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Original Article

Open surgery *versus* branched endovascular repair of the aortic arch in residual dissections after type A surgical repair

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Abstract

Background: Redo open arch repair is challenging; arch branched endovascular aortic repair (a-BEVAR) offers a less invasive alternative. However, direct comparisons are lacking. The aim of this study was to compare the outcomes of open arch repair *versus* a-BEVAR in patients with residual aortic dissection after ascending aorta replacement for acute Stanford type A aortic dissection.

Methods: This multicentre retrospective study included patients treated for residual dissection after type A aortic dissection in ten high-volume centres from January 2018 to May 2024. Propensity score matching (1 : 1) was used to adjust for baseline differences. Primary endpoints included 30-day mortality and stroke rates, and secondary endpoints included acute kidney injury, spinal cord ischaemia, reintervention, aortic-related mortality, and hospital length of stay.

Results: A total of 183 patients were included: 89 (48.6%) underwent open arch repair and 94 (51.4%) underwent a-BEVAR. After propensity score matching, there were 57 patients in each group. The 30-day mortality rate was 3.5% for open arch repair and 5.3% for a-BEVAR ($P = 0.220$). The stroke rate was 5.3% for open arch repair and 3.5% for a-BEVAR ($P = 0.650$). Open arch repair was associated with significantly higher rates of prolonged (>48 h) intubation (28.1% *versus* 3.5%; $P < 0.001$), acute kidney injury (31.6% *versus* 8.8%; $P = 0.002$), and temporary dialysis (22.8% *versus* 7.0%; $P = 0.002$). The median hospital length of stay was 21 days for open arch repair and 10 days for a-BEVAR ($P < 0.001$). During a median follow-up of 30 months (i.q.r. 7-49), no difference in mortality was observed (10.5% for open arch repair *versus* 12.3% for a-BEVAR; $P = 0.770$).

Conclusion: a-BEVAR provides a less invasive alternative to open arch repair with reduced complications. Long-term studies are needed.

Introduction

Acute Stanford type A aortic dissection (TAAD) is a life-threatening condition, requiring emergency open ascending aorta repair to avoid aortic rupture and cardiac tamponade, and to solve dissection-related malperfusion[1,2]. Conventional surgery for TAAD typically involves repairing a limited section of the diseased aorta with ascending aorta or hemiarch replacement[3]. However, due to the progression of the underlying disease, 11.5–22.7% of patients will require a second surgery for residual arch and descending thoracic aorta (DTA) dissection after open TAAD repair[3–5].

Frozen elephant trunk (FET) and elephant trunk (ET), with extensive repair including graft replacement of the ascending aorta and aortic arch and integrated stent grafting of the descending aorta, are recommended for the treatment of residual aortic arch dissection[6]. Redo open arch repair (OAR) remains demanding for the surgeon and the patient, associated

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with high morbidity and mortality due to factors such as redo sternotomy, adhesions, the complexity of the operative field, circulatory arrest with hypothermia, and the patient's physiological condition[7].

Arch branched endovascular aortic repair (a-BEVAR) offers a less invasive approach, potentially reducing surgical risks[4,8]. Several studies have evaluated the outcomes of open and endovascular repair independently, without direct comparison[4,9–14].

The aim of this study was to compare, using propensity score matching, the early and mid-term outcomes of two treatment strategies—redo OAR *versus* a-BEVAR—in patients with residual chronic aortic arch and DTA dissection, previously treated for TAAD through open ascending aorta replacement.

Methods

Study design

This was a non-randomized, retrospective multicentre study of consecutive, prospectively enrolled patients who underwent aortic arch intervention with either OAR or a-BEVAR after previous open ascending aorta replacement for TAAD at ten high-volume aortic centres between January 2018 and May 2024. Open and endovascular aortic arch repair were available in all of the participating institutions that were part of the international multicentre Post-Dissection Arch Repair Study Group. Institutional Review Board and Ethics Committee approval were required and were obtained (Ethics Committee for Clinical Experimentation, Rome: study ID 2529). The ClinicalTrials.gov ID is NCT04014907. The requirement for individual consent was waived due to the retrospective design of the study and the use of anonymized data. Data privacy was managed according to the National Privacy Act. Study data were collected at each centre and gathered using Research Electronic Data Capture (REDCap) tools[14]. Prospectively collected data were available for OAR and a-BEVAR from all of the centres, except for OAR from three centres (Paris, Hamburg, and Massachusetts). The database included preoperative demographics, risk factors, anatomical features, procedural details, and follow-up outcomes (postoperative clinical events and imaging examinations).

