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ORIGINAL PAPER

Surgery of the ascending aorta via a right anterior minithoracotomy: initial surgical experience of a single center

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ABSTRACT

Objectives: Full median sternotomy (FMS) is the common surgical access for patients undergoing replacement of the ascending aorta (AA) with or without aortic valve replacement (AVR). The right anterior mini-thoracotomy (RAMT) approach has been increasingly adopted for AVR. This approach has been shown to decrease blood loss and hospital length of stay (LOS) compared with FMS. The RAMT approach may also be beneficial in selected patients requiring AA procedures with or without AVR. We present our initial clinical experience of patients who have undergone a RAMT for supracommissural replacement of the tubular AA with or without AVR.

Methods: This is a single-center retrospective review of 10 patients who underwent an elective RAMT for replacement of the tubular AA with or without AVR between November 2019 and January 2022. Clinical outcomes evaluated include 30-day mortality, intensive care and hospital LOS, time to extubation, operative times, as well as postoperative complications such as stroke and bleeding.

Results: Median cross-clamp and cardiopulmonary bypass times were 109 and 148 min, respectively. Median time to extubation was 2.5 h and median intensive care unit and hospital stay were 2 and 10 days, respectively. There were two re-thoracotomies for postoperative bleeding and two cases of sub-xiphoidal pericardial drainage for pericardial effusion. There were no strokes and no in-hospital nor 30-day mortalities.

Conclusions: The replacement of the AA with or without concomitant AVR can be performed through a RAMT in carefully selected patients. However, the safety of this approach, as compared to full/partial median sternotomy, remains to be proven.

VISUAL ABSTRACT

Key questions: Can ascending aorta surgery with or without aortic valve replacement be safely performed *via* right thoracotomy?

Key Findings: A good experience of right thoracotomy approach helps performing ascending aorta surgery *via* that access in carefully selected patients.

Take home message: Center with expertise in right thoracotomy can performed ascending aorta surgery through that access in carefully selected patients. However, the safety of this approach, as compared to full or partial median sternotomy, remains to be proven.

Abbreviations: AA: ascending aorta; AV: aortic valve; AVR: aortic valve replacement; FMS: full median sternotomy; IQR: interquartile range; ICU: intensive care unit; LOS: length of stay; MIAS: minimally invasive aortic surgery; OR: operating room; RAMT: right anterior minithoracotomy; RMT: right minithoracotomy; SD: standard deviation; ST: sinotubular

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KEYWORDS
Right anterior mini-thoracotomy; ascending aorta replacement; aortic valve replacement; minimally invasive cardiac surgery

Introduction

Despite increased interest in minimally invasive cardiac surgery over the past decades, full median sternotomy (FMS) remains the gold-standard approach for the replacement of the ascending aorta (AA) and aortic valve (AV) in many centers. Indeed, this technique offers an excellent surgical exposure for the thoracic aorta and central canulation sites and yields solid results. Minimal invasive procedures involving various types of partial sternotomy have been successfully developed for thoracic aorta pathology [1–6]. However, the technical challenges and the steep learning curve required by these techniques limit their widespread adoption.

An alternative approach for minimally invasive aortic surgery (MIAS) is the right minithoracotomy (RMT), which includes the right anterior minithoracotomy (RAMT) and the lateral/transaxillary minithoracotomy. While this approach is increasingly

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used for mini aortic valve replacement (AVR) interventions [7,8], only few groups described the feasibility of RMT access in thoracic aortic surgery [9–15].

After establishing a successful minimally invasive surgery program for isolated AVR *via* a RAMT [16], we have extended this expertise to AA surgery.

The present study reports our initial single center clinical experience of AA surgery (isolated or combined with AVR) through a RAMT.

Materials and methods

Patients selection and study protocol

Between November 2019 and January 2022, 10 adult patients (≥18 years old) underwent an elective replacement of the AA with ($n = 7$) or without AVR ($n = 3$) through a RAMT incision at the department of cardiovascular surgery, University Hospital center of Liege, Belgium. Patients included in the study all presented an AA aneurysm localized in the tubular portion of the AA with preservation of the sino-tubular (ST) junction and no extension to the arch.

