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Comparison of minimally invasive versus conventional thoracic aortic operations: Early and midterm results in a series of 624 patients

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Abstract

Objective: Despite minimally invasive techniques having gained wider application in cardiac surgery, current evidence on minithoracic aortic surgery is still limited. The aim of this study was to compare early and midterm outcomes of patients undergoing operations of the proximal thoracic aorta through ministernotomy (MS) versus full sternotomy (FS).

Methods: Data from 624 consecutive patients who underwent proximal aortic repair through MS ($n = 214$, 34.3%) and FS ($n = 410$, 65.7%) at two aortic centers were analyzed. Treatment selection bias was addressed using propensity score matching (MS vs. FS). After matching, two well-balanced groups of 202 patients each were created.

Results: Median cardiopulmonary bypass and cross-clamp times were 88 and 68 min, respectively, with no difference between groups. Overall, 30-day mortality was 1% ($n = 2$) in MS and 0.5% ($n = 1$) in FS ($p = .6$). No difference was found in the rates of stroke (MS $n = 5$, 2.5%; FS $n = 5$, 2.5%), dialysis (MS $n = 1$, 0.5%; FS $n = 4$, 2%), bleeding (MS $n = 7$, 3.5%; FS $n = 7$, 3.5%), and blood transfusions (MS $n = 67$, 33.3%; FS $n = 57$, 28.4%). Patients receiving MS showed a lower incidence of respiratory insufficiency compared with FS (0% vs. 2.5%, $p = .04$). Intensive care unit and hospital stays were similar between groups. Two-year survival rate was 97.2% in MS and 96.5% in FS ($p = .9$).

Conclusions: Mini proximal aortic operations can be performed successfully without compromising the proven efficacy and safety of conventional access. In selected patients, MS was associated with very low mortality and morbidity rates. Additionally, MS demonstrated superior clinical outcomes as regards respiratory adverse events, when compared with FS.

KEYWORDS

mini-Bentall operation, mini-David operation, minimally invasive cardiac surgery, thoracic aortic surgery

Abbreviations: AVR, aortic valve replacement; CPB, cardiopulmonary bypass; FS, full sternotomy; ICU, intensive care unit; IQR, interquartile range; MS, ministernotomy; MICS, minimal invasive cardiac surgery; NYHA, New York Heart Association; PS, propensity score; SD, standard deviation.

1 | INTRODUCTION

Thoracic aortic operations have been traditionally performed through median sternotomy access. This approach provides optimal exposure of the entire proximal thoracic aorta and proven solid results. Nowadays, cardiovascular surgery is experiencing a remarkable period of technical and technological advancements, due to the popularization of minimally invasive and catheter-based techniques. Minimally invasive cardiac surgery (MICS) has been increasingly embraced by the surgical community to reduce operative trauma and improve patients' outcomes and satisfaction. In multiple studies, MICS demonstrated improved results in patients receiving aortic and mitral valve surgery and has become the first-choice approach in many referral heart valve centers.[1,2,3–6] Recently, the increased experience with MICS has led to its adoption in more complex operations like thoracic aortic interventions. However, available data comparing minimally invasive surgery of the thoracic aorta and conventional full sternotomy (FS) approach are limited, and typically single centers reports.[1,2,3–6] Thus, the value of MICS in patients undergoing thoracic aorta reconstruction remains to be defined.

The objective of this study was to compare early and midterm outcomes of patients undergoing proximal thoracic aortic interventions through ministernotomy (MS) and FS at two aortic centers.

2 | MATERIALS AND METHODS

2.1 | Ethical statement

The study protocol was approved by the local institutional review board (no. 2019361, November 11, 2019) and the consent of patients has been waived.