Study population

Patients who underwent open or endovascular arch intervention for residual chronic aortic arch and DTA dissection after previous TAAD repair with ascending aortic with or without hemiarch replacement were included. The emergency TAAD surgery was performed depending on the location of the primary entry tear through median sternotomy[15,16]. Additional procedures such as valve substitution or coronary artery bypass grafting were performed as required on a case-by-case basis[15,16].

Primary indications for the aortic arch index procedure were maximum aortic diameter >55 mm and rapid growth (>10 mm/year). Patients were excluded in case of aortic rupture or an emergency setting with haemodynamic instability. Analysis of the preoperative CT angiography (CTA) was performed for all patients using a dedicated workstation. Each procedure was analysed, planned, and performed by an experienced operator (>50 aortic procedures/year). The treatment strategy was decided on by a dedicated multidisciplinary aortic team at each participating centre based on individual co-morbidity and aortic anatomy. a-BEVAR was preferentially offered to patients deemed at high surgical risk, unfit for open surgery with suitable anatomy for endovascular repair. The technical details of the surgical procedure have been previously reported[4,17,18]. The endovascular approach was performed according to the instructions for use (IFU) of the device. The thoracic and thoraco-abdominal completion procedure was performed according to the practice of each participating centre. Patients were evaluated at regular postoperative appointments. CTA was performed 1 month and 6 months after surgery and yearly thereafter.

Endpoints

Outcomes were in accordance with the current guidelines and reporting standards for aortic dissection[1,19]. The primary endpoints were operative mortality, late aortic-related mortality, and early stroke rates. Operative mortality included all deaths occurring within 30 days of the index procedure or during the index hospitalization. Late aortic-related mortality included any death caused by dissection-, device-, or procedure-related events during follow-up. Stroke was defined as a focal or global neurological deficit lasting for >24 h that occurred within 30 days of intervention, using the National Institutes of Health Stroke Scale (NIHSS) score: minor (NIHSS score ≤4), moderate to severe (NIHSS score 5–20), or major (NIHSS score ≥21).

Secondary endpoints included early cardiovascular events, respiratory complications, acute kidney injury (AKI), spinal cord ischaemia (SCI), reinterventions at 30 days, prolonged (>48 h) intubation after repair, intensive care unit (ICU) length of stay, hospital length of stay, and discharge to rehabilitation facilities. AKI was defined according to the Acute Kidney Injury Network (AKIN) classification[19,20].

Statistical analysis

Propensity score matching between the OAR group and the a-BEVAR group was conducted using 1 : 1 matching and the nearest neighbour method without replacement and a caliper of 0.5 s.d. of the propensity score distribution. Pre-specified variables including age at arch repair, previous myocardial infarction (MI), previous percutaneous coronary intervention (PCI), chronic kidney disease (CKD), connective tissue disorders, presence of a bovine aortic arch, the descending thoracic aortic arch diameter, and presence of dissection in the brachiocephalic, left common carotid and left subclavian arteries were used to generate the propensity score with a multivariable logistic regression model. Continuous variables are presented as mean (standard deviation (s.d.)) or median (interquartile range (i.q.r.)) and were compared using Student's *t* test or Wilcoxon's rank-sum test where appropriate. Categorical variables are presented as *n* (%) and were compared using the chi-squared test or Fisher's exact test where appropriate. A competing risks analysis to account for the event of death was performed. The cumulative incidence function (CIF) was used to estimate the probability of aortic death and arch-related reinterventions over time, accounting for the competing events of non-aortic death and death respectively; differences between CIF values were evaluated using the Gray test.

Overall survival was plotted using Kaplan–Meier curves and analysed using the log rank test. $P < 0.050$ was considered statistically significant. Data analysis was performed using SPSS® (IBM, Armonk, NY, USA; version 27.0) and R (version 4.1.2) with the MatchIt library.

Results

Baseline demographics

During the study interval, 183 patients with residual chronic aortic arch or DTA dissection were included, of which 89