Moreover, we only included patients with normal left ventricular ejection fraction, and with no concomitant cardiac procedures such as coronary artery bypass, other valves surgeries (except for the aortic valve), and aortic arch or root surgeries. In addition, patients requiring emergency surgery for acute aortic syndrome such as aortic dissection or intra-mural hematoma, were also excluded. A preoperative thoraco-abdominal computed tomography scan was performed in all patients to assess the aorta anatomy and dimensions, presence of aortic calcification, as well as the position of the ascending aorta relative to the sternum. In addition, the exam was also important to evaluate any peripheral vascular disease. Patients with aortas positioned left of the sternal midline on preoperative imaging were excluded for this approach, as well as those with heavily calcified ascending aorta or porcelain aorta. Finally, The RAMT approach was not performed in patients with previous right thoracic surgery or prior sternotomy.

Patients data were collected by retrospective review of medical records. Our Institutional Ethics committee waived the need for specific consent given the retrospective nature of the study.

Data obtained included patient clinical characteristics such as age, sex, medical comorbidities and indications for surgery. Intraoperative course and perioperative clinical outcomes were evaluated. Data specific to the patient's AA aneurysm (Localization, size, isolated or concomitant to an aortic valve pathology) were also recorded.

For patients with aortic valve pathology, the lesion was assessed by diagnostic catheterization and echocardiography.

Study endpoints were short-term survival (30-day and in-hospital mortality). The median follow-up time was 12 months (7–21 months). The follow-up was complete for all patients at the end of February 2022.

Surgical technique (Figure 1)

Our surgical technique for AVR *via* RAMT has previously been described [16]. The AA and the aortic valve were reached *via* a 4–6 cm RAMT incision in the second intercostal space. No costochondral cartilage dislocation was required in our series. Cardiopulmonary bypass was established by cannulation of the femoral vessels. In our study, we only performed this approach for aneurysm limited to the tubular portion of the aorta. Therefore, the aorta was distally cross-clamped close to the innominate artery with a Chitwood aortic clamp positioned through a separate incision in the third intercostal space on the anterior mid-axillary line. Left ventricular venting was established with a cannula placed directly into the right superior pulmonary vein. All procedures were performed under moderate hypothermia (32°). Myocardial protection was achieved using 2 L of cold crystalloid cardioplegia (Custodiol) delivered into the aortic root or directly into the coronary ostia, if a significant aortic insufficiency was present. The aneurysmal part of the AA was completely transected at the level of the ST junction proximally, and few centimeters proximal to the cross-clamp distally. After completion of the distal anastomosis, a clamp was placed on the graft just proximal to the suture line, and the proximal anastomosis was completed at the level of the ST junction. In case of a concomitant AVR procedure, the valve was resected in the usual manner as for a median sternotomy and the aortic valve was replaced before performing the distal and proximal graft anastomosis. A right ventricular pacing wire was placed. Finally, the graft was de-aired and the patient was weaned off cardiopulmonary bypass. The cannulas were removed. A pleural and a pericardial chest tubes were placed. All surgical procedures were performed by a single surgeon.

