A totally endoscopic approach for aortic valve surgery

Alaaddin Yilmaz a,* , Silke Van Genechtena , Jade Claessensa , b , Loren Packléa , Jos Maessen c and Abdullah Kaya a,b

a Department of Cardiothoracic Surgery, Jessa Hospital, Stadsomvaart 11, 3500 Hasselt, Belgium
b UHasselt - Hasselt University, Faculty of Medicine and Life Sciences - LCRC, Agoralaan, 3590 Diepenbeek, Belgium
c Department of Cardiothoracic Surgery, Heart and Vascular Centre, Maastricht University Medical Centre, P. Debyelaan 25, 6229 HK Maastricht, The Netherlands

* Corresponding Author: Stadsomvaart 11, 3500 Hasselt/Belgium, Tel: +3211337104; e-mail: alaaddin.yilmaz@jessazh.be (A.Yilmaz).

Received 16 March 2022; received in revised form 8 June 2022; accepted 26 September 2022

Abstract

OBJECTIVES: Our goal was to describe a new approach for totally endoscopic aortic valve replacement.

METHODS: From October 2017 through December 2020, a total of 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 these, 250 (93.98%) patients were designated 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 4 (1.50%) patients within 30 days. Overall hospital mortality was 1.50%. Twenty additional deaths (7.52%) occurred during the 3-year follow-up period. An early thoracoscopic revision was needed in 7 patients due to signs of bleeding or cardiac tamponade. Fourteen patients required a permanent pacemaker implant.

†The first two authors contributed equally to this study.

© The Author(s) 2022. Published by Oxford University Press on behalf of the European Association for Cardio-Thoracic Surgery. All rights reserved.
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

INTRODUCTION

Minimally invasive cardiac surgery is evolving progressively. Cosgrove et al. described the first minimally invasive aortic valve replacement (AVR) via a ministernotomy [1]. Nowadays, ministernotomy 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 AVR like the right anterolateral minithoracotomy and right anterior minithoracotomy [2–4]. Current European guidelines advocate a transcatheter aortic valve implant for patients older than 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 ministernotomy 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 with 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 8 September 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 who had consecutive surgical AVR was included in this study. These were all patients operated on by the lead surgeon (A.Y.). In his absence, 20 urgent ministernotomies were performed. Previous cardiac surgery, ministernotomy, sutureless valve implantation or combination operations were excluded.

Procedure

All procedures are performed with the patient under general anaesthesia. The patients are placed in a supine position and receive 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 are placed at the patient’s forehead, and a transoesophageal echocardiography (TEE) probe is inserted.

The first 5-mm air-sealed trocar is introduced approximately 2 cm below the anterior axillary line in the third intercostal space and used for the 0-degree endoscope (5 mm, Karl Storz, Tuttlingen, Germany) (Fig. 1). This initial trocar is introduced during a short period of apnoea followed by CO₂-insufflation using the trocar’s side port, creating a pneumothorax of 6–8 mmHg to facilitate an adequate working space and avoid selective lung ventilation.

A working port is created by a 15- to 20-mm skin incision through the second intercostal space, large enough for the width of an index finger (Fig. 1). The pectoral muscle is divided in line with the muscle fibres, and an extra small soft tissue retractor (Shanghai International Holding Corporation GmbH, Hamburg, Germany) is placed.

Subsequently, heparin is administered after exposing the common femoral artery and vein, followed by cannulation using the Seldinger method under TEE guidance. CPB with retrograde perfusion is 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 are inserted. One port in the third intercostal space is placed directly caudal to the larger access port and one in the second intercostal space at the anterior
paravalvular leakage, weaning from CPB is initiated. In all cases, stable and TEE confirmation shows a good valve function without the presence of free air on TEE. Once the patient is haemodynamically stable and a ventricular venting catheter, which was removed only in the absence of free coronary ostia, the ascending aorta is closed using a double-layered suture Prolene 4–0. Epicardial venous drainage is established through the lateral 5-mm access point in the second intercostal space. Through this same incision, transthoracic aortic cross-clamping is obtained (Chitwood aortic clamp, GEISTER Medizintechnik GmbH, Tuttingen, Germany), immediately 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, TX, USA) inserted directly in the aorta through the large access port.

