European Journal of Cardio-Thoracic Surgery 2025, 67(12), ezaf438
https://doi.org/10.1093/ejcts/ezaf438 Advance Access publication 3 December 2025

ORIGINAL ARTICLE

Cite this article as: Berretta P, Nakamura M, Fiore A, Lamelas J, Bonaros N, Kempfert J *et al*. Surgical Techniques and Outcomes for Atrial Functional Mitral Regurgitation: Insights From the Mini Mitral International Registry. Eur J Cardiothorac Surg 2025; doi:10.1093/ejcts/ezaf438.

Surgical Techniques and Outcomes for Atrial Functional Mitral Regurgitation: Insights From the Mini Mitral International Registry

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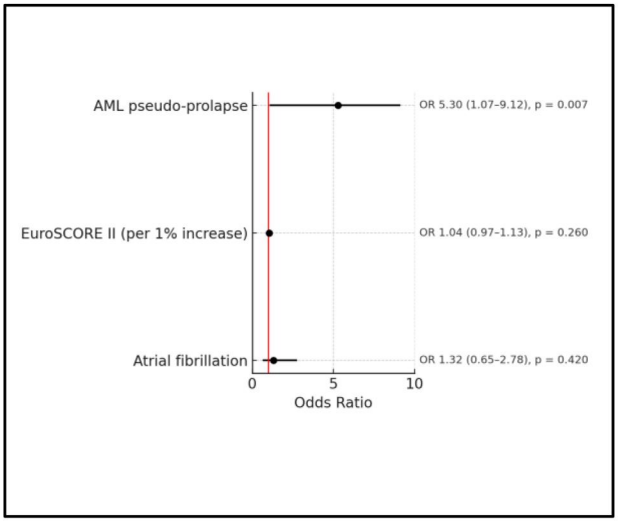
Received: September 11, 2025; Revised: November 10, 2025; Accepted: November 20, 2025

Graphical abstract

Surgical Techniques and Outcomes for Atrial Functional Mitral Regurgitation: Insights from the Mini Mitral International Registry

Summary

In 430 AFMR patients from the Mini Mitral Registry, minimally invasive mitral surgery achieved a 91% repair rate, almost exclusively through isolated annuloplasty with complete rings. Outcomes included 99% ≤mild residual MR, and 2.3% mortality. Anterior mitral leaflet pseudo-prolapse was independently associated with valve replacement.



Legend: AFMR: atrial functional mitral regurgitation. MR: mitral regurgitation

Abstract

Objectives: Evidence on optimal therapeutic strategies for atrial functional mitral regurgitation (AFMR) remains limited. This study aimed to evaluate patient characteristics, surgical techniques, and outcomes in AFMR patients from the Mini Mitral International Registry (MMIR).

Methods: Patients undergoing mini mitral surgery for AFMR between 2015 and 2023 were identified. Exclusion criteria included organic lesions, abnormal leaflet motion, reduced left ventricular function, absence of annular dilation, and previous mitral procedures.

Results: Of 7957 patients, 430 (5.4%) met AFMR criteria. The cohort was elderly (median age 73), predominantly female (67.7%), with frequent atrial fibrillation (AF) (69.7%). Mitral repair was performed in 91.4% of patients, all via isolated annuloplasty except 3. Complete rings were used in 97.1%. On multivariable analysis, anterior mitral leaflet (AML) pseudo-prolapse was associated with an increased likelihood of valve replacement (OR 5.3, 95% CI 1.07-9.12). Concomitant tricuspid repair, AF ablation, and left atrial appendage closure were performed in 44.2%, 40.5%, and 25.6%, respectively. At discharge, 99% had none or mild regurgitation; in-hospital mortality and stroke were 2.3% and 1.9%.

