due to a lack of experience and missing instrumentation(13, 14). Tokoro *et al.* described an operation, clamping, and CPB time of 188 [56], 90 [34], and 130 [43] minutes, respectively(8). Although all of the implanted valves in our series were sutured valves, which need more time for implantation than sutureless valves, long aortic cross-clamping and CPB times were not seen in our first series. In our experience, the operation, clamping, and CPB times were acceptable compared to standard AVR by sternotomy and other endoscopic techniques (6, 8, 15). We expect that the clamping and CPB times will reduce more with the use of sutureless bioprosthetic valves.

Moreover, postoperative blood loss was low, with a median of 187.50 [100.0,338.8] ml and 0 [0,0] units of postoperative blood transfusion. A higher postoperative blood loss of 295.0 [325.0] ml with a median blood transfusion of 0 [4] units was reported by Tokoro *et al.*(8).

A revision surgery occurred in nine patients (3.38%), which is less than half of the revisions after median sternotomy, partial upper sternotomy, and anterolateral mini-thoracotomy (7.3%, 6.7%, and 12%, respectively)(16). A reason for the revision might be inadequate functioning of the small (19 Fr) Blake drain, mispositioning, or cloth formation. A more thorough inspection of the port incisions a few minutes after protamine administration might help diminish the cases of revisions.

New neurologic symptoms are similar to previous studies(17, 18). Three patients had an epileptic insult, of which two were treated with anti-epileptics. Moreover, stroke occurred in five (1.88%) patients. Stroke can occur due to general cerebral ischemia resulting from lower cerebral perfusion pressures, lower than the patient's cut-off pressure. Retrospectively, no periods of very low pressures could be found on the near-infrared spectroscopy. Additionally, stroke can be caused by emboli originating from aortic manipulation with dislocations of calcium or atheromatous plaques during the surgery on the aortic valve. Another cause might be the retrograde perfusion technique(19). However, this was not observed in a previous study by Stessel *et al.(20)*. CO2 insufflation in the operative field and de-airing the left ventricle before closing the aortotomy is thus considered an essential step to diminish the occurrence of peri-operative strokes. The CO2 inflation must remain at a low continuous flow level to avoid an overload of high flow air travelling to and reaching the pulmonary venous system. In such cases, emboli can be formed when ventilation is started at the end of the surgery, and trapped air bubbles are demobilised. In patients enduring hemiparesis, we postulate that air embolisation occurred when starting the ventilation after removing the left ventricular venting catheter. After these cases, the left ventricular vent was removed after filling the ventricle combined with ventilation until all macroscopic air bubbles disappeared. Another de-airing option might be the Valsalva manoeuvre or saline injection through the left vent or to insert an aortic root cannula, as performed in conventional AVR surgery(21).

In-hospital pacemaker implantation was required in 14 patients (5.26%) due to a complete AV block. As seen in bicuspid valves, the extensiveness of the calcification might form another reason for an increased risk for pacemaker implantation. Almost 23% of our operated patients had functional bicuspid valves. A thorough decalcification or stitches placed too deep at the perimembranous area might be another cause. Our reported rates can be considered acceptable when comparing our pacemaker rate (5.26%) to conventional AVR, where 2–7 % of cases require permanent pacemaker implantation(22, 23). Moreover, our hospital's threshold for pacemaker implantation is relatively low. Compared to the results of transcatheter pacemaker implantation in low-risk patients (PARTNER 3 trial), where pacemaker implantation was required in 6.6% of patients, our findings are put more into perspective(24). Furthermore, the hospital stay was 5 [4.0, 7.0] days, in line with the 7 [2] days described by Tokoro *et al.*(8).

The difference between this technique and Pitsis *et al.* is the sizing of the working port and trocars, which is half the size in our series. Accordingly, the procedure's invasiveness is further reduced, and the recovery is expedited(9).

An essential aspect of this experience with TEAVR is that it consists of all consecutive patients operated by the leading surgeon. We did not encounter any RALT or RAMT, thanks to our experience in endoscopic procedures. No extra imaging such as Computed Tomography (CT) of the thorax was necessary to evaluate the accessibility or indication for minimally invasive surgery as designated by the group of Glauber *et al.(23)*.