2.2 | Study population and clinical data

From September 2016 to March 2021, 624 consecutive patients underwent proximal aortic operations through MS (n = 214, 34.3%) or FS (n = 410, 65.7%) at two Italian aortic centers (Lancisi Cardiovascular Center, Polytechnic University of Marche, Ancona; Careggi University Hospital, Firenze). The choice of surgical approach was made at the discretion of the operating surgeon. All patients received a preoperative computed tomography (CT) angiography scan. Exclusion criteria for MS were total arch replacement or other associated cardiac procedures, prior cardiac operations, emergency procedures, severe chest wall deformities, and active endocarditis. Patients who met these criteria were excluded from the study. A prospectively maintained clinical database and medical records were reviewed for pre-, intra-, and postoperative data. The definitions of the main variables are described in the Supporting Information: Appendix. The patients were followed by outpatient clinic, imaging review, and telephone calls. Data were presented using statistical methods controlling for treatment-selection bias (propensity score [PS] analysis).

2.3 | Surgical technique

All procedures were performed under general anesthesia. Our MS technique to access proximal aortic pathology has been previously described.[7] Briefly, after a 5–6 cm midline skin incision, a right-sided J-shaped or a left-sided L-shaped MS extended into the fourth intercostal space was performed. Cardiopulmonary bypass (CPB) was instituted using a central arterial cannulation site (distal ascending aorta or aortic arch), axillary artery, brachiocephalic trunk, or femoral artery, as indicated. The left side of the heart was vented through the right superior pulmonary vein. Antegrade infusion of cold crystalloid cardioplegia or warm blood cardioplegia via the aortic root or directly into the coronary arteries in the presence of significant aortic regurgitation was used for myocardial protection. Aortic repair was performed according to aortic pathology using the surgeon's standard techniques (Bentall/David procedure or supracoronary ascending aorta replacement ± aortic valve replacement [AVR]), regardless of the surgical access. In patients requiring open distal anastomosis, moderate hypothermic (26–28°C) circulatory arrest and antegrade selective cerebral perfusion were used for organ protection.

2.4 | Statistical analysis

Continuous variables were expressed as mean ± standard deviation (SD) and categorical variables as percentages. Where continuous variables did not follow a normal distribution (tested using the Kolmogorov–Smirnov test for normality and Q–Q plots), the median and interquartile range (IQR) were reported. Continuous data were compared with unpaired t-test or Mann–Whitney U-test, as appropriate. Categorical variables were compared by χ^2 test. To account for potential confounding effects and treatment allocation bias in our analyses, PS matching was performed to generate a study cohort of matched MS- and FS-treated patients. PSs were estimated using logistic regression modeling with surgical approach (MS vs. FS) as the dependent variable and 20 relevant covariates as the independent variables (center, age, sex, body mass index, hypertension, diabetes, smoking, chronic lung disease, cerebrovascular disease, peripheral vascular disease, coronary artery disease, atrial fibrillation, New York Heart Association class, connective tissue disease, preoperative hemoglobin, preoperative hematocrit, renal insufficiency, thoracic aorta pathology, site of thoracic aorta pathology, aortic valve disease). Patients undergoing MS were matched on a one-on-one basis with patients undergoing FS on the basis of PS, by the use of nearest-neighbor matching without replacement, and a matching tolerance (caliper) of 0.2, resulting in equal-size study cohorts. Covariate balance was measured using the standardized differences between the two treatment groups, which were calculated as the differences in the means divided by the pooled standard deviation and expressed as a percentage. A standardized difference greater than 10% is suggested to represent a meaningful covariate imbalance.[8] Postoperative outcomes were then compared between matched groups using standard univariate statistical tests of association. Continuous data were compared with paired t-test or Wilcoxon's signed-rank test, as appropriate.

