

# Transaxillary minimally invasive mitral valve surgery: early and mid-term outcomes in 763 patients

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**Background:** The transaxillary (TAXA) approach has been developed as a simplified direct-vision minimally invasive access for heart valve surgery. We report a large single-center cohort of patients undergoing TAXA minimally invasive mitral valve surgery and evaluate early safety, procedural efficacy, recovery and mid-term outcomes.

**Methods:** Consecutive patients who underwent TAXA mitral valve surgery at the University Hospital of Marche, Ancona, Italy, between January 2017 and April 2026 were included. Mitral repair or replacement procedures were considered with or without concomitant tricuspid valve repair, atrial fibrillation ablation or left atrial appendage occlusion. Early outcomes were analyzed in the overall cohort. Mid-term survival and reoperation were assessed in patients undergoing repair for degenerative mitral regurgitation.

**Results:** The study included 763 patients. Mitral valve repair was performed in 640 patients and replacement in 123. The repair rate was 89% in patients with mitral regurgitation and 92% in patients with degenerative mitral regurgitation. Concomitant tricuspid repair, atrial fibrillation ablation and left atrial appendage occlusion were performed in 17%, 5% and 10% of patients, respectively. Mean cardiopulmonary bypass and cross-clamp times were 103 and 63 minutes. Thirty-day mortality was 0.4%, stroke or transient ischemic attack occurred in 0.7%, and conversion to sternotomy was required in 0.7%; no conversion was due to poor exposure. Median ventilation time was 2 [interquartile range (IQR), 0–6] hours, 54% of patients were extubated in theatre and 80% were extubated within 6 hours. Median intensive care unit and hospital stays were 24 (IQR, 22–48) hours and 7 (IQR, 6–9) days. In the degenerative repair cohort, Kaplan-Meier survival was 97.0% at 5 years, and cumulative incidence of reoperation was 4.3% at 5 years.

**Conclusions:** In this large contemporary experience, TAXA minimally invasive mitral valve surgery was associated with low early mortality and morbidity, reasonable operative times, frequent ultra fast-track extubation, and satisfactory mid-term results.

**Keywords:** Mitral valve; mitral valve repair; minimally invasive cardiac surgery; enhanced recovery after surgery



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## Introduction

Minimally invasive mitral valve surgery has evolved over almost three decades through various technical and technological advances. These strategies have shared the same general aim of avoiding a complete median sternotomy by using reduced surgical access, with or without the aid of video assistance, telemanipulation technology or robotic

platforms (1-7). Contemporary institutional series (8-14), registry analyses (15,16) and meta-analyses (17,18) of minithoracotomy mitral valve surgery have shown excellent technical results, with perioperative safety at least comparable with full sternotomy and potential advantages in terms of postoperative morbidity, transfusion, intensive care unit stay and recovery.

Despite these results, the adoption of minimally invasive mitral surgery remains heterogeneous. Only a minority of mitral operations are performed through reduced access or robotic approaches, and the percentage is likely to be even lower for combined procedures (19-21). Concerns about technical complexity, longer cardiopulmonary bypass (CPB) and cross-clamp times, the need for dedicated instruments, technological costs and the learning curve continue to limit wider implementation.

The transaxillary (TAxA) approach was developed as a simplified direct-vision minimally invasive access for valve surgery. Through a single right lateral minithoracotomy along the anterior axillary line, the surgeon obtains a 90-degree visual trajectory to the mitral and tricuspid valve planes and to the left atrial appendage. This setup preserves conventional eye-hand alignment and avoids the need for video assistance or endovascular tools. Previous reports from our group showed low postoperative mortality and morbidity and reasonable operative times with TAxA surgery compared with full sternotomy (22), as well as favorable early recovery and reduced hospitalization within dedicated fast-track perioperative pathways (23). The aim of the present study was to report the early and mid-term results of a large cohort of patients undergoing TAxA minimally invasive mitral valve surgery, with specific focus on the technical features of the approach, intraoperative performance, early postoperative recovery and mid-term outcome

## Methods

### Study design and population

This is a retrospective outcome evaluation from institutional records with prospective data entry. Consecutive patients who underwent TAxA mitral valve surgery, either as an isolated procedure or in combination with concomitant tricuspid valve repair, surgical atrial fibrillation ablation or left atrial appendage occlusion, at the University Hospital of Marche, Ancona, Italy, from January 2017 to April 2026 were included.

The study was approved by Comitato Etico Regionale delle Marche (CERM 2019 361). Consent for the use of clinical data was obtained according to institutional policy.