Pre-operative CT-scanning can lead to changes in choices concerning cannulation sites, aortic cross-clamping strategies, cardioprotection, and even cancellation of surgery (25). In contrast, when entering the chest cavity in our totally endoscopic approach, the optimal endoscopic angulation can be directly tailored to the patient's anatomy, shifts in anatomy due to single lung ventilation, and position on the table. Suboptimal endoscope trocar placement can even be slightly adjusted due to the use of 30 degrees endoscope. Although our approach is relatively forgiving after the initial incision, we believe that global adaptation of such a technically demanding endoscopic approach relies on pre-operative imaging to facilitate less-experienced minimally invasive operators. Once one has passed its initial learning curve, further refinement in minimising operative strategy should evaluate whether routinely pre-operative CT scanning offers significant advantages to justify its radiation dose and nefro-toxic effects of the contrast agent.

Since there are no significant incisions except the stab or minimal incisions for the trocars to reach the aorta, the use of ECC is the only real factor of invasiveness. The disadvantages of the ECC, known for conventional systems, are minimised using our MiECC system(11, 30). This system is nearly an ECMO (extracorporeal myocardial oxygenator) system consisting of a closed small tubing system with active draining using the oxygenator(11).

Tips and tricks

The transition from any approach under direct vision to TEAVR is a major technical change due to the transition from a 3D approach with tactile feedback to a 2D procedure without such feedback. The addition of 3D endoscopes might facilitate widespread adaptation in the cardiosurgical community to a similar extent as in laparoscopic surgery(27). Although endoscopic surgery for mitral valve repair is identical to our current technique, approaching the aortic valve poses significant challenges due to its different anatomic localisation and much smaller access space and manoeuvre possibilities. The placement of the annular stitches is considered most technically demanding and could be the focus of training in a simulation model comparable to currently available simulators for mitral valve surgery(28). Cardiac surgery residents are nowadays still primarily taught to get acquainted with technically challenging open procedures using standard instruments. The step towards a minimally invasive approach requires a different skill-set. In comparison, colonic surgeons transiting from open to laparoscopic colorectal surgery took five to ten years before requiring sufficient self-reported proficiency(29). In contrast: during TEAVR, the anatomic working space is generally more confined, the heart axis may vary significantly, and the right hemidiaphragm is often elevated (especially in obese), all attributing to a more technically demanding procedure. Besides these exposure-related difficulties, tissue quality in the elderly population and heavy calcified (bicuspid) valves can further complicate our proposed approach. Pre-planning using CT can be essential when starting a TEAVR program, but extensive experience in Video Assisted Thoracoscopic Surgery is essential since TEAVR requires significant dexterity and dedication. We thus propose that surgeons aspiring to perform these procedures ideally start training complex endoscopic procedures early in their residency programs and/or follow a dedicated fellowship in a speciality centre. Such fellowship might not be only necessary to get taught TEAVR in the appropriate fashion but also to get acquainted with peri-procedural complications and how to manage them minimally invasively.

Limitations

This report's retrospective nature is a limitation, which induces selection bias. Another limitation of this study is that most patients were followed up in other hospitals, so not all follow-up data was available. Moreover, all patients were operated on by a single surgeon, limiting the external validity of this trial. A multicenter study should prove the reproducibility of this technique.

Conclusion

TEAVR seems to be a feasible technique, easily implemented in any cardio-thoracic centre without big financial investments or need for instruments, except for an endoscopic tower system already present in all centres. Compared to robotically-assisted surgery, this technique is less expensive but technically more challenging, and there is still room for improvement. The development of new endoscopic instruments and surgical devices could further improve the results of this technique. Additionally, fast-track cardiac surgery, in which the peri-operative anaesthetic management intends to extubate the patients within 1-6 hours postoperatively, could benefit the patients' outcomes by reducing the postoperative pain and accelerating the recovery.

In conclusion, a retrospective analysis of our initial experience with TEAVR in 266 consecutive patients demonstrated satisfactory results, with low mortality and acceptable morbidity rates.

Author contributions statement

A.Y. S.V. and A.K. contributed to the design and implementation of the research. J.C and L.P. collected the data. J.C. and L.P. performed the statistical analysis. S.V. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

Funding Statement and conflict of interest statement

A research grant from Edwards Lifesciences was received to perform this study.

Data availability statement

The article's data will be shared on reasonable request to the corresponding author.

Figure Legends

Figure 1: Operation field after installing all ports for totally endoscopic aortic valve replacement (A) and schematic drawing (B) of the trocar placement and 5mm utility port

Figure 2: Introduction of a sutured valve through the 5mm utility port.