TABLE 1 Demographics

Characteristics	Overall cohort Ministernotomy (n = 214)	Overall cohort Full sternotomy (n = 410)	Overall cohort Standardized difference[a]	Overall cohort p Value	Propensity-matched cohort Ministernotomy (n = 202)	Propensity-matched cohort Full sternotomy (n = 202)	Propensity-matched cohort Standardized difference[a]	Propensity-matched cohort p Value
Male	144 (67.3)	283 (69)	−3.7	.7	136 (67.3)	138 (68.3)	−2.1	.9
Age, median (IQR)	69 (57–77)	70 (59–76)	−4.2	.9	68.5 (57–77)	70 (58–76)	−3.2	.9
NYHA Class III–IV	29 (13.6)	56 (13.7)	−0.3	1	28 (13.9)	32 (15.8)	−5.8	.7
Hypertension	160 (74.8)	316 (77)	−5.3	.6	151 (74.8)	152 (75.2)	−1.1	1
BMI, median (IQR)	26.23 (23.89–28.48)	26.67 (24.18–29.68)	−30.6	.04	26.17 (23.99–28.46)	26.34 (24.01–28.88)	−0.7	.8
Obesity	32 (15)	91 (22.8)	−22.3	.03	32 (15.9)	34 (17)	−2.8	.8
Diabetes	9 (4.2)	34 (8.3)	−20.3	.07	9 (4.5)	13 (6.4)	−9.8	.5
Smoking	47 (22)	97 (23.7)	−4.1	.7	47 (23.3)	48 (23.8)	−1.2	1
Atrial fibrillation	16 (7.5)	48 (11.7)	−16	.03	16 (7.9)	17 (8.4)	−1.9	1
PM	2 (0.9)	-	6.1	.1	2 (1)	-	3.8	.5
CAD	18 (8.4)	38 (9.3)	−3.1	.8	18 (8.9)	21 (10.4)	−5.3	.7
Cerebrovascular disease	9 (4.2)	37 (9)	−24	.04	9 (4.5)	8 (4)	2.5	.9
Peripheral vascular disease	8 (3.7)	16 (3.9)	−0.9	1	8 (4)	7 (3.5)	2.6	1
Renal insufficiency (CC < 85 ml/min)	118 (55.1)	229 (55.9)	−1.4	.9	112 (55.4)	110 (54.5)	2	.9
Dialysis	1 (0.5)	2 (0.5)	−0.3	1	1 (0.5)	1 (0.5)	-	1
Chronic lung disease	16 (7.5)	38 (9.3)	−6.8	.5	14 (6.9)	16 (7.9)	−3.8	.9
Bicuspid aortic valve	68 (31.8)	130 (31.7)	1.3	1	65 (32.2)	58 (28.7)	3.2	.5
Connective tissue disease	7 (3.3)	14 (3.4)	−0.8	1	7 (3.5)	8 (4)	−2.8	1
Thoracic aorta pathology			1.1	.9			-	1
Aneurysm	213 (99.5)	407 (99.3)			201 (99.5)	201 (99.5)		
Chronic dissection	1 (0.5)	3 (0.7)			1 (0.5)	1 (0.5)		
Site of aortic pathology			−30.6	<.001			−2.3	.7
Ascending aorta	160 (74.8%)	252 (61.5%)			148 (73.3)	146 (72.3)		
Aortic root	54 (25.2%)	158 (38.5%)			54 (26.7)	56 (27.7)		

TABLE 1 (Continued)

Characteristics	Overall cohort Ministernotomy (n = 214)	Full sternotomy (n = 410)	Standardized difference[a]	p Value	Propensity-matched cohort Ministernotomy (n = 202)	Full sternotomy (n = 202)	Standardized difference[a]	p Value
Aortic valve disease								
Aortic valve stenosis ≥2+	45 (21)	82 (20)	2.1	.8	42 (20.8)	37 (18.4)	3.2	.6
Aortic valve regurgitation ≥2+	121 (56.6)	277 (67.8)	−18.1	.03	118 (58.5)	126 (62.6)	−4.5	.7
Euroscore II (%), median (IQR)	2.01 (1.26–2.97)	2.00 (1.37–3.03)	1.1	.6	2.0 (1.26–2.93)	1.99 (1.31–2.85)	1.4	1

Abbreviations: BMI, body mass index; CAD, coronary artery disease; CC, creatinine clearance; IQR, interquartile range; NYHA, New York Heart Association; PM, pacemaker.