### Definitions and endpoints

Preoperative variables were defined according to EuroSCORE II criteria (24). Early mortality and postoperative complications were defined as events occurring within 30 days after surgery. Postoperative outcomes were recorded using standardized definitions (25).

The study endpoints included 30-day mortality, stroke, intraoperative complications, postoperative morbidity, mechanical ventilation time, intensive care unit (ICU) stay, postoperative hospital stay and discharge destination. Residual mitral regurgitation and mean transmitral gradient were assessed before hospital discharge in patients

undergoing repair for degenerative mitral regurgitation. Survival and risk of reoperation were assessed during a median follow-up of 2.7 [interquartile range (IQR), 1.3–4.3] years. Follow-up for vital status was 100% complete, while information on mitral valve reoperation was available in 587 of 597 patients (98.3%). Vital status was obtained from the Marche regional administrative records. Information on mitral valve reoperation was obtained from institutional clinical follow-up records and/or direct telephone contact by medical staff.

### Surgical technique

All operations were performed under general anesthesia using a standard single-lumen endotracheal tube; single-lung ventilation was not required. Patients were placed in the supine position. A pillow was positioned under the right scapula to allow the right hemithorax to be slightly elevated and rotated towards the left side. The right arm was generally moved slightly away from the chest without rotation. In obese patients or in women with large breasts, the right arm was suspended to flatten the subcutaneous tissue and facilitate widening of the intercostal space. After the surgeon had marked the site of the thoracic incision, the anesthesiologist performed the serratus plane block.

The right internal jugular vein was punctured under ultrasound guidance by the anesthesiologist, and a 16F to 18F cannula was advanced and positioned under transesophageal echocardiographic guidance as part of bicaval venous drainage. Femoral vessels were surgically exposed through a small groin incision and cannulated using the Seldinger technique under transesophageal echocardiographic guidance. CPB was conducted under normothermic management with centrifugal pumps, a membrane oxygenator with integrated arterial filter and vacuum-assisted venous drainage.

The TAXA access consisted of a 4- to 5-cm skin incision on the right anterior axillary line, usually through the third or fourth intercostal space. The third intercostal space was generally favored for isolated mitral valve procedures; the fourth intercostal space was used when tricuspid valve surgery was planned. After entering the pleural cavity, CPB was started. A minithoracotomy retractor was generally used only in the initial phase to facilitate a central opening of the pericardium, similarly to what is obtained through full sternotomy. This allowed a wide pericardial flap to be created and retracted away from the phrenic nerve. A soft-tissue retractor was used for exposure thereafter. Seven sutures were placed for pericardial suspension and directly anchored to the skin: three on the upper/medial part of the pericardium and four on the lower/lateral part. Traction on the pericardial stay sutures shifted the heart toward the operator and reduced the distance between the surgical access and the cardiac structures, typically to 8–12 cm. The ascending aorta was occluded distal to the pulmonary artery bifurcation using a flexible clamp introduced through the minithoracotomy. Myocardial protection was achieved with antegrade cardioplegia delivered into the ascending aorta; histidine-tryptophan-ketoglutarate cardioplegia was used until December 2021, and del Nido cardioplegia thereafter.

The mitral valve was exposed through a left atriotomy in the interatrial groove using a conventional atrial retractor. The mitral valve apparatus was inspected and treated under direct vision, without video assistance. Valve repair techniques included implantation of artificial chordae, leaflet resection, edge-to-edge repair, commissural or cleft closure, isolated or associated annuloplasty and combinations of these techniques.

Mitral valve replacement was performed with standard stented biological or mechanical prostheses. Concomitant tricuspid repair, atrial fibrillation ablation and left atrial appendage occlusion were performed through the same access when indicated. The pericardium was closed and pericardial and right pleural drains were placed at the end of the procedure.

### Ultra fast-track perioperative management

The TAxA program was integrated into an institutional enhanced recovery pathway for heart valve surgery (23,26,27). The key components included, alongside reduction of tissue trauma through a minithoracotomy access, normothermic CPB, low-dose opioid-based anesthesia, regional analgesia with serratus plane block, local wound infiltration and continuous postoperative analgesia, early respiratory physiotherapy, mobilization and oral feeding. The intended extubation target was on-table extubation at the end of the surgical procedure when predefined hemodynamic, respiratory, neurological, bleeding and temperature criteria were met. Fast-track extubation was defined as extubation within 6 hours after the end of the operation.