Conclusions: Findings from the MMIR indicate that mitral repair with isolated annuloplasty was the preferred surgical strategy for AFMR, providing satisfactory procedural and early clinical outcomes. The presence of AML pseudo-prolapse reduced the likelihood of valve repair. Overall operative results were favourable, with 99% of patients experiencing no or mild residual mitral regurgitation. These findings may serve as a reference for clinical decision-making in AFMR treatment pathways.

Keywords: atrial functional mitral regurgitation; Mini Mitral International Registry (MMIR); minimally invasive mitral valve repair; minimally invasive mitral valve surgery.

INTRODUCTION

Atrial functional mitral regurgitation (AFMR) is an increasingly recognized disease entity characterized by mitral insufficiency in the setting of a structurally normal valve, preserved left ventricular function, and left atrial enlargement.[1] It typically arises in elderly patients with atrial fibrillation (AF) and is primarily driven by atrial remodelling, mitral annular dilation, and leaflet-annular mismatch. Unlike ventricular functional MR, which is secondary to left ventricular dysfunction, AFMR presents a distinct pathophysiologic substrate that may benefit from different therapeutic strategies.

Despite its growing clinical relevance, the management of AFMR remains poorly defined and current guidelines do not provide specific recommendations. AFMR has long been overlooked as a distinct clinical entity in research, leading to a paucity of data on its management and outcomes, particularly in the surgical setting. Most available evidence derives from small, single-centre studies, often heterogeneous in terms of patient selection, surgical technique, and outcome reporting.[2-7]

In particular, no dedicated data exist on the outcomes of minimally invasive surgical treatment for AFMR.

The Mini Mitral International Registry (MMIR) is a large, multicentre registry specifically designed to capture contemporary outcomes of minimally invasive mitral valve surgery across a wide range of indications.[8,9] The aim of this study was to evaluate patient characteristics, surgical strategies, and procedural and operative outcomes in patients undergoing minimally invasive surgery for AFMR within the MMIR cohort.

PATIENTS AND METHODS

Ethical statement

The study protocol was approved by the institutional review boards of all participating institutions, following central approval from the Coordinating Centre (n.2020189, July 30th, 2020). Informed consent was obtained in accordance with local ethical regulations and waived by the respective Ethics Committees when not required.

Study cohort, definitions, and outcomes

The MMIR is an independent, multicentre registry that includes patients undergoing minimally invasive mitral valve surgery at 17 specialized heart valve centres worldwide. The rationale and methodology of the MMIR and all variable and outcome definitions have been previously described.[8] The study population consisted of patients undergoing minimally invasive mitral valve surgery for any indication, using various surgical approaches and materials. Data collection across all participating centres followed standardized definitions and assessment criteria in accordance with European Society of Cardiology and ACC/AHA/HRS Guidelines, the EuroSCORE II model, and the Mitral Valve Academic Research Consortium (MVARC) end-point definitions.[10-12]

At the time of this study, the MMIR had enrolled 7957 patients from 2015 to 2023. The present analysis includes patients with AFMR who underwent mini mitral operations.

AFMR was defined according to consensus recommendations, requiring the presence of all of the following: (1) normal left ventricle size, (2) preserved left ventricular function (LVEF ≥50%), (3) dilated left atrium, (4) dilated mitral valve annulus, (5) normal leaflet morphology, (6) normal leaflet motion, and (7) leaflet coaptation point at annular level or mildly displaced apically.[1] Exclusion criteria were: organic leaflet lesions, ventricular functional MR, abnormal leaflet motion, absence of annular dilatation, impaired LV function, and prior mitral procedures. Patients' characteristics, surgical techniques, and procedural and operative results were assessed. Successful mitral valve repair was defined as the absence of (1) mitral regurgitation > mild, (2) early reintervention (within 30 days), and (3) mitral valve prosthesis implantation. In-hospital mortality was defined as death occurring in the same hospital where the operation was performed, before discharge. Stroke was defined as a focal or global neurological deficit lasting ≥24 hours or <24 hours if neuroimaging confirmed a new intracranial or subarachnoid haemorrhage, central nervous system infarction, or if the neurological deficit resulted in death. Myocardial infarction involves either periprocedural (≤48 h after the procedure) or spontaneous (>48 hours after the procedure) infarction. Low cardiac output was defined as the need for inotropic support >24 hours or the use of temporary mechanical circulatory support. Chronic kidney disease (CKD) was defined according to the Kidney Disease Improving Global Outcomes (KDIGO) criteria, based on estimated glomerular filtration rate (eGFR) categories: mild (eGFR 60-89 mL/min/1.73 m^2), moderate (eGFR 30-59 mL/min/1.73 m^2), and severe (eGFR <30 mL/min/1.73 m^2) or dialysis dependence. Postoperative dialysis was defined as postoperative acute kidney injury requiring renal replacement therapy. Delirium was defined as an acute and fluctuating disturbance in attention, awareness, and cognition, documented by the treating team. Vascular complications were defined according to MVARC criteria.