[a]Standardized difference is the mean difference divided by the pooled standard deviation, expressed as percentage.

Time-to-event analyses were performed with the use of Kaplan–Meier estimates and were compared with the use of log-rank test. $p < 0.05$ were considered statistically significant. Statistical analysis was performed using Statistical Package for Social Sciences version 27.0 (IBM SPSS Inc.).

3 | RESULTS

3.1 | Patients' characteristics

The baseline characteristics of the two groups are listed in Table 1. The median age of the study population was 70 (58–76) years and the median EuroSCORE II was 2.01% (1.3–3.1) with no difference between groups. In the unmatched cohort, patients treated with MS presented with a lower body mass index (26.23 vs. 26.6, p = .04), lower prevalence of obesity (15% vs. 22.8%, p = .03), and lower prevalence of significant aortic regurgitation (56.6% vs. 67.8%, p = .03). Patients who received FS were more likely to have aortic root disease when compared with those who received MS (38.5% vs. 25.2%, p < .001). PS matching yielded 202 pairs treated with MS and FS. Baseline characteristics were well balanced after PS matching (Table 1). The PS-matched data are reported in the following sections.

3.2 | Operative data

The operative data are detailed in Table 2. Surgical procedures involved isolated ascending aorta replacement (MS n = 51, FS n = 53), aortic valve repair/replacement and ascending aorta replacement (MS n = 97, FS n = 93), and aortic root replacement using Bentall (MS n = 31, FS n = 40) or David (MS n = 23, FS n = 16) techniques, with no difference between groups. CPB and cross-clamp times were similar between MS and FS regardless of the type of intervention.

3.3 | 30-Day and midterm outcomes

Thirty-day outcomes are reported in Table 3. Overall, 30-day mortality was 1% (n = 2) in the MS group, and 0.5% (n = 1) FS group (p = .6). Main complication rates were similar between MS and FS; however, a lower incidence of respiratory insufficiency was observed in MS group (0% vs. 2.5%, p = .04). No significant differences were found either in intensive care unit (ICU) or hospital length of stay.

The completeness of follow-up was 98.1% and the median follow-up time was 25.8 (14.2–39.8) months. Fourteen patients died during the follow-up (MS n = 5, FS n = 9). The cause of death was cardiac-related in four patients (MS n = 1, FS n = 3), noncardiac-related in seven, and unknown in two. The estimated survival at 1, 2, and 3 years was 97.9%, 97.2%, and 97.2%, respectively, in the MS group, and 98.4%, 97.3%, and 96.5% in the FS group (log-rank p = .9) (Figure 1). The incidence of procedure-related rehospitalization was similar between MS and FS (Figure 2A). Aortic reintervention was uncommon in both groups

TABLE 2 Operative data

Variable	Ministernotomy ($n = 202$)	Full sternotomy ($n = 202$)	p Value
Isolated ascending aorta replacement	51 (25.2)	53 (26.2)	
AVR + ascending aorta replacement	88 (43.8)	80 (39.6)	
AV repair + ascending aorta replacement	9 (4.5)	13 (6.4)	
Root surgery	54 (26.7)	56 (27.7)	.9
Bentall	31 (15.4)	40 (19.8)	
David	23 (11.4)	16 (7.9)	
Hypothermic circulatory arrest + ASCP	12 (5.9)	6 (3)	.2
Arterial cannulation site			.9
Ascending aorta/arch	177 (87.6)	178 (88.1)	
Axillary/innominate artery	17 (8.4)	23 (11.4)	
Femoral artery	8 (4)	1 (0.5)	
Cardioplegia type			.02
Blood cardioplegia	92 (45.6%)	60 (29.7)	
Crystalloid cardioplegia	110 (54.4%)	142 (70.3)	
CPB time (min), median (IQR)			
Isolated ascending aorta surgery	72 (59.25–83)	65 (53–81)	.6
Ascending aorta + valve surgery	86 (74.25–99)	86 (74.5–102.5)	1
Bentall	106 (92–125)	108.5 (89.75–134.75)	.5
David	147 (135–156)	146 (128.5–160.75)	.9
Cross-clamp time (min), median (IQR)			
Isolated ascending aorta surgery	50 (42.75–60.25)	49 (38.5–61)	.9
Ascending aorta + valve surgery	66 (55–76)	65 (57.5–74)	.7
Bentall	90 (79–109)	90 (75.25–107.5)	1
David	125.5 (118.25–138)	129.5 (117–148)	.7
Conversion to full sternotomy	1 (0.5)	-	-