After cardioplegic arrest, a transverse aortotomy is realized at the point of the cardioplegia needle, followed by 2 traction sutures. Next, complete excision of the diseased aortic valvular leaflets and the annular decalcification is performed primarily to size the aortic annulus through the large utility port with conventional sizers. Approximately 12 pledged sutures (Ethibond 2–0, Johnson & Johnson, Somerville, NJ, USA) are placed in an inverse manner in the aortic annulus, which is subsequently put through the sewing ring of the extracorporeal prosthetic valve. The prosthetic valve is then gently parachuted transversely through the working port to its annular position without the holder and secured using the Cor-Knot system (LSI Solutions, Victor, NY, USA) (Fig. 2). After determining the function of the prosthetic valve and checking the free coronary ostia, the ascending aorta is closed using a double-layered suture Prolene 4–0. Epicardial ventricular pacing wires are positioned on the right ventricle before removing the aortic cross-clamp. De-airing is achieved by the left ventricular venting catheter, which was removed only in the absence of free air on TEE. Once the patient is haemodynamically stable and TEE confirmation shows a good valve function without paravalvular leakage, weaning from CPB is initiated. In all cases, the pericardium is approximated using Vicryl 2–0 sutures; a chest tube (Blake drain 19Fr, Johnson & Johnson, Somerville, NJ, USA) is introduced through a trocar incision into the right pleural space. All patients are transferred to the intensive care unit postoperatively.

Outcomes

The primary objectives are the occurrence of major adverse cardiac and cerebrovascular events (MACCE) and death at 30 days, 1 year and 3 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 haemodynamic dysfunction” [12]. Additionally, perioperative bleeding is defined as the amount (mL) of blood collected during the operation via suction, whereas postoperative bleeding is measured for 24 h through the thorax drains. Moreover, hospital and intensive care unit lengths of stay and complications, including surgical revisions, neurologic complications, new-onset atrial fibrillation and pacemaker implants, are secondary end points.

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 were 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%). Dyspnoea was the most common symptom (56.77%), 28.20% of the patients experienced no symptoms. The median EuroSCORE II was 1.68 [1.07,2.52], corresponding to a low perioperative risk. Pertinent preoperative patient characteristics are given in Table 1.

Early results

TEAVR was successful in all cases except in 1 patient who needed conversion to a partial upper sternotomy. Predominantly, a bioprosthesis 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] min, respectively. The operating room time was 139.0 [122.0,161.0] min. When comparing the operating room time of the first and last 10 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 a second CPB run. Other intraoperative data are presented in Table 2.

The median intensive care unit stay was 27.00 [22.00, 51.75] h, with a ventilation time of 4.00 [3.00, 6.40] h. Postoperative blood
loss was limited to 187.5 [100.00, 338.80] ml over 24 h. A thorascopic re-exploration within 48 h was performed in 5 patients (1.88%) due to signs of perpetual bleeding. In 4 cases, no active bleeding was found. Also, 2 patients, 1 of which was taking novel oral anticoagulants, required revision surgery because of a tamponade. One patient developed late bleeding 1 week postoperatively, for which thoracoscopic drainage was needed.

Postoperative neurologic symptoms were observed in 14 patients (5.27%), 5 of whom were diagnosed by computed tomography (CT) or magnetic resonance imaging as a stroke. The symptoms were temporary in 1 patient, 1 died and 3 did not fully recuperate.

Additionally, 14 (5.26%) patients developed a complete atrioventricular block requiring a pacemaker to be implanted during the hospital stay. At discharge, in-hospital TTE showed mild paravalvular leakage in 1 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 2 patients needed a reoperation (Table 4). In 2 patients, a reoperation was necessary due to tamponade and a fenestration. Early prosthetic degeneration was detected in 1 patient for which a 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, 2 (0.75%) of which showed a mild paravalvular leakage but no structural valve deterioration (Table 4).