Chest physiotherapy usually started 3–6 hours after extubation. Mobilization was initiated within 6–12 hours and included bed exercises, sitting, standing and assisted ambulation according to clinical conditions. Oral feeding was resumed within 6–12 hours. Drain removal and discharge from the ICU were targeted for postoperative day one whenever feasible.

### Statistical analysis

Continuous variables are reported as mean  $\pm$  standard deviation or median [interquartile range]. Categorical variables are reported as frequencies and percentages. Changes in operative times across sequential TAxA cases were assessed using linear regression of log10-transformed CPB and cross-clamp times, adjusted for combined procedures. Restricted cubic spline models with four knots at the 5th, 35th, 65th and 95th percentiles of sequential case numbers were used to characterize the evolution of operative times; adjusted predicted values were back transformed to minutes for graphical presentation. Survival probabilities were estimated using the Kaplan-Meier method and reported with 95% confidence intervals (CIs). Reoperation was analyzed using cumulative incidence estimates with death as a competing event and reported with 95% CIs. Statistical analyses were performed using SAS version 9.4, maintenance release 8 (SAS Institute Inc., Cary, NC, USA).

## Results

### Patients' characteristics

During the study period, 1,355 mitral valve operations without concomitant aortic valve, coronary artery bypass grafting or ascending aortic surgery were performed at our institution. Of these, 763 (56%) were performed through a TAxA approach and constituted the study cohort. Mean age was 64 years and 460 patients (60%) were male. Advanced symptoms, defined as New York Heart Association (NYHA) class III or greater, were present in 191 patients (25%). A history of atrial fibrillation was

recorded in 177 patients (23%) and 147 patients (19%) were in atrial fibrillation preoperatively. Mean left ventricular ejection fraction was 62%, and 35 patients (5%) had left ventricular ejection fraction below 50%. Pure mitral regurgitation was the main indication for surgery in 720 patients (94%). Moderate or greater tricuspid regurgitation was present in 192 patients (25%) (*Table 1*).

**Table 1** Preoperative patients' characteristics

| Variables                                 | Value (N=763) |
|-------------------------------------------|---------------|
| Age (years)                               | 64 [13]       |
| Male sex                                  | 460 [60]      |
| BMI (kg/m <sup>2</sup> )                  | 24.8±5.6      |
| Hypertension                              | 441 [58]      |
| Diabetes mellitus                         | 57 [7]        |
| Dyslipidemia                              | 296 [39]      |
| Smoking history                           | 138 [18]      |
| CKD (eGFR <50 mL/min/1.73m <sup>2</sup> ) | 86 [11]       |
| Peripheral arterial disease               | 9 [1]         |
| Previous cerebrovascular accident         | 21 [3]        |
| Previous CAD                              | 49 [6]        |
| Previous PCI                              | 31 [4]        |
| Previous cardiac surgery                  | 9 [1]         |
| NYHA class ≥ III                          | 191 [25]      |
| Permanent pacemaker                       | 17 [2]        |
| History of AF                             | 177 [23]      |
| Preoperative AF                           | 147 [19]      |
| Preoperative ventricular arrhythmia       | 20 [2]        |
| Hemoglobin (g/dL)                         | 13.6±1.6      |
| Hematocrit (%)                            | 41.2±4.8      |
| LVEF (%)                                  | 62±8          |
| LVEF <50%                                 | 35 [5]        |
| Pure mitral regurgitation                 | 720 [94]      |
| Etiology of pure mitral regurgitation     |               |
| Degenerative                              | 649 [90]      |
| Functional                                | 38 [5]        |
| Rheumatic                                 | 3 [1]         |
| Infective                                 | 22 [3]        |
| Failed transcatheter procedure            | 8 [1]         |

**Table 1** (*continued*)

**Table 1** (continued)

| Variables                                                                                                                                                                                                                                                                                                                                                                          | Value (N=763) |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|
| PAPs $\geq 30$ mmHg                                                                                                                                                                                                                                                                                                                                                                | 304 [40]      |
| Tricuspid regurgitation $\geq$ moderate                                                                                                                                                                                                                                                                                                                                            | 192 [25]      |
| EuroSCORE II (%)                                                                                                                                                                                                                                                                                                                                                                   | 1.2 $\pm$ 0.9 |
| Data are presented as n [%] or mean $\pm$ standard deviation. AF, atrial fibrillation; BMI, body mass index; CAD, coronary artery disease; CKD, chronic kidney disease; eGFR, estimated glomerular filtration rate; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; PAPs, pulmonary artery pressure systolic; PCI, percutaneous coronary intervention. |               |