Abbreviations: ASCP, antegrade selective cerebral perfusion; AVR, aortic valve replacement; CPB, cardiopulmonary bypass; IQR, interquartile range.

(MS $n = 4$, FS $n = 5$). Reoperative procedures included root/ascending aorta replacement (MS $n = 2$, FS $n = 2$) and AVR (MS $n = 1$, FS $n = 0$) for endocarditis, and thoracic endovascular aortic repair (MS $n = 1$, FS $n = 3$) for aneurysmal progression of the aortic disease. Freedom from aortic reintervention at 1, 2, and 3 years was 96.5%, 94.8%, and 94.8%, respectively, in the MS group, and 97.8%, 96.8%, and 96.8% in the FS group (log-rank $p = .4$) (Figure 2B).

4 | DISCUSSION

Over the last decade, MICS has gained wider clinical application in cardiac surgery. As surgeons' experience is growing, more complex and technically demanding operations have been performed through less invasive approaches. In this regard, however, while MICS has been suggested to be a reliable approach for root and ascending aorta reconstruction,[9–11] its adoption is still limited in aortic surgery.[12] A considerable number of surgeons are skeptical about less invasive aortic techniques, claiming that smaller incisions may lead to poor exposure and make it hard to deal with any perioperative complication. In our two-center series, less invasive aortic operations provided the same safety and efficacy as the conventional FS approach and were associated with very low mortality and morbidity. Overall, 30-day mortality and stroke rates were 0.7% and 2.5%, respectively, with no difference between MS and FS approaches. These results are consistent with those reported by other high-volume aortic referral centers.[3,4,12,13] In the largest single-center study on mini ascending and root interventions, Levack et al.[4] reported comparable early results between MS and FS approaches in terms of mortality and major complication rates. Moreover, MS

TABLE 3 Thirty-day outcomes

Variable	Ministernotomy (n = 202), n (%)	Full sternotomy (n = 202), n (%)	p Value
Death	2 (1.0)	1 (0.5)	.6
Stroke	5 (2.5)	5 (2.5)	1
TIA	2 (1.0)	2 (1.0)	1
Delirium	24 (11.9)	14 (7.0)	.1
Intubation time (h), median (IQR)	5 (4–8)	6 (4–10)	.2
Respiratory insufficiency	0 (0.0)	5 (2.5)	.04
Acute kidney injury	7 (3.5)	7 (3.5)	.3
1	3 (1.5)	2 (1)	
2	1 (0.5)	1 (0.5)	
3	3 (1.5)	4 (2)	
Temporary dialysis	1 (0.5)	4 (2)	.4
Bleeding (requiring revision)	7 (3.5)	7 (3.5)	1
Transfusions	67 (33.3)	57 (28.4)	.3
Trasfusion (unit), median (IQR)	0 (0–1)	0 (0–1)	.3
Acute myiocardial infarction	3 (1.5)	3 (1.5)	1
Atrial fibrillation	83 (41.3)	79 (39.1)	.7
Definitive PM implantation	3 (1.5)	2 (1.0)	1
Sternal diastasis	5 (2.5)	1 (0.5)	.09
Superficial dehiscence	5 (2.5)	2 (1.0)	.1
Sepsis	3 (1.5)	2 (1.0)	1
ICU stay (h), median (IQR)	24 (22–43)	25 (22–47)	.3
Hospital stay (days) median (IQR)	8 (6–12)	7 (6–11)	.7