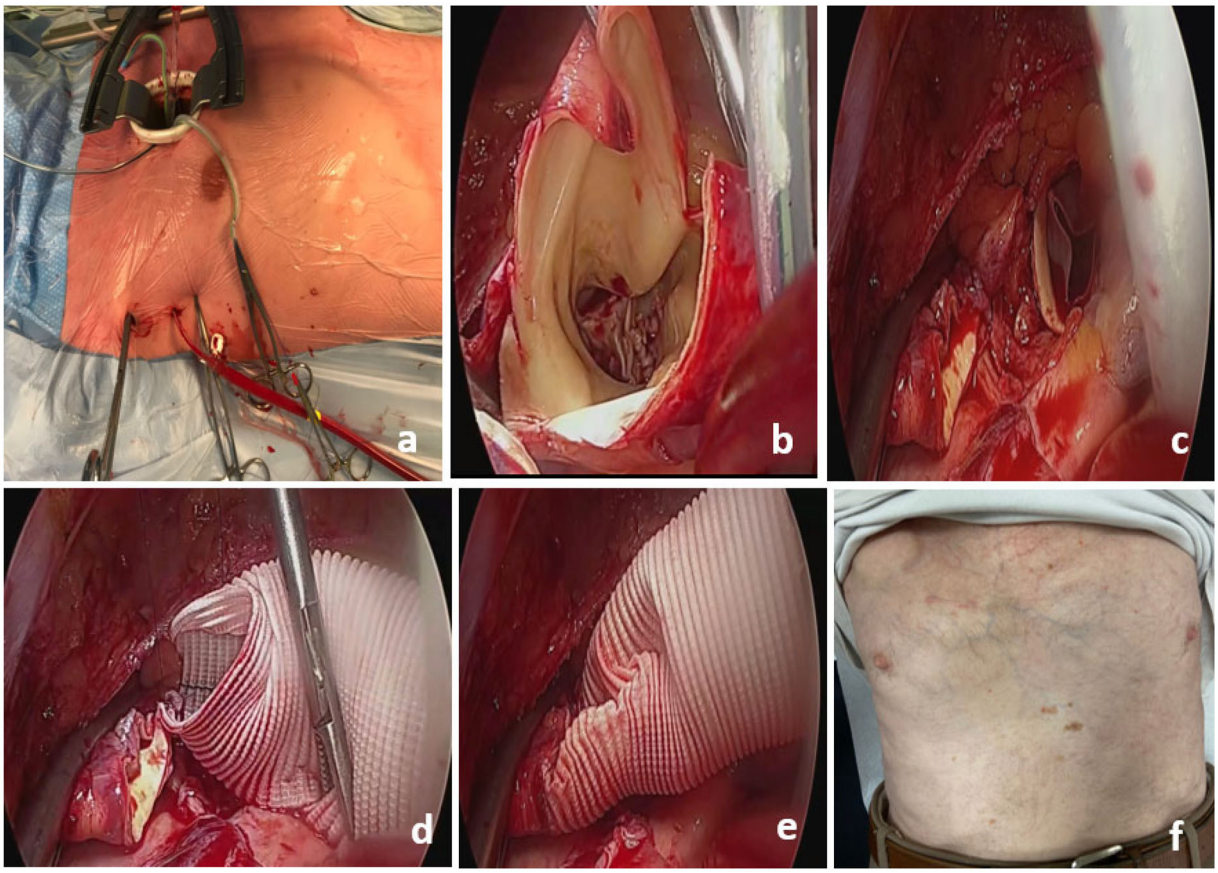

Figure 1. Concomitant ascending aorta and aortic valve replacement *via* a right anterior minithoracotomy. (a) Patient positioning with a soft tissue retractor and a rib retractor, Chitwood clamp, CO_2 insufflator, and a left ventricular vent. (b,c) Resection of the ascending aorta aneurysm, visualization of a stenotic aortic valve, and replacement of the aortic valve with a bioprosthesis. (d,e) Distal anastomosis of the tube graft with the distal ascending aorta with two running fashion Prolene 5–0. Proximal anastomosis of the tube graft to the proximal aorta at the sino-tubular junction with two running fashion prolene 5–0. (f) Patient at 4 weeks follow-up.

Statistical methods

Categorical variables were presented as numbers and percentages, while continuous variables were expressed as mean (± *SD*) or as median and interquartile range (IQR) (25–75%). The statistical analysis were performed using the SAS version 9.4 software (SAS Institute, Cary, NC).