### Major adverse cardiac and cerebrovascular events

MACCE occurred in 4 patients within 30 days (Fig. 3A). One patient died of cardiac-related issues, and 3 had a stroke. Three more patients developed MACCE over the course of a year (Fig. 3C). One suffered a cardiac-related death, whereas 2 had a stroke. During the 3-year follow-up period, 6 other patients had MACCE (Fig. 3E). One patient died of cardiac causes, and five individuals had strokes. No significant difference was noted when comparing the occurrence of MACCE at 1 year between the first and last 10 patients (0 vs 0).

### All-cause mortality

Four in-hospital deaths occurred. No additional patients died within 30 days (Fig. 3B). Seven other patients died 1 year after their procedure (Fig. 3D). Fifteen more individuals died during the 3-year follow-up period (Fig. 3F). The survival rate at 30 days, 1 year and 3 years was 98.4%, 95.1% and 84.9%, respectively. No significant difference in the number of deaths at 1 year was observed in the first and last 10 patients (0 vs 0).
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 1-year mark, 7 other patients had passed away. Moreover, during the 3-year follow-up, 15 more patients died.

In 1.50%, 3.01% and 5.26% of patients, a MACCE occurred at 30 days, 1 year and 3 years, respectively. When comparing the first and last 10 patients, there was no significant difference in 1-year MACCE and the number of deaths. Previous research regarding endoscopic surgery has shown a significant learning curve. Operating, aortic clamping and CPB times were longer due to a lack of experience and a lack of instruments [13, 14]. Tokoro et al. described operating, clamping and CPB times of 188 [56], 90 [34] and 130 [43] min, respectively [8]. Although all of the implanted valves in our series were sutured valves, which need more time to implant than sutureless valves, long aortic cross-clamping and CPB times were not seen in our first series. In our experience, the operating, clamping and CPB times were acceptable compared to those for a standard AVR by sternotomy and other endoscopic techniques [6, 8, 15]. We expect that the clamping and CPB times will be further reduced more with the use of sutureless bioprosthetic valves.

Moreover, postoperative blood loss was low, with a median of 187.50 [100.00 ,338.80] ml, and 38 (14.29%) patients needed a blood transfusion. A higher postoperative blood loss of 295.0 [325.0] ml was reported by Tokoro et al. [8].

Nine patients (3.38%) had revision operations, which is less than half of the revisions after a median sternotomy, partial upper sternotomy and anterolateral minithoracotomy (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 clot formation. A more thorough inspection of the porter incisions a few minutes after protamine administration might help diminish the cases needing revisions.

New neurologic symptoms are similar to those reported in previous studies [17, 18]. Three patients had an epileptic insult, 2 of which were treated with antiepileptic agents. Moreover, strokes occurred in 5 (1.88%) patients. Stroke can occur due to general cerebral ischaemia 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 near-infrared spectroscopy. Additionally, stroke can be caused by emboli originating from aortic manipulation with displacements of calcium or atheromatous plaques during an operation on the aortic valve. Another cause might be the retrograde perfusion technique [19]. However, this situation 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 are thus considered essential steps to diminish the occurrence of perioperative strokes. 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 operation, and trapped air bubbles are demobilized. In patients enduring hemiparesis, we postulate that air embolization occurred when starting the ventilation after removing the left ventricular vent 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 insertion of 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 atrioventricular 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 patients who were operated on 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 that of conventional AVR, where 2–7% of cases require permanent pacemaker implants [22, 23]. Moreover, the threshold of our hospital for pacemaker implants is relatively low. Compared to the results of transcatheter pacemaker implants in low-risk patients (PARTNER 3 trial), in whom pacemakers were 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 that of Pitsis et al. is the size of the working port and trocars, which are half the size in our series. Accordingly, the invasiveness of the procedure is further reduced, and the recovery is expedited [9].

An essential aspect of this experience with TEAVR is that it comprises all consecutive patients operated on by the lead

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), 1 year (C, D) and 3 years (E, F).
surgeon. We did not encounter a right anterolateral minitho-
racotomy or right anterior minithoracotomy, thanks to our experi-
ence with endoscopic procedures. No extra imaging such as
computed tomography (CT) of the thorax was necessary to
evaluate the accessibility of or indication for minimally invasive
surgery as designated by Glauber et al. [23].