Figure 3: Estimated survival of the all-cause mortality (Kaplan–Meier) and major adverse cardiac and cerebrovascular events (MACCE)(cumulative incidence function) after 30 days (A,B), one year (C,D), and three years (E,F).

Table 1. Preoperative patient characteristics (n=266).

Variables	**Median [IQR] or n (%)**
Age (years)	72.00 [15]
Male patients	168 (63.16)
BMI (kg/m^2)	27.08 [23.93, 30.08]
NYHA	
I	87 (32.71)
II	144 (54.14)
III	32 (12.03)
IV	3 (1.13)
LVEF (%)	
Good	222 (83.46)
Moderate	41 (15.41)
Poor	2 (0.75)
Very poor	1 (0.38)
EuroSCORE II (%)	1.68 [1.07, 2.52]
Hypertension	154 (57.89)
Diabetes mellitus	52 (19.55)
Hyperlipidemia	175 (65.79)
Smoking history	
- Active	65 (24.44)
- Stop	35 (13.16)
COPD	22 (8.27)
Neurologic history	17 (6.39)
Peripheral vascular disease	9 (3.38)
Impaired renal function	18 (6.77)
Atrial fibrillation	39 (14.66)
Indication	
- AS	250 (93.98)
- AR	7 (2.63)
- AS + AR	8 (3.01)
- AS + endocarditis	1 (0.38)
Endocarditis	6 (2.26)
Bicuspid valve	61 (22.93)
Pulmonary hypertension	
- Moderate (31-55 mmHg)	27 (10.15)
- Severe (>55mmHg)	4 (1.50)
TTE	
- Peak aortic valve gradient (mm Hg)	72.0 [60.0, 86.8]
	46.00 [39.0, 58.0]

- Mean aortic valve gradient (mm Hg)	0.8 [0.6, 0.9]
- aortic valve area (cm^2)	

AS/AR: aortic valve stenosis/aortic valve regurgitation;BMI: body mass index; COPD: chronic obstructive pulmonary disease; Euroscore II: European System for Cardiac Operative Risk Evaluation; GOLD: Global Initiative for Obstructive Lung Disease; LVEF: left ventricular ejection fraction; NYHA: New York Heart Association; TTE: transthoracic echocardiography.

Table 2: Intraoperative Outcomes (n=266).

Variables	**Median [IQR] or n (%)**
CPB time (min)	91.0 [80.0, 105.0]
AoXC time (min)	61.0 [54.0, 71.8]
OR time (min)	139.0 [122.0, 161.0]
Conversion to mini-sternotomy	1 (0.38)
Arterial cannulation	
- Femoral artery	262 (98.50)
- Subclavian artery	6 (2.26)
Valve size (mm)	25
Mechanical (Carbomedics LivaNova)	1 (0.38)
Bioprosthesis	
- Epic™ (St.Jude Medical)	178 (66.92)
- Trifecta™ (St.Jude Medical)	69 (25.94)
- Avalvus	4 (1.50)
- Magna ease	9 (3.38)
- Other	5 (1.88)
Blood loss (ml)	300.0 [200.0, 500.0]
Transfusion (units)	0 [0,0]
Inotropic agent	48 (18.05)

AoXC: aortic cross-clamp; CPB: cardiopulmonary bypass; OR: operating room.

Table 3: Postoperative Outcomes (n=266).

Variables	**Median [IQR] or n (%)**
Ventilation time (h)	4.00 [3.0, 6.4]
Ventilation <6h	215 (80.83)
Bleeding in 24h (ml)	187.50 [100.0, 338.8]
Blood transfusion (units)	0 [0,0]
ICU LOS (h)	27 [22.0, 51.8]
Hospital LOS (days)	5 [4, 7]
Pacemaker (in hospital)	14 (5.26)
Early revision (<48h)	
- Bleeding	5 (1.88)
- Tamponade	2 (0.75)
Late revision (>48h)	
- Bleeding	1 (0.38)
- Tamponade	0 (0)
- Other	1 (0.38)
Neuro	
- CVA	4 (1.50)
- TIA	1 (0.38)
- Epilepsy	3 (1.13)
New atrial fibrillation	71 (26.69)
Electrical reconversion	19 (7.14)
LVEF (%)	
- Good	196 (73.68)
- Moderate	43 (16.17)
- Poor	4 (1.50)
- Very poor	0 (0)
Pulmonary hypertension	

- Moderate (31-55 mmHg)	46 (17.29)
- Severe (>55mmHg)	0 (0)
TTE	
- Peak aortic valve gradient (mm Hg)	20.0 [14.0, 26.3]
- Mean aortic valve gradient (mm Hg)	11.25 [8.0, 14.3]
- Aortic valve area (cm^2)	1.82 [1.6, 2.2]
- Paravalvular leak	1 (0.38)

CVA: cerebrovascular accident; ICU: intensive care unit; LOS: length of stay; LVEF: left ventricular ejection fraction; TIA: transient ischemic attack; TTE: transthoracic echocardiography.