### Surgical data

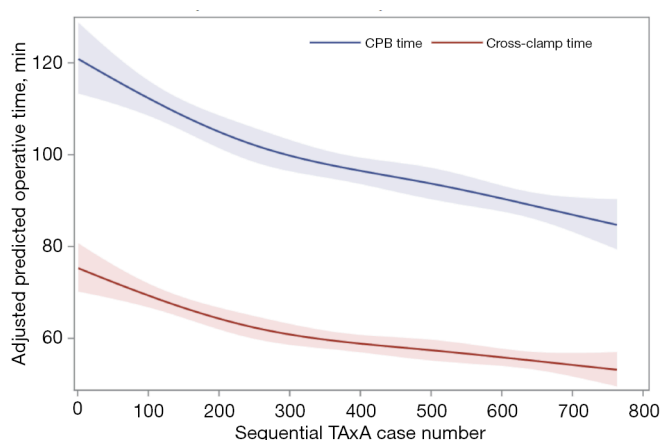
Mitral valve repair was performed in 640 patients and mitral valve replacement in 123 patients. Among patients with mitral regurgitation, the overall repair rate was 89% (640/720). Repair was achieved in 597 of 649 patients (92%) with degenerative mitral regurgitation. Among the 52 patients with degenerative mitral regurgitation who underwent mitral valve replacement, 10 (1.5% of the degenerative cohort) had an initially attempted repair converted to replacement because of an unsatisfactory intraoperative result. In the remaining 42 patients (6.5%), replacement was planned mainly because of extensive leaflet, annular or subvalvular calcification/fibrosis; other reasons included advanced age or comorbidity, unfavorable valve anatomy and leaflet tear. The most frequently used repair strategy was implantation of neochords (418/640, 65%); multiple techniques were applied in 43 patients (7%). Annuloplasty was performed in nearly all repair procedures, using a complete ring in 575 cases (90%) and a partial ring in 62 cases (9%). Concomitant tricuspid valve repair was performed in 131 patients (17%), atrial fibrillation ablation in 37 patients (5%) and left atrial appendage occlusion in 74 patients (10%) (*Table 2*). Mean CPB and cross-clamp times were 103 and 63 minutes, respectively. In isolated mitral valve procedures, mean CPB and cross-clamp times were 98 and 60 minutes. After adjustment for combined procedures, both CPB and cross-clamp times decreased significantly across sequential TAxA cases (both  $P < 0.001$ ). Restricted cubic spline modeling showed a progressive reduction in adjusted predicted CPB time from approximately 121 to 85 minutes and in cross-clamp time from 76 to 54 minutes from the beginning to the end of the experience (*Figure 1*).

| Table 2 Intraoperative data                |               |
|--------------------------------------------|---------------|
| Variables                                  | Value (N=763) |
| Mitral repair/replacement                  | 640/123       |
| Concomitant procedures                     |               |
| Tricuspid valve repair                     | 131 [17]      |
| Atrial fibrillation ablation               | 37 [5]        |
| Left atrial appendage occlusion            | 74 [10]       |
| Mitral repair for MR                       | 640/720 [89]  |
| Mitral repair for degenerative MR          | 597/649 [92]  |
| Annuloplasty ring                          |               |
| Complete                                   | 575/640 [90]  |
| Partial                                    | 62/640 [9]    |
| No ring                                    | 3/640 [1]     |
| Repair techniques                          |               |
| Resection ( $\pm$ sliding)                 | 43/640 [7]    |
| Neochordae                                 | 418/640 [65]  |
| Edge-to-edge                               | 37/640 [6]    |
| Other(s)                                   | 27/640 [4]    |
| Isolated annuloplasty                      | 72/640 [11]   |
| Multiple                                   | 43/640 [7]    |
| Neochordae + edge-to-edge                  | 31            |
| Resection + neochordae                     | 10            |
| Resection + edge-to-edge                   | 2             |
| Vascular complications                     | 5 [0.7]       |
| Cannulation-related vascular complications | 4 [0.5]       |
| RJV/SVC hematoma                           | 4             |
| Aortic dissection                          | 1 [0.2]       |
| Coronary artery complications              | 5 [0.7]       |
| Left circumflex kinking/occlusion          | 4             |
| RCA injury                                 | 1             |
| Conversion to full sternotomy              | 5 [0.7]       |
| Poor exposure                              | 0             |
| CPB management                             | 1             |
| Uncontrollable bleeding                    | 2             |
| Coronary artery complication(s)            | 1             |
| Vascular complication(s)                   | 1             |
| Cardiopulmonary bypass time (minutes)      | 103 $\pm$ 32  |
| Table 2 (continued)                        |               |