Statistical analysis

Continuous variables were expressed as mean ± standard deviation (SD) and categorical variables as percentages. When continuous variables did not follow a normal distribution (tested using the Kolmogorov-Smirnov test for normality and Q-Q plots), they were reported as median and interquartile range (IQR). Variable-level missingness is reported in **Table S1**. Missingness pattern analysis did not reveal systematic dependence on observed covariates, supporting a missing at random mechanism. Missing data were handled using multiple imputation by chained equations with 5 imputations and 50 iterations per chain, including all predictors and the outcome variable in the imputation model. Parameter estimates and variances were combined using Rubin's rules. Predictors of mitral valve replacement were explored using Firth's penalized logistic regression with a random intercept for centre, implemented as a penalized mixed-effects model. Three clinically relevant variables were included: EuroSCORE II (continuous), AF, and anterior mitral leaflet (AML) pseudo-prolapse. Model performance was assessed by bootstrap resampling (1000 iterations). After bootstrap correction, the model showed acceptable discrimination and calibration (C-statistic 0.75, optimism-corrected 0.73; calibration slope 0.91; shrinkage factor 0.89). The analysis was designed as exploratory and hypothesis-generating, not inferential or predictive. Statistical significance was set at $P < .05$. Statistical analyses were conducted using IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Of 7957 patients enrolled in the MMIR, 430 (5.4%) met the predefined criteria for AFMR. The cohort was predominantly elderly (median age 73 years), mostly female (67.7%), and had a high prevalence of AF (69.7%). Anterior mitral leaflet pseudo-prolapse was observed in 6 patients (1.7%). Patients' characteristics are summarized in **Table 1**.

Surgical access was achieved via direct vision (24.7%), video assisted (34.2%), and full endoscopic (41.2%) approaches. Procedural details are presented in **Table 2**. Mitral repair was performed in 91.4% of cases ($n = 393$), while 8.6% ($n = 37$) required replacement, with 0.7% ($n = 3$) being converted to replacement due to unsuccessful repair. All mitral repairs were isolated annuloplasties, except for 3 patients who received an additional edge to edge repair. A complete ring was used in 97.1% of repairs ($n = 371$) and a partial ring in 2.9% ($n = 11$).

Table 1. Patients' Characteristics (n = 430)

	Frequency (*n* = 430)	%
Female	291	67.7
Age, median (IQR)	73 (65.75-77)	
NYHA class III-IV	276	64.5
Hypertension	270	76.9
Diabetes	52	12.1
Smoking	20	5.7
Obesity	99	23.1
Preoperative AF	264	69.7
Paroxysmal	65	17.2
Persistent	58	15.3
Long-standing persistent	46	12.1
Permanent	94	24.8
Pacemaker	33	7.7
Chronic kidney disease		
Mild	159	37.9
Moderate	157	37.4
Severe	16	3.8
Dialysis	3	0.7
Chronic lung disease	47	10.9
Cerebrovascular disease	10	2.3
Peripheral arteriopathy	24	5.6
Previous cardiac surgery	29	6.7
AML pseudo-prolapse	6	1.7
Tricuspid valve regurgitation		
Mild	75	17.5
Moderate	131	30.5
Severe	72	16.8
Tricuspid annular dilatation (≥ 40 mm or >21 mm/m^2)	129	37.9
Pulmonary hypertension	166	38.8
Urgent status (refractory heart failure/ decompensation)	28	6.5
Euroscore II, median (IQR)	2.43 (1.13-3.91)	

Abbreviations: AML: anterior mitral leaflet; IQR: interquartile range.