Table 4: Follow-up (n=262).

Variables	**Median [IQR] or n (%)**
Reoperation	6 (2.26)
Endocarditis	4 (1.50)
TTE	153 (57.52)
- Peak aortic valve gradient (mm Hg)	19.0 [13.8, 23.0]
- Mean aortic valve gradient (mm Hg)	12.0 [10.0, 13.3]
- Aortic valve area (cm^2)	2.1 [1.6, 2.2]
- Paravavulvular leak	2 (0.75)

TTE: transthoracic echocardiography.

References

1. Cosgrove DM, 3rd, Sabik JF. Minimally invasive approach for aortic valve operations. Ann Thorac Surg. 1996;62:596-7.
2. Van Praet KM, van Kampen A, Kofler M, Richter G, Sündermann SH, Meyer A, et al. Minimally invasive surgical aortic valve replacement: The RALT approach. J Card Surg. 2020;35:2341-6.
3. Meyer A, van Kampen A, Kiefer P, Sündermann S, Van Praet KM, Borger MA, et al. Minithoracotomy versus full sternotomy for isolated aortic valve replacement: Propensity matched data from two centers. J Card Surg. 2021;36:97-104.
4. Bonacchi M, Dokollari A, Parise O, Sani G, Prifti E, Bisleri G, et al. Ministernotomy compared with right anterior minithoracotomy for aortic valve surgery. J Thorac Cardiovasc Surg. 2021.
5. Corrigendum to: 2021 ESC/EACTS Guidelines for the management of valvular heart disease: Developed by the Task Force for the management of valvular heart disease of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). European Heart Journal. 2022;43:2022-.
6. Vola M, Fuzellier JF, Chavent B, Duprey A. First human totally endoscopic aortic valve replacement: an early report. J Thorac Cardiovasc Surg. 2014;147:1091-3.
7. Cresce GD, Sella M, Hinna Danesi T, Favaro A, Salvador L. Minimally Invasive Endoscopic Aortic Valve Replacement: Operative Results. Semin Thorac Cardiovasc Surg. 2020;32:416-23.
8. Tokoro M, Sawaki S, Ozeki T, Orii M, Usui A, Ito T. Totally endoscopic aortic valve replacement via an anterolateral approach using a standard prosthesis. Interact Cardiovasc Thorac Surg. 2020;30:424-30.
9. Pitsis A, Boudoulas H, Boudoulas KD. Operative steps of totally endoscopic aortic valve replacement. Interactive CardioVascular and Thoracic Surgery. 2020;31:424-.
10. Yilmaz A, Robic B, Starinieri P, Polus F, Stinkens R, Stessel B. A new viewpoint on endoscopic CABG: technique description and clinical experience. J Cardiol. 2020;75:614-20.