Abbreviations: ICU, intensive care unit; IQR, interquartile range; PM, pacemaker; TIA, transient ischemic attack.

demonstrated shorter ICU and hospital stays and decreased in-hospital costs. In our study, patients receiving MS were less likely to have postoperative respiratory adverse events compared to those receiving FS (0% vs. 2.5%, p = .04). As observed in patients undergoing mini-AVR,[14,15] the reduced chest injury and the increased stability of the thoracic cage that allows patients to move early and cough more effectively, may have contributed to this finding. It has to be noted also, that our data demonstrated that thoracic aortic operations can be performed through an MS approach as safely as conventional FS, not only when focusing on early outcomes but also when considering late results. All the measured midterm outcomes, namely, survival, freedom from aortic reoperation, and need for rehospitalization, were similar in MS and FS patients.

We failed to demonstrate a significant effect of MS on length of stay, despite several single-center reports of shorter hospitalization in MS patients in the literature.[16] This may be related to the multicentric retrospective design of the present analysis with the lack of predefined and agreed protocols for early discharge as well as the difference in the institutional policy regarding postoperative patient management.

One of the main concerns regarding minimally invasive operations is the perception that the increased technical demands of working through a limited space may result in prolonged operative times. This assumption was not confirmed by our findings. CPB and cross-clamp times were similar between MS and FS groups, regardless of the type of intervention. In our experience, MS access was confirmed to be very similar to conventional FS, providing excellent exposure of the entire proximal thoracic aorta, requiring no specialized techniques or equipment and only a minimal learning curve. However, in the context of minimally invasive aortic surgery, an optimized surgical strategy is mandatory to obtain successful and reproducible results. Our approach involved either a right-sided J-shaped or a left-sided L-shaped MS. The choice between the right- or the left-sided MS was based on the preprocedural CT-scan evaluation of the position of the aorta and the type of planned intervention. As a rule, L-shaped MS increases the exposure of the aortic root and the aortic arch. Thus, it was preferred in patients who required aortic root replacement or open distal anastomosis and in those presenting with left-sided ascending aorta. On the other hand, J-shaped MS facilitates access to the right superior pulmonary vein for the