Results

A retrospective database review identified 10 patients who underwent replacement of the AA with ($n = 7$) or without AVR ($n = 3$) *via* a RAMT approach. There were six men and four females. The mean age at the time of surgery was 66.8 ± 8.6 years. Mean logistic Euroscore II (European system for cardiac operative risk evaluation) was 2.6 ± 1.1. Mean Left ventricular ejection fraction was 62.3 ± 4.4%. There was one patient with a history of ischemic cardiomyopathy. All the aneurysms were located in the tubular portion of the AA with a mean diameter of 47.9 ± 5.2 mm. For the three patients, with isolated replacement of the AA, the diameter of the tubular ascending aorta ranged from 50 to 60 mm. Aortic valve pathologies were aortic valve stenosis (7/7). Aortic valve morphology was bicuspid (4/7) and tricuspid (3/7). In six patients, a conventional bioprosthesis was used, while a mechanical valve was implanted in the remainder ($n = 1$). Median aortic cross-clamp and cardiopulmonary bypass times were 109 min (100–127 min) and 148 min (120–153 min) respectively. There was no intraoperative conversion to sternotomy. The mean ventilation time was 2.5 h (0–6 h), with five patients who were extubated directly in the operating room (OR). The median intensive care unit (ICU) and hospital length of stay (LOS) were 2 days (1–2 days) and 10 days (8–15 days) respectively. Post-operative complications included surgical revision for bleeding in two patients with one requiring a sternotomy and the other needing a re-thoracotomy. A subxiphoidal pericardial drainage was performed in two patients through a 2 cm incision, for moderate pericardial effusion. All the four patients who were reoperated for bleeding or pericardial effusion, received blood transfusion (40%). The mean chest tubes output at 24 h postoperatively was 815 ± 500 mL (and

518.75 ± 204.06 mL when removing the two patients who were reoperated for bleeding). There were no strokes nor in- hospital mortality. The 30-day survival was 100%. All 10 patients were alive at the last clinical follow-up. The baseline characteristics of our patients and their perioperative outcomes are described in Tables 1 and 2.

Discussion

Several authors have shown that complex AA (ascending aorta, arch, aortic root) surgeries can be performed through various partial sternotomy approaches with excellent clinical outcomes [5,17–20]. Perotta et al. in a literature review comparing different ministernotomy incisions to FMS for surgery of the aortic root and the AA, reported significant advantages for the ministernotomy, including reduced pain, blood use, ventilator time, ICU LOS and lower risk of infection [17]. In addition, in a meta-analysis comparing intraoperative and perioperative outcomes of MIAS (Partial sternotomy and RMT) to those of a FMS, Rayner et al. reported similar mortality rates for both groups and some evidence of improved outcomes for patients who had MIAS. However, the low quality of the available evidence highlights the need for powered randomized controlled trials to confirm these findings [21].

AA surgery with or without AVR *via* a RMT has only been reported by few centers [10–13,15]. In a study of patients requiring circulatory arrest for AA aneurysm with or without aortic valve involvement, the authors found that perioperative morbidity and mortality between the RMT and FMS approaches were comparable. The primary benefits seen in the RMT group were reduced ICU and hospital LOS, and fewer transfusion requirements [10]. Johnson et al. described a retrospective case series of 7 Bentall procedures through RAMT using thoracoscopic visualization and automated suturing technology in some cases. The authors achieved excellent clinical outcomes [13]. Finally, Ji et al. recently reported a retrospective series of 15 successful Bentall procedures through RAMT, with no in-hospital nor 30-day mortalities [15].

Our center performed about 65 isolated or concomitant AA procedures per year *via* FMS. Since 2017, RAMT approach has become the preferred

Table 1. Preoperative characteristics.

Age (years), mean±*SD*	66.8 ± 8.6
Male gender, *n*(%)	6 (60)
BMI (kg/m^2), mean±*SD*	27.5 ± 3.4
Arterial hypertension, *n*(%)	9 (90)
Diabetes, *n*(%)	3 (30)
Current smoker, *n*(%)	1 (10)
Ex-smoker, *n*(%)	3 (30)
Dyslipidemia, *n*(%)	6 (60)
COPD, *n*(%)	1 (10)
Ischemic cardiomyopathy, *n*(%)	1 (10)
Euroscore II (%), mean ±*SD*	2.6 ± 1.1
LVEF ≥ 60%, *n*(%)	10 (100)
NYHA 1, *n*(%)	2 (20)
2, *n*(%)	6 (60)
3, *n*(%)	2 (20)
4, *n*(%)	0 (0)

BMI: body mass index; COPD: chronic obstructive pulmonary disease; LVEF: left ventricular ejection fraction; NYHA: New York heart association; *SD*: standard deviation.