11. Starinieri P, Declercq PE, Robic B, Yilmaz A, Van Tornout M, Dubois J, et al. A comparison between minimised extracorporeal circuits and conventional extracorporeal circuits in patients undergoing aortic valve surgery: is 'minimally invasive extracorporeal circulation' just low prime or closed loop perfusion ? Perfusion. 2017;32:403-8.
12. Capodanno D, Petronio AS, Prendergast B, Eltchaninoff H, Vahanian A, Modine T, et al. Standardised definitions of structural deterioration and valve failure in assessing long-term durability of transcatheter and surgical aortic bioprosthetic valves: a consensus statement from the European Association of Percutaneous Cardiovascular Interventions (EAPCI) endorsed by the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). European Heart Journal. 2017;38:3382-90.
13. Vo AT, Nguyen DH, Van Hoang S, Le KM, Nguyen TT, Nguyen VL, et al. Learning curve in minimally invasive mitral valve surgery: a single-center experience. Journal of cardiothoracic surgery. 2019;14:213-.
14. Masuda T, Nakamura Y, Ito Y, Kuroda M, Nishijima S, Okuzono Y, et al. The learning curve of minimally invasive aortic valve replacement for aortic valve stenosis. Gen Thorac Cardiovasc Surg. 2020;68:565-70.
15. Fujita B, Ensminger S, Bauer T, Möllmann H, Beckmann A, Bekeredjian R, et al. Trends in practice and outcomes from 2011 to 2015 for surgical aortic valve replacement: an update from the German Aortic Valve Registry on 42 776 patients. European Journal of Cardio-Thoracic Surgery. 2017;53:552-9.
16. Semsroth S, Matteucci Gothe R, Raith YR, de Brabandere K, Hanspeter E, Kilo J, et al. Comparison of Two Minimally Invasive Techniques and Median Sternotomy in Aortic Valve Replacement. Ann Thorac Surg. 2017;104:877-83.
17. Bucerius J, Gummert JF, Borger MA, Walther T, Doll N, Onnasch JF, et al. Stroke after cardiac surgery: a risk factor analysis of 16,184 consecutive adult patients. Ann Thorac Surg. 2003;75:472-8.
18. Gaudino M, Rahouma M, Di Mauro M, Yanagawa B, Abouarab A, Demetres M, et al. Early Versus Delayed Stroke After Cardiac Surgery: A Systematic Review and Meta-Analysis. J Am Heart Assoc. 2019;8:e012447.
19. Modi P, Chitwood WR, Jr. Retrograde femoral arterial perfusion and stroke risk during minimally invasive mitral valve surgery: is there cause for concern? Ann Cardiothorac Surg. 2013;2:E1.
20. Stessel B, Nijs K, Pelckmans C, Vandenbrande J, Ory JP, Yilmaz A, et al. Neurological outcome after minimally invasive coronary artery bypass surgery (NOMICS): An observational prospective cohort study. PLoS One. 2020;15:e0242519.
21. Orihashi K, Ueda T. "De-airing" in open heart surgery: report from the CVSAP nation-wide survey and literature review. Gen Thorac Cardiovasc Surg. 2019;67:823-34.
22. Young Lee M, Chilakamarri Yeshwant S, Chava S, Lawrence Lustgarten D. Mechanisms of Heart Block after Transcatheter Aortic Valve Replacement - Cardiac Anatomy, Clinical Predictors and Mechanical Factors that Contribute to Permanent Pacemaker Implantation. Arrhythm Electrophysiol Rev. 2015;4:81-5.
23. Glauber M, Ferrarini M, Miceli A. Minimally invasive aortic valve surgery: state of the art and future directions. Ann Cardiothorac Surg. 2015;4:26-32.
24. Mack MJ, Leon MB, Thourani VH, Makkar R, Kodali SK, Russo M, et al. Transcatheter Aortic-Valve Replacement with a Balloon-Expandable Valve in Low-Risk Patients. N Engl J Med. 2019;380:1695-705.
25. den Harder AM, de Heer LM, Meijer RC, Das M, Krestin GP, Maessen JG, et al. Effect of computed tomography before cardiac surgery on surgical strategy, mortality and stroke. Eur J Radiol. 2016;85:744-50.

26. Lapar DJ, Ailawadi G, Irvine JN, Jr., Lau CL, Kron IL, Kern JA. Pre-operative computed tomography is associated with lower risk of peri-operative stroke in reoperative cardiac surgery. Interact Cardiovasc Thorac Surg. 2011;12:919-23.
27. Fergo C, Burcharth J, Pommergaard HC, Kildebro N, Rosenberg J. Three-dimensional laparoscopy vs 2-dimensional laparoscopy with high-definition technology for abdominal surgery: a systematic review. Am J Surg. 2017;213:159-70.
28. Sardari Nia P, Heuts S, Daemen JHT, Olsthoorn JR, Chitwood WR, Jr, Maessen JG. The EACTS simulation-based training course for endoscopic mitral valve repair: an air-pilot training concept in action. Interactive CardioVascular and Thoracic Surgery. 2020;30:691-8.
29. Parker JM, Feldmann TF, Cologne KG. Advances in Laparoscopic Colorectal Surgery. Surg Clin North Am. 2017;97:547-60.
30. Yilmaz A, Rehman A, Sonker U, Kloppenburg GT. Minimal access aortic valve replacement using a minimal extracorporeal circulatory system. Ann Thorac Surg. 2009;87:720-5.