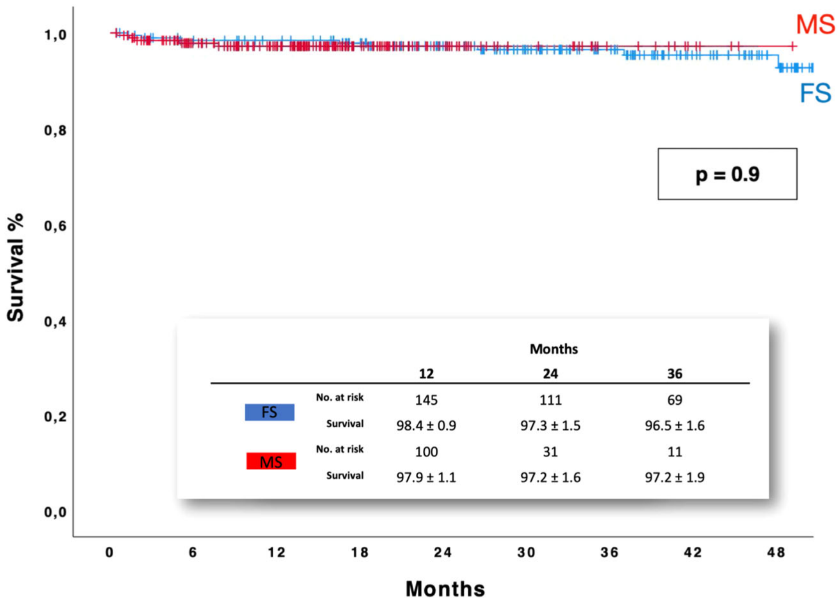

FIGURE 1 Kaplan–Meier estimate of survival

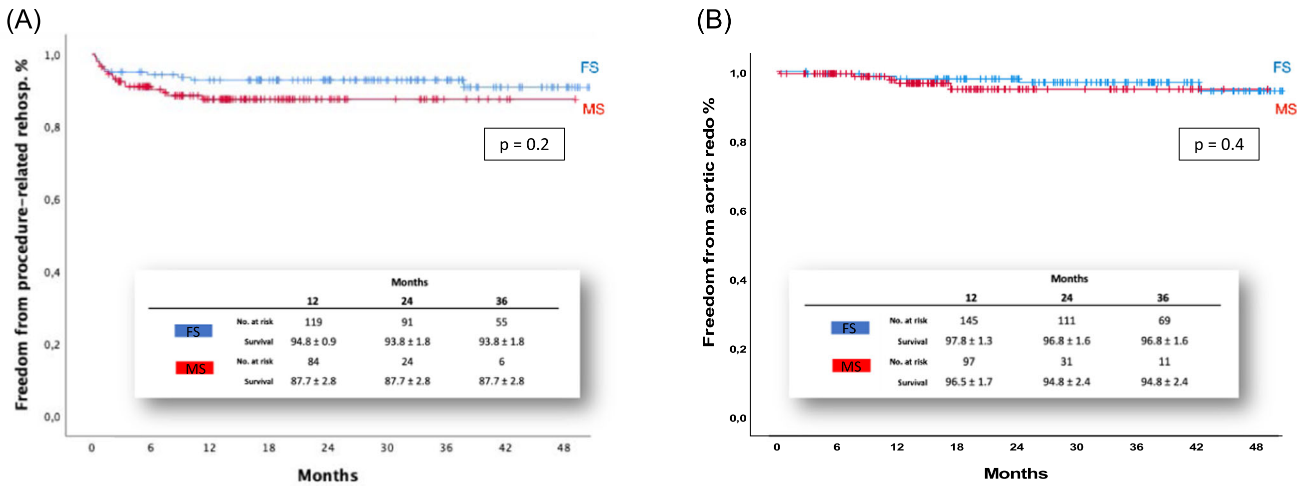

FIGURE 2 Kaplan–Meier estimate of freedom from procedure-related rehospitalization (A) and freedom from aortic reintervention (B).

placement of the left ventricular vent and avoids any potential injury to the left internal mammary artery, should it be used for coronary revascularization in the future. Accordingly, J-shaped MS was performed in patients who underwent isolated ascending aorta replacement (except for those with left-sided aorta) and in those with right-sided aorta. Using this patient-tailored approach, an optimized surgical exposure was obtained in all but one case; no conversion to FS because of uncontrolled bleeding or operative complications occurred, and only one patient (0.5%) required conversion to FS due to poor exposure. In this case, a huge ascending and root aneurysm with extremely caudal aortic root dislodgement was observed. Although our findings may suggest that there are no anatomical contraindications to MS, this access should be approached cautiously in patients with the giant ascending aorta and root aneurysms.

5 | LIMITATIONS

The present study obviously has certain limitations. It is a nonrandomized, retrospective analysis with a relatively small cohort of patients from two aortic centers, and therefore conclusions are necessarily limited in their application. Propensity analysis is a powerful statistical technique, but it is limited by the number and accuracy of the assessed variables. However, it is worth noting that in our analysis a considerable number of plausible preoperative and intraoperative covariates were used to compute the PS, and postmatching covariate balance was excellent. Finally, this study may induce selection bias because the choice of surgical approach was left to the operating surgeon.

6 | CONCLUSIONS

Findings from our study showed that minimally invasive thoracic aortic operations can be performed successfully, in selected patients, without compromising the proven safety and efficacy of conventional FS. MS approach yielded excellent early and midterm results with very low mortality and morbidity rates. In addition, MS demonstrated superior clinical outcomes as regards respiratory adverse events, when compared with FS.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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