Table 2. Operative Data

	Frequency (*n* = 430)	%
Surgical approach		
Direct vision	106	24.7
Video-assisted	147	34.2
Totally endoscopic	177	41.2
Conversion to full sternotomy	8	1.9
Aortic cross-clamping type		
External clamp	325	75.6
Endoclamp	96	22.3
Type of surgery		
Mitral valve repair	393	91.4
Mitral valve replacement	34	7.9
Replacement due to unsuccessful repair	3	0.7
Mitral valve repair technique		
Annuloplasty	393	91.4
Complete ring	371	97.1
Partial ring	11	2.9
Large AP ratio	123	40.1
Low AP ratio	184	59.9
Artificial chords	–	–
Resection	–	–
Sliding	–	–
Edge to edge	3	0.7
Tricuspid repair	190	44.2
Atrial fibrillation surgery	174	40.5
LAA closure	110	25.6
Repeated cross clamping	9	2.1
Intraoperative SAM	1	0.2
CPB time (min), median (IQR)	129 (100-168)	
Cross clamp time (min), median (IQR)	68 (52.00-92.25)	

Abbreviations: AP: antero-posterior; CPB: cardiopulmonary bypass; IQR: interquartile range; LAA: left atrial appendage; SAM: systolic anterior motion.

On multivariable analysis AML pseudo-prolapse (OR 5.3, 95% CI 1.07-9.12) was significantly associated with valve replacement. Heterogeneity in repair versus replacement decisions among institutions was limited (random intercept variance 0.12) (**Figure 1**).

Concomitant tricuspid repair, AF ablation, and left atrial appendage closure were performed in 190 (44.2%), 174 (40.5%), and 110 (25.6%) patients, respectively.

In-hospital outcomes are reported in **Table 3**. In-hospital mortality occurred in 2.3% (*n* = 10) of patients, and stroke in 1.9% (*n* = 8). Median ICU and hospital stay were 2 (IQR 1-3) and 9 (IQR 7-13) days, respectively. At discharge, 99% of patients (*n* = 404) had no/mild MR with a mean valve gradient of 3.9 mmHg.

DISCUSSION

This study reports an international multicentre experience supporting the safety and efficacy of minimally invasive mitral repair for AFMR. In a large cohort of elderly and comorbid patients, isolated annuloplasty yielded excellent technical and clinical outcomes. To our knowledge, this represents the largest multicentre experience reported to date on surgical treatment of AFMR, and the first to focus on the minimally invasive approach. Previous studies have primarily consisted of small, single-centre experiences, limiting the generalizability of their findings.[2-7] Additionally, this analysis adopted a consistent definition of AFMR based on recent consensus recommendations, enhancing phenotypic consistency, and diagnostic specificity, and facilitating meaningful comparison with both surgical and transcatheter studies.[1]

The clinical profile of our cohort aligns with patterns commonly described in AFMR, elderly, predominantly female individuals with a high prevalence of AF. These patients consistently exhibit preserved ventricular function and atrial enlargement, reflecting the central role of atrial remodelling and annular dilatation in the pathophysiology of the disease. Their frequent frailty and comorbidity burden further supports the need for effective, less invasive therapeutic strategies. In this regard, transcatheter edge-to-edge repair (TEER) has gained popularity as a treatment option for AFMR, particularly in high risk or inoperable patients.[13-15] However, its performance may be suboptimal in the setting of atrial remodelling, annular dilation, and unfavourable leaflet geometry. Residual mitral regurgitation is not uncommon after TEER, and the absence of annular correction may compromise durability, especially in anatomically complex cases. Thus, while TEER remains a valuable option in selected high risk patients, its limitations in addressing the full pathophysiologic spectrum of AFMR should be acknowledged.