**Table 2** (continued)

| Variables                                                             | Value (N=763) |
|-----------------------------------------------------------------------|---------------|
| Cross-clamp time (minutes)                                            | 63±21         |
| Cardiopulmonary bypass time (minutes) (isolated mitral valve surgery) | 98±29         |
| Cross-clamp time (minutes) (isolated mitral valve surgery)            | 60±20         |

Data are presented as n, n [%], n/N [%], or mean ± standard deviation. CPB, cardiopulmonary bypass; MR, mitral regurgitation; RCA, right coronary artery; RJV, right jugular vein; SVC, superior vena cava.



**Figure 1** Restricted cubic spline analysis of CPB and cross-clamp times across sequential transaxillary cases, adjusted for combined procedures. Solid lines represent adjusted predicted operative times and shaded areas represent 95% confidence intervals. TAxA, transaxillary; CPB, cardiopulmonary bypass.

### Procedural complications

Vascular complications occurred in 5 patients (0.7%). Four events were related to right internal jugular vein cannulation and consisted of cervical hematoma limited to the puncture site in one patient and hematoma extending to the superior vena cava or mediastinum in three patients. In these cases, the surgical procedure was interrupted and computed tomography was performed to rule out active bleeding. After clinical and imaging monitoring, all patients subsequently underwent mitral valve surgery through the TAxA access during the same hospitalization. One patient experienced iatrogenic type A aortic dissection after removal of the cardioplegia cannula in the context of a mildly dilated ascending aorta. The patient underwent emergency repair of the aortic dissection; however, the postoperative course was unfavorable, and the patient died of multiple organ failure on postoperative day five.

Coronary artery complications occurred in five patients (0.7%), including left circumflex artery kinking or occlusion in four patients and right coronary artery injury in one patient. The patients with left circumflex artery complications were all treated in

the catheterization laboratory with coronary artery stent implantation, while the right coronary artery injury required conversion to sternotomy for coronary artery bypass grafting. All these patients were ultimately successfully discharged from hospital.

Conversion to full sternotomy was necessary in five patients (0.7%); no conversion was related to poor exposure (*Table 2*).

### Early outcomes

Thirty-day mortality was 0.4% (3 patients). The causes of death were multiple organ failure after emergency repair of an iatrogenic type A aortic dissection, extensive intracranial hemorrhage in a patient operated on for active infective endocarditis complicated by cerebral embolism, and severe biventricular dysfunction following surgical repair of an atrioventricular groove rupture occurring a few hours after ICU admission. Strokes occurred in two patients (0.3%) and transient ischemic attacks in three patients (0.4%). Re-thoracotomy was required in 39 patients (5%), including 23 patients (3%) for postoperative bleeding and 16 patients (2%) for late pleural or pericardial effusion. Continuous veno-venous hemodialysis was required in four patients (0.5%). Deep thoracic wound complications occurred in six patients (0.8%) and groin wound complications in seven patients (1%). Red blood cell transfusion was required in 249 patients (32%) (*Table 3*).

The median mechanical ventilation time was 2 [IQR, 0–6] hours. On-table extubation was achieved in 414 patients (54%) (*Figure 2*) and fast-track extubation (within 6 hours after the end of the surgical procedure) in 612 patients (80%). Median ICU stay was 24 [IQR, 22–48] hours and median postoperative hospital stay was 7 [IQR, 6–9] days. Overall, 428 patients (56%) were discharged directly home without transfer to an in-hospital cardiology ward or to a rehabilitation or nursing facility.

Among patients undergoing repair for degenerative mitral regurgitation, 451 (76%) were discharged with none or trace residual regurgitation, 133 (22%) with mild residual regurgitation and nine (2%) with moderate residual regurgitation. Mean predischarge mitral valve gradient was  $3.4 \pm 1.5$  mmHg. Seven patients (1%) required early reoperation for repair failure; four underwent repeat mitral valve repair and three mitral valve replacement. All reoperations were performed through the original TAxA access.