Table 2. Operative details and postoperative outcomes.

Aortic indication	
True aneurysm, *n*(%)	10 (100)
Aneurysm localization	
Tubular ascending aorta, *n*(%)	10 (100)
Aorta procedure	
Isolated Supracoronary ascending aorta replacement, *n*(%)	3 (30)
Concomitant Supracoronary ascending aorta replacement + AVR, *n*(%)	7 (70)
Valve indication	
Stenosis	7 (100)
-Bicuspid, *n*(%)	4 (57)
-Degenerative tricuspid, *n*(%)	3 (43)
Tubular ascending aorta diameter, mean±*SD*	47.90 ± 5.2
Operative details	
Cross-clamp time (min), median (IQR)	109 (100–127)
CPB time (min), median(IQR)	148 (120–153)
Postoperative outcomes	
Ventilation time (h), median (IQR)	2.5 (0–6)
ICU LOS (days), median(IQR)	2.0 (1–2)
Hospital LOS (days), median (IQR)	10.0 (8–15)
Blood loss (mL), mean±*SD*	815 ± 500
Blood product use (units), mean±*SD*	
-Red blood cells	1 ± 2.5
-Fresh frozen plasma	1.5 ± 2.5
-Platelets	0.8 ± 1.8
In-hospital death, *n*(%)	0.0 (0)
30-day mortality, *n*(%)	0.0 (0)
Follow-up (months), median (IQR)	12 (7–21)

AVR: aortic valve replacement; CPB: cardiopulmonary bypass; ICU: intensive care unit; IQR: interquartile range; LOS: length of stay; *SD:* standard deviation.

technique used in our center for isolated AVR. Our initial clinical results have been reported previously [16]. Our growing experience with mini-AVR techniques enabled us to adequately develop a routine approach which minimizes the challenge of converting from isolated AVR to AA surgery with or without AVR. Moreover, the authors initially selected low-risk patients, with AA aneurysm localized in the tubular portion of the AA without arch involvement, to undergo surgery *via* RAMT (Figure 2). Table 3 describes the patient selection criteria between the different surgical approaches for surgery of the ascending aorta in our center.

In the present study, the median cross-clamp and CPB times are relatively long compared with FMS, but remain consistent with reported series of ascending aorta surgery with or without AVR *via* RMT [10,13,15]. However, the type of surgeries performed are quite heterogenous between the series (Bentall, Ascending aorta with or without AVR, used of circulatory arrest) (Table 4) which complicates direct comparison. In our study, 50% of the