Surgical intervention, by contrast, enables comprehensive anatomical correction. Beyond mitral annuloplasty, the surgical approach allows concomitant treatment of atrial and right-sided pathology, including AF ablation, tricuspid valve repair, and left atrial appendage exclusion, interventions that may contribute to

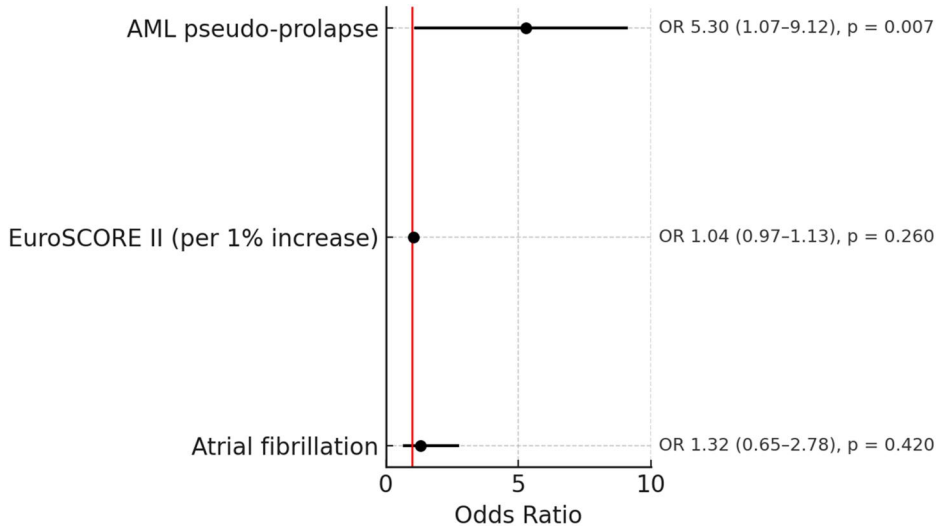


Figure 1. Factors Associated with Mitral Valve Replacement. Abbreviation: AML: anterior mitral leaflet

Table 3. In-Hospital Outcomes

	Frequency (*n* = 430)	%
In-hospital mortality	10	2.3
Thirty-day mortality	11	2.8
Stroke	8	1.9
Delirium	32	9.1
Intubation time (hours), median (IQR)	8 (5-15)	
Bleeding requiring revision	41	9.6
Transfusions (units), median (IQR)	0 (0-2)	
New onset atrial fibrillation	37	10.6
Definitive pacemaker implantation	10	2.3
Myocardial infarction	5	1.2
Periprocedural (≤48 h)	3	0.7
Spontaneous (>48 hours)	2	0.5
Low cardiac output syndrome	14	3.3
Acute kidney injury	31	8.9
Dialysis	8	2.3
Vascular complications	7	1.8
Major vasc. complications	6	1.5
Minor vasc. complications	1	0.3
Thoracic wound complications	6	1.4
MV insufficiency (after MV repair)		
No/trivial	298	79.7
Mild	72	19.3
Moderate	3	0.8
Severe	1	0.3
Mean valve gradient (mmHg), median (IQR)	3.9 (3-5)	
Redo for early failure	6	1.4
PVL (after MV replacement)	–	–
Tricuspid insufficiency		
No/trivial	147	41.8
Mild	169	48
Moderate	33	9.4
Severe	3	0.9
ICU stay (hours), median (IQR)	24 (20-72)	
Hospital stay (days), median (IQR)	9 (7-14)	

Abbreviations: ICU: intensive care unit; IQR: interquartile range; MV: mitral valve.

reverse remodelling and functional improvement. In our cohort, AF ablation was performed in over 70% of patients with preoperative AF, and tricuspid repair in 97% of those meeting current guideline-based indications (class I or IIa). Although long-term rhythm outcomes were beyond the scope of this analysis, existing evidence suggests that combining mitral repair with treatment of atrial pathology may reduce recurrence of MR and improve atrial function over time.