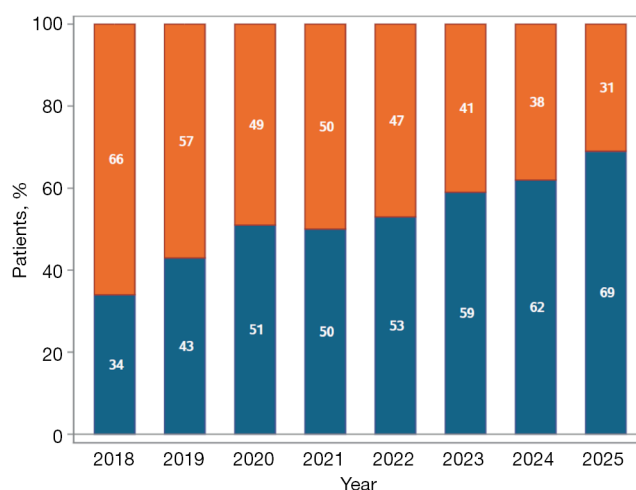
**Table 3** Postoperative results

| Variables                           | Value (N=763) |
|-------------------------------------|---------------|
| 30-day mortality                    | 3 [0.4]       |
| Stroke                              | 2 [0.3]       |
| TIA                                 | 3 [0.4]       |
| Delirium                            | 26 [3]        |
| Re-thoracotomy                      | 39 [5]        |
| <b>Table 3</b> ( <i>continued</i> ) |               |

**Table 3** (continued)

| Variables                                                | Value (N=763) |
|----------------------------------------------------------|---------------|
| Postoperative bleeding                                   | 23 [3]        |
| Late pleural/pericardial collection                      | 16 [2]        |
| CVVHD                                                    | 4 [0.5]       |
| Mechanical ventilation time (hours)                      | 2 [0–6]       |
| Ultra fast-track with on-table extubation                | 414 [54]      |
| Fast-track with extubation within 6 hours                | 612 [80]      |
| ICU stay (hours)                                         | 24 [22–48]    |
| New onset AF (in preoperative sinus rhythm)              | 169/616 [27]  |
| Permanent pacemaker                                      |               |
| Overall                                                  | 40 [5]        |
| Isolated mitral surgery                                  | 17/567 [3]    |
| Thoracic deep wound complication                         | 6 [0.8]       |
| Groin wound complication                                 | 7 [1]         |
| Infection                                                | 2 [0.2]       |
| Lymphocele                                               | 5 [0.8]       |
| Red blood cells transfusion (number of patients)         | 249 [32]      |
| Redo for early failure degenerative mitral regurgitation | 7 [1]         |
| Re-mitral valve repair                                   | 4             |
| Re-mitral valve replacement                              | 3             |
| Grade of residual regurgitation <sup>†</sup>             |               |
| None or trace                                            | 451 [76]      |
| Mild                                                     | 133 [22]      |
| Moderate                                                 | 9 [2]         |
| Mean mitral valve gradient (mmHg) <sup>†</sup>           | 3.4±1.5       |
| Hospital stay (days)                                     | 7 [6–9]       |
| Discharge home                                           | 428 [56]      |

Data are presented as n, n [%], n/N [%], or median [interquartile range]. <sup>†</sup>, after repair of degenerative mitral regurgitation, excluding one patient who died before discharge and three patients who had early redo mitral valve replacement during the same hospitalization. AF, atrial fibrillation; CVVHD, continuous veno-venous hemodialysis; ICU, intensive care unit; TIA, transient ischemic attack.



**Figure 2** Annual proportion of on-table extubation after transaxillary mitral valve surgery during the complete calendar years 2018–2025. Bars represent the annual percentages of patients undergoing on-table extubation (blue) and those not extubated on table (orange). Values within the bars indicate percentages.

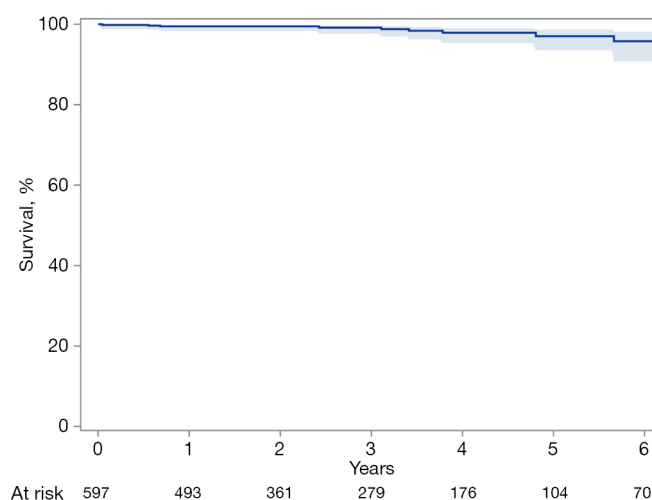
### Mid-term results

During mid-term follow-up, 10 deaths and 13 mitral valve reoperations occurred in patients who underwent repair for degenerative mitral regurgitation. Survival probabilities were 99.5% (95% CI: 99.2–99.8%) at 1 year and 97.0% (95% CI: 95.8–98.2%) at 5 years (*Figure 3*). The cumulative incidence of reoperation, with death as a competing event, was 0.9% (95% CI: 0.4–2.1%) at 1 year and 4.3% (95% CI: 2.2–7.5%) at 5 years (*Figure 4*).