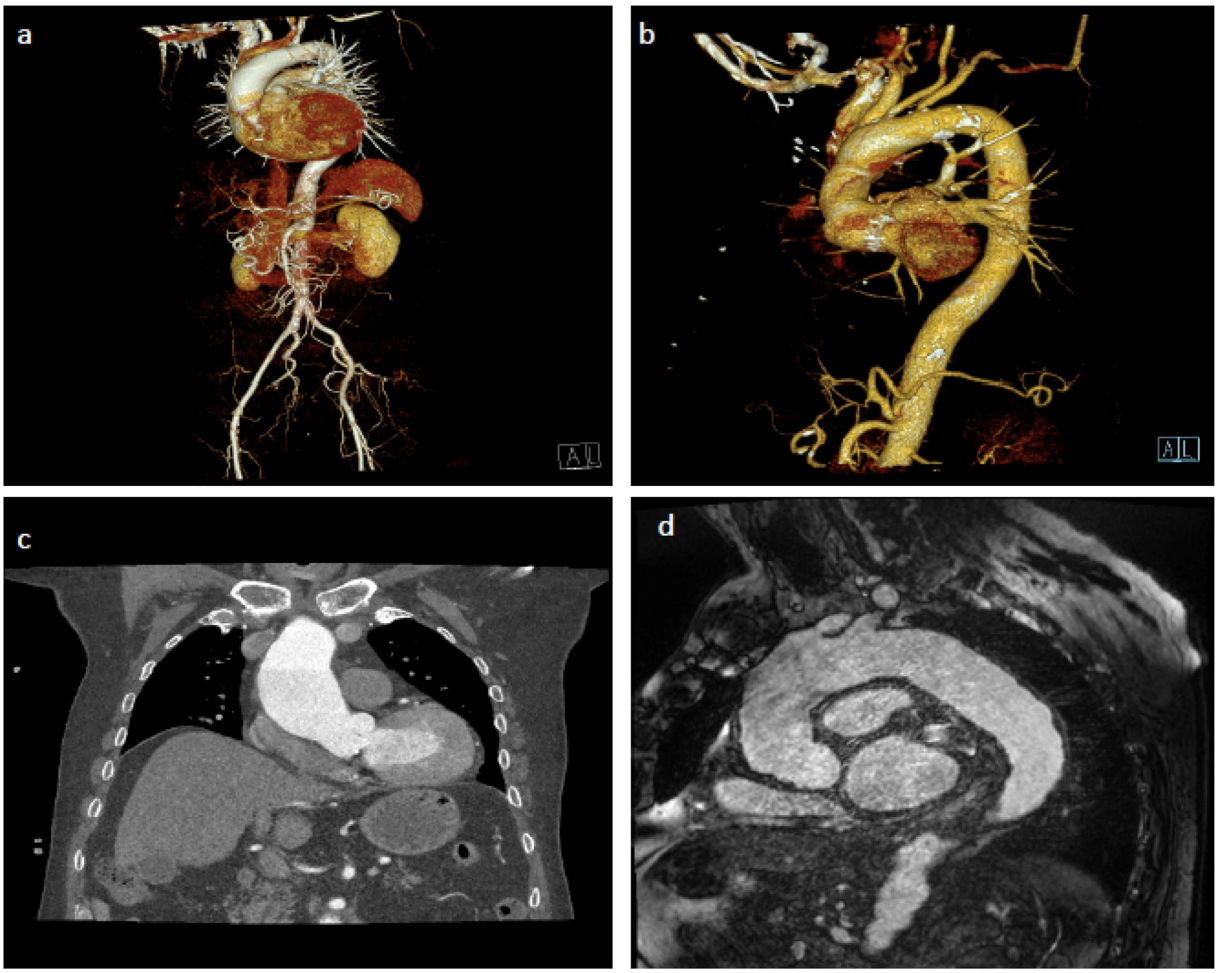

Figure 2. Patient 1 (a,b). Preoperative 3D reconstruction of angioCT images of the entire aorta showing an aneurysm of the tubular ascending aorta at 45 mm (a). The patient underwent a replacement of the ascending aorta with a 26 mm vascular Graft, combined to a replacement of a stenotic aortic valve with a bioprosthesis. Angio CT 3D reconstruction at 7 months postoperatively (b). Patient 2 (c,d). Thoracic angioCT showing an aneurysm of the tubular ascending aorta at 60 mm (c). Replacement of the tubular ascending aorta with a 34 mm vascular Graft. AngioMRI at 1 year postoperatively (d).

Table 3. Patients selection criteria between the different surgical approaches for surgery of the ascending aorta at the university hospital center of Liege (Belgium) (Initial experience).

	FMS	PUS (J)	RAMT
Position of the ascending aorta			
Left of the sternal midline	ok	ok	no
Tubular ascending aorta aneurysm characteristics			
Size	No limitation	No limitation	No limitation
ST junction dilatation	ok	ok	no
Root aneurysm	ok	ok	no
Arch aneurysm	ok	Only hemi-arch	no
Combined procedures	ok	only AVR	only AVR

AVR: aortic valve replacement; FMS: full median sternotomy; PUS (J): J partial upper sternotomy; RAMT: right anterior mini-thoracotomy; ST: sinotubular junction.

Table 4. Summary of reported studies of minimally invasive aortic surgery *via* right minithoracotomy.