Minimally invasive mitral valve repair, based almost exclusively on isolated annuloplasty, proved both safe and effective. The observed repair rate (91.4%), and residual postoperative MR (99% ≤ mild) support the rationale of targeting annular dilation in AFMR, where leaflet morphology is preserved and coaptation can be restored through annular remodelling. Consistently, rings with a lower antero-posterior (AP) ratio were most frequently used (60%), while larger-AP designs accounted for 40% of cases. However, excessive down-sizing may increase transvalvular gradients. In our cohort, the median predischarge gradient was low (3.9 mmHg), but the long-term stability of these gradients remains uncertain and warrants prospective evaluation. Notably, AML pseudo-prolapse was associated with an increased likelihood of valve replacement. This echocardiographic finding is associated with "atriogenic" tethering of the posterior leaflet, a phenomenon increasingly recognized as an intermediate form between classical Carpentier type I and type IIIb lesions.[16] It is characterized by progressive posterior left atrial enlargement extending beyond the basal posterior wall of the left ventricle, which displaces the posterior mitral annulus outward towards the ventricular crest. This anatomical distortion alters the geometry of the mitral apparatus, steepens the posterior leaflet angle, and compromises coaptation.[17] In such cases, conventional annuloplasty may be insufficient, and advanced repair techniques or valve replacement should be considered. Recognition of these anatomical variants is essential to guide surgical strategy and optimize patient selection. Nevertheless, given the limited number of events in our cohort, these findings should be interpreted as hypothesis-generating and warrant confirmation in larger datasets.

Limitations

This study has the inherent limitations of observational registry research, including the absence of centralized adjudication of patient inclusion and data collection. The lack of a comparable control population precludes causal inference and may introduce selection bias. Procedural preferences and device selection

were left to the practice of each participating centre. Echocardiographic assessments were site-reported without core-lab validation, which may have affected the accuracy of specific anatomical classifications. All participating institutions are tertiary referral centres, potentially limiting the generalizability of findings to broader or community-based practice settings. The multivariable analysis was limited by the small number of valve replacement events, which constrained the number of variables that could be reliably modelled. To minimize bias and variance, missing data were handled using multiple imputation, and a Firth-penalized mixed-effects logistic model with random intercept for centre was applied. Despite acceptable discrimination and calibration, these results should be interpreted as exploratory and hypothesis-generating, given the modest event count and possible residual confounding. Finally, long-term follow-up data on repair durability and late outcomes were not available.

CONCLUSIONS

This study reports an international multicentre experience supporting isolated annuloplasty as a safe and effective surgical strategy for AFMR within a minimally invasive setting. Anterior mitral leaflet pseudo-prolapse was observed to be associated with reduced repair feasibility and may help refine patient selection. These findings may serve as a reference for clinical decision-making in AFMR treatment pathways.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

FUNDING

None declared.

CONFLICTS OF INTEREST

Nikolaos Bonaros had speakers honoraria by Edwards Lifesciences, Medtronic, institutional grant by Edwards Lifesciences, Corcym; and travel Grants by Abbott, Medtronic, Edwards Lifesciences. Jörg Kempfert had speaker honoraria by Edwards Lifesciences, Medtronic, Artivion, Abbott. Antonios Pitsis had speaker honoraria by Medtronic, Edwards Lifesciences, Delacroix Chevalier. The other authors have no conflicts of interest to declare.

DATA AVAILABILITY

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

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European Journal of Cardio-Thoracic Surgery, 2025, 67, ezaf438
https://doi.org/10.1093/ejcts/ezaf438
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