Preoperative CT scanning can lead to changes in choices con-
cerning cannulation sites, aortic cross-clamp strategies, cardio-
protection and even cancellation of surgery [25]. In contrast,
when entering the chest cavity with our totally endoscopic ap-
proach, the optimal endoscopic angulation can be tailored dir-
ectly 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
a 30° 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 aid less-experienced minimally invasive
operators. Once one has passed the initial learning curve, further
refinement in minimizing operative strategy should include an
evaluation of whether routinely preoperative CT scanning offers
significant advantages to justify its radiation dose and the
nephrotoxic effects of the contrast agent.

Because 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 invasive factor. The disadvantages of the
ECC, known for conventional systems, are minimized using our
MiECC system [11, 26]. It is similar to a myocardial extracorporeal
membrane oxygenation system consisting of a closed small tub-
ing 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 3-dimen-
sional approach with tactile feedback to a 2-dimensional proc-
dure without such feedback. The addition of 3-dimensional
endoscopes might facilitate widespread adaptation in the cardio-
surgical community to a similar extent similar to that in laparo-
scopic surgery [27]. Although endoscopic surgery for mitral valve
repair is identical to our current technique, approaching the aor-
tic valve poses significant challenges due to its different anatomic
localization and much smaller access space and manoeuvre pos-
sibilities. The placement of the annular stitches is considered
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 still pri-
marily taught to become acquainted with technically challenging
open procedures using standard instruments. The step towards a
minimally invasive approach requires a different skill set. In com-
parison, colonic surgeons transiting from open to laparoscopic
colorectal surgery took 5 to 10 years before attaining sufficient
self-reported proficiency [29]. In contrast, during TEAVR, the an-
tomic working space is generally more confined, the heart axis
may vary significantly and the right hemidiaphragm is often ele-
vated (especially in patients who are obese), all contributing to a
more technically demanding procedure. Besides these exposure-
related difficulties, tissue quality in the elderly population
and heavily calcified (bicuspid) valves can further complicate our
proposed approach. Preplanning using CT is 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 begin training to learn these
complex endoscopic procedures early in their residency pro-
grams and/or follow a dedicated fellowship in a specialty centre.
Such a fellowship might be necessary not only to be taught
TEAVR in the appropriate fashion but also to become acquainted
with periprocedural complications and how to manage them in
the minimally invasive environment.

Limitations
This study has several limitations. It is retrospective in nature,
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 were available. Moreover, all patients were oper-
ated on by a single surgeon, limiting the external validity of this
trial. A multicentre study is necessary to prove the reproducibil-
ity of this technique.

CONCLUSION
TEAVR is a feasible technique, easily implemented in any cardio-
thoracic centre without large financial investments or the 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 room for improvement. The development of new
endoscopic instruments and surgical devices could further im-
prove the results of this technique. Additionally, fast-track cardiac
surgery, in which perioperative anaesthetic management intends
to extubate the patients within 1–6 h postoperatively, could
benefit patient outcomes by reducing postoperative pain and
accelerating recovery.

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

Funding statement
A research grant (Grant SURG-I21-031) from Edwards
Lifesciences was received to perform this study.
Conflicts of interest

Alaaddin Yilmaz, Silke Van Genechten, Jade Claessens and Abdullah Kaya have received a research grant from Edwards Lifesciences to perform this study. Loren Packlé and Jos Maessen have no conflict of interest regarding this research.

Data availability statement

The data from this article will be shared on reasonable request to the corresponding author.

Author contributions statement

Alaaddin Yilmaz: design and implementation of the research; provided critical feedback and helped shape the research, analyses, and manuscript; Silke Van Genechten: design and implementation of the research; took the lead in writing the manuscript; provided critical feedback and helped shape the research, analysis, and manuscript; Jade Claessens: collected the data; performed statistical analyses; provided critical feedback and helped shape the research, analysis, and manuscript; Loren Packlé: collected the data; performed statistical analyses; provided critical feedback and helped shape the research, analysis, and manuscript; Jos Maessen: provided critical feedback and helped shape the research, analyses, and manuscript; Abdullah Kaya: design and implementation of the research; provided critical feedback and helped shape the research, analyses, and manuscript.

REFERENCES