Author study period	Number of patients	Type of surgery (%)	CPB (min), median (IQR)	Cross-clamp (min), median (IQR)	CA (min), median (IQR)	Ventilation time (h), median (IQR)	ICU LOS (day), median (IQR)	Hospital LOS (day), median (IQR)	Re-exploration for bleeding, *n*	30-day mortality, *n* (%)	Mean FU (months), median (IQR)
Johnson et al. [13] 2016–2018	7	Bentall (100%)	217 (NA)	153 (NA)	28 (NA)	10 (NA)	1 (NA)	4 (NA)	1	0 (0)	NA
Lamelas et al. [10] 2009–2012	74	AAR with CA with or without AVR*	183 (153–205)	141 (113–164)	37 (33–43)	9.3 (3.95–17.95)	1.2 (1–3)	5 (4–7)	0	2 (3.2)	NA
Ji et al. [15] 2019–2021	15	Bentall (100%)	138.5 (130.5–163.5)	95 (85.5–98.8)	No CA	12.5 (11–25)	1.5 (1–3)	5.8 ± 1.2**	0	0 (0)	8 (6–10)
Present study 2019–2022	10	Isolated AAR (30%) AAR + AVR (70%)	148 (120–153)	109 (100–127)	No CA	2.5 (0–6)	2 (1–2)	10 (8–15)	2	0 (0)	12 (7–21)

*The authors did not report the proportion of patient for each procedure.
**The data was expressed as the mean (*SD*) postoperative LOS and not as the median (IQR) hospital LOS.
AAR: ascending aorta replacement; AVR: aortic valve replacement; CA: circulatory arrest; CPB: cardiopulmonary bypass; FU: follow-up; ICU: intensive care unit; IQR: interquartile range; LOS: length of stay; NA: not available.

patients were directly extubated in the OR reducing the ventilator time compared to other series of AA surgery through RMT (Median 2.5 (0–6) h). Yet, we observed a prolonged hospital LOS in our group compared to other series. This is due to the 4 patients who required reoperation for bleeding or pericardial effusion in our series. This also explains the higher postoperative chest tubes output in our series compared to the literature. Patients undergoing re-exploration for bleeding were done through reopening the minithoracotomy incision ($n = 1$) or conversion to FMS ($n = 1$). The latter was brought back to the OR at postoperative day (POD) 1 when an inadvertent flush of vasopressors raised the systolic blood pressure to 220 mmHg with an increased output of blood through the chest tubes. After performing a rapid sternotomy because of hemodynamic instability, the patient was found to have an active bleeding from the aortotomy site. Finally, a pericardial drainage for moderate pericardial effusion was performed through a 2 cm subxiphoidal incision in 2 patients at POD 4 and 10, respectively. We found this subxiphoidal approach straightforward and in our experience, this small additional incision did not compromise the clinical outcome of the patients.

Over time, we noticed a reduction in the rate of re exploration for bleeding. Despite these complications, there were no stroke, no in-hospital death, and the 30-day survival was 100% in our series.

Moreover, during a median follow-up period of 12 months (7–21 months), all 10 patients survived without reoperation, with an improved NYHA functional class (Class I), and no perivalvular leak in the subgroup with concomitant AVR.

Limitations of our study include its retrospective and observational design and the short follow-up period. Furthermore, the sample size is small ($n = 10$) and there is no control group including patients who underwent the same procedure through partial or FMS. Therefore, no definitive conclusions can be drawn on the advantages of this approach. Finally, this is a group of selected patients with few comorbidities, low surgical risk (Mean Logistic-Euroscore II of 2.6 ± 1.1), and normal ejection fraction suggesting that the study results might not be transposable to higher risk patients.

Conclusions

Despite a high rate of post-operative bleeding or pericardial drainage, our results indicated that RAMT for surgery of the AA with or without

concomitant AVR is feasible in carefully selected patients. However, the safety of RAMT, as compared to full or partial MS, remains to be proven both during hospital stay as well as at mid/long-term follow-up. Finally, we emphasize the need for prolonged experience with RAMT approach and careful patient selection in the early stages of a RAMT program for the AA with or without concomitant AVR.

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Author contributions

VTS, conception, study design, data analysis and collection, manuscript drafting; SB, data analysis and interpretation; EML, AH, data analysis and collection, QD, GH, MGL, OJ, helped to treat the patients and contributed to data collection, JOD, critical revision; JPL, conception, study design, critical revision.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data that support the findings of this study are available from the corresponding author (VTS) upon reasonable request.

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