### Discussion

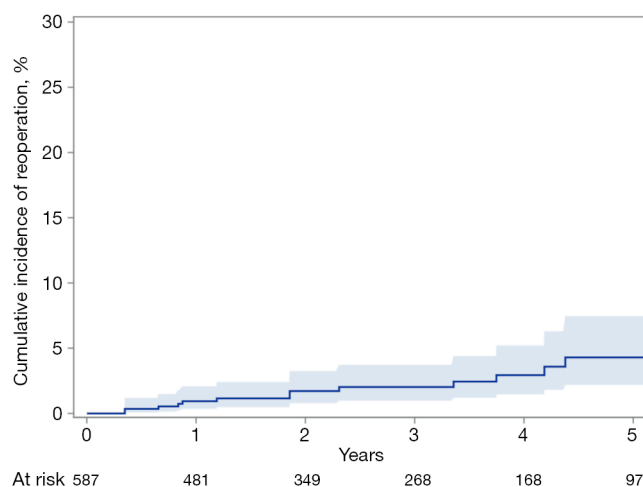
The current debate on minimally invasive mitral valve surgery is not only whether a reduced incision can reproduce the safety of sternotomy. This issue has been largely addressed by previous institutional series, registry analyses and meta-analyses showing excellent early and late outcomes (8–18,28–30). A more practical question is how minimally invasive mitral surgery can be made reproducible in daily practice. Many surgical programs have followed a strategy of technological escalation to overcome the intrinsic limitations of a reduced operative field. This may require a dedicated environment, specific instruments, video-endoscopic skills, robotic platforms or endovascular tools. Although these solutions have proved effective in dedicated institutional or single surgeon practices, they may increase the perceived distance between conventional mitral surgery and minimally invasive surgery.

The TAxA access can reduce this distance. Its innovative element is not the addition of further technology, but the simplification of the procedure with the aim of improving reproducibility. By restoring a direct relationship between the surgeon and the operative field and reducing the cognitive and technological burden by avoiding mandatory video assistance or the use of additional robotic, endoaortic or transthoracic tools,



**Figure 3** Kaplan-Meier survival probabilities in patients undergoing repair for degenerative mitral regurgitation. The solid line represents the survival estimate and the shaded area represents the 95% confidence interval. Numbers at risk are shown below the x-axis. Median follow-up was 2.7 [interquartile range, 1.3–4.3] years.

the TAxA approach may facilitate the transition from sternotomy to minithoracotomy for surgeons already experienced in conventional valve surgery. This aspect has been emphasized by external experience with the technique, in which the absence of costly dedicated equipment and the relative ease of transition from sternotomy-based surgical skills were considered important factors supporting adoption also by early-career surgeons (31).



**Figure 4** Cumulative incidence of mitral valve reoperation in patients undergoing repair for degenerative mitral regurgitation, with death treated as a competing event. The solid line represents the cumulative incidence estimate and the shaded area represents the 95% confidence interval. Numbers at risk are shown below the x-axis.

From a technical perspective, the more posterior and lateral position of the TAxA access provides a 90-degree visual trajectory to the mitral valve apparatus. With systematic pericardial suspension, the heart is shifted towards the operator and the distance from the incision to the target valve is reduced to approximately 8–12 cm. The mitral valve and subvalvular apparatus can therefore be approached under direct vision, with familiar instruments and preserved eye-hand coordination. The same operative view also includes the tricuspid valve and the left atrial appendage, which may help explain why no conversion in the present series was related to poor exposure and provides the anatomical basis for comprehensive treatment of mitral disease and associated cardiac conditions through the same incision.

In our cohort, concomitant tricuspid valve repair was performed in 17% of patients, atrial fibrillation ablation in 5% and left atrial appendage occlusion in 10%. These proportions are in keeping with those reported in large mitral valve surgery populations (10,20). By allowing associated atrioventricular and left atrial procedures through the same incision, the TAxA approach may also help experienced minimally invasive cardiac surgeons broaden the applicability of their practice, reduce the need for restrictive patient selection and provide more comprehensive treatment of concomitant cardiac conditions.

Longer CPB and cross-clamp times remain a common concern in minimally invasive mitral surgery. In the present series, mean CPB and cross-clamp times were 103 and 63 minutes, decreasing to 98 and 60 minutes in isolated mitral procedures. Importantly, after adjustment for combined procedures, both CPB and cross-clamp times decreased significantly across sequential TAxA cases (both  $P < 0.001$ ). Restricted cubic spline analysis showed a progressive reduction in adjusted predicted CPB time from approximately 121 to 85 minutes and in cross-clamp time from 76 to 54 minutes from the beginning to the end of the experience. This progressive reduction supports increasing procedural efficiency across the institutional experience. These operative times compare favorably with many non-robotic and robotic minimally invasive reports and are close to the times expected for conventional mitral surgery in experienced practice (14,32). The clinical relevance of reasonable operative times is important, because prolonged CPB and myocardial ischemic times may increase postoperative morbidity and mortality also in the typical middle-aged low-risk patients with degenerative mitral valve disease (32). In our experience, this evolution also paralleled and may have facilitated the progressive implementation and expansion of an ultra-fast-track perioperative pathway (23,26).

In this setting, the reduced incision represents one of the key components of a wider strategy aimed at limiting tissue trauma, biological stress and the overall burden of the surgical journey. The low 30-day mortality and neurological event rates observed in this series are consistent with the safety of the approach, and are also in line with real world mitral valve surgery results whether performed through sternotomy, minithoracotomy or robotic access (20,21). If minimally invasive surgery is intended to provide additional value beyond the preservation of the standard hard endpoints, recovery-related outcomes become particularly relevant. Early extubation, shorter ICU stay, early mobilization, reduced hospitalization and direct discharge home are not secondary advantages, but measurable targets of a lower perioperative impact (27).

In our experience, 54% of patients were extubated on-table and 80% were extubated within 6 hours. Median ICU stay was 24 hours, and median postoperative hospital stay

was 7 days, with 56% of patients discharged directly home. These findings are consistent with previous work from our group showing that TAxA surgery was associated with enhanced early recovery, including shorter hospital stay compared with full sternotomy (22), and with the UK Mini Mitral randomized trial, which reported shorter postoperative hospitalization and more frequent early discharge after minithoracotomy compared with sternotomy, despite no difference in recovery of physical function at 12 weeks (33). The potential early recovery benefits of minimally invasive surgery may be further enhanced when the surgical approach is embedded within a dedicated enhanced-recovery pathway. In our previous experience, an ERAS-inspired ultra-fast-track protocol was associated with shorter ICU stay and hospitalization after TAxA mitral surgery (23).

The technical efficacy of reduced access must also be judged by valve-related outcomes and durability. Mitral repair was performed in 92% of patients operated on for degenerative regurgitation. Importantly, repair was successful in 98.4% of patients in whom it was attempted, as most valve replacements were planned because of unfavorable anatomical or clinical characteristics. Among patients undergoing repair for degenerative mitral regurgitation, 98% were discharged with none/trace or mild residual mitral regurgitation and the mean transmitral gradient was low. Early redo surgery for repair failure was uncommon. During the available follow-up, survival remained high and the cumulative incidence of reoperation was low. These outcomes are in the range of historical and contemporary high-volume mitral repair series, including conventional, non-robotic minimally invasive and robotic experiences in degenerative mitral regurgitation (20,21).

This study has the limitations inherent to a retrospective observational single-center experience, although data were prospectively entered into dedicated institutional databases and follow-up was performed by medical staff. The study was not designed as a comparative analysis and cannot determine whether TAxA is superior to other minimally invasive approaches or to full sternotomy. Patient selection for the TAxA approach was individualized, and specific anatomical or pathological conditions may have favored sternotomy (22). Results were obtained in a center that has adopted TAxA surgery as a standard approach over time, and they should therefore be interpreted as the product of a standardized surgical and perioperative pathway. Finally, hospital stay and discharge destinations are influenced by local health care organization and rehabilitation policies and may therefore not be directly comparable across different health systems.

In conclusion, in this large contemporary single-center experience, TAxA minimally invasive mitral valve surgery was associated with low early mortality and morbidity, a high rate of repair, the ability to perform associated tricuspid and left atrial procedures, reasonable operative times and frequent ultra fast-track extubation. Mid-term outcomes in the degenerative repair cohort were satisfactory, with high survival and low reoperation risk.

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## Footnote

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