Table 1 Clinical and demographic features of the patients

	Unmatched cohorts (*n* = 183)		P	Propensity score-matched cohorts (*n* = 114)		P
	OAR (*n* = 89)	a-BEVAR (*n* = 94)		OAR (*n* = 57)	a-BEVAR (*n* = 57)	
Male	62 (69.7)	63 (67.0)	0.620	39 (68.4)	42 (73.7)	0.631
Age (years), mean(s.d.)	58 (10.5)	68 (9.6)	<0.001*	63 (7)	65 (9)	0.120
Smoking	27 (30.7)	30 (33.3)	0.710	17 (29.8)	15 (27.8)	0.812
Hypertension	78 (87.6)	88 (93.6)	0.160	49 (86.0)	55 (95.5)	0.047*
Coronary artery disease	8 (9.0)	13 (13.8)	0.300	6 (10.5)	6 (10.5)	0.990
Previous MI	1 (1.1)	7 (7.4)	0.041*	1 (1.8)	2 (3.5)	0.560
Previous CABG	2 (2.2)	3 (3.2)	0.700	2 (3.5)	2 (3.5)	0.990
Previous PCI	0 (0)	8 (8.5)	0.005*	0 (0)	0 (0)	NE
Aortic mechanical valve	17 (19.1)	12 (12.8)	0.240	8 (14.0)	11 (19.3)	0.450
COPD	13 (14.6)	13 (13.8)	0.880	7 (12.3)	5 (8.8)	0.540
Diabetes mellitus	6 (6.7)	2 (2.1)	0.130	3 (5.3)	1 (1.8)	0.310
Dyslipidaemia	30 (33.7)	35 (37.2)	0.620	22 (38.6)	23 (40.4)	0.850
CKD	7 (7.9)	17 (18.1)	0.041*	6 (10.5)	11 (19.3)	0.190
CKD—eGFR (mL/min)						
<15	0 (0)	2 (2.1)		0 (0)	2 (3.5)	
15–29	1 (1.1)	3 (3.2)		1 (1.8)	1 (1.8)	
30–44	2 (2.2)	3 (3.2)		1 (1.8)	2 (3.5)	
45–59	3 (3.4)	3 (3.2)		3 (5.3)	2 (3.5)	
60–90	1 (1.1)	6 (6.4)		1 (1.8)	4 (7.0)	
Connective tissue disease	18 (20.2)	5 (5.3)	0.002*	7 (12.3)	5 (8.8)	0.540
Cerebral vessel disease	8 (9.0)	3 (3.2)	0.100	4 (7.0)	2 (3.5)	0.400
Previous abdominal aortic surgery	1 (1.1)	5 (5.3)	0.110	1 (1.8)	4 (7.0)	0.170
Type A dissection previous repair						
Age at the previous ascending aorta reconstruction (years), mean(s.d.)	52(12)	62(11)	<0.001*	56(10)	58(11)	0.180
Previous ascending aorta reconstruction			0.056*			0.046*
Tube	42 (46.2)	58 (61.8)		26 (45.6)	37 (64.9)	
Hemiarch	47 (52.8)	36 (38.2)		31 (54.4)	20 (35.1)	
Additional cardiac procedure during ascending aorta reconstruction	28 (31.4)	25 (26.6)	0.830	15 (26.3)	17 (29.8)	0.680
Bentall	20 (22.5)	12 (12.8)		12 (21.1)	10 (17.5)	
CABG	4 (4.5)	11 (11.7)		2 (3.5)	6 (10.5)	
Aortic valve	4 (4.5)	2 (2.1)		2 (3.5)	1 (1.8)	
Stroke after previous aortic surgery	9 (10.1)	12 (12.9)	0.560	7 (3.5)	8 (14.0)	0.780
MI after previous aortic surgery	2 (2.2)	4 (4.3)	0.430	1 (1.8)	0 (0)	0.320
Time between the two aortic surgeries (months), median (i.q.r.)	42 (25–107)	50 (23–109)	0.970	52 (28–105)	50 (21–128)	0.640

Values are *n* (%) unless otherwise indicated. *Significant. OAR, open arch repair; a-BEVAR, branched endovascular aortic repair; MI, myocardial infarction; CABG, coronary artery bypass grafting; PCI, percutaneous coronary intervention; NE, not evaluable; COPD, chronic obstructive pulmonary disease; CKD, chronic kidney disease; eGFR, estimated glomerular filtration rate; i.q.r., interquartile range.

patients (48.6%) underwent OAR and 94 patients (51.4%) underwent a-BEVAR (*Table 1*).

Patients who underwent OAR were younger than those who underwent a-BEVAR (mean (s.d.) age of 58 (10.5) *versus* 68 (9.6) years; $P < 0.001$). Compared with patients in the a-BEVAR group, those in the OAR group had a higher rate of connective tissue disease (20.2% *versus* 5.3%; $P = 0.002$) and lower rates of previous MI (1.1% *versus* 7.4%; $P = 0.040$), previous PCI (0% *versus* 8.5%; $P = 0.005$), and CKD (7.9% *versus* 18.1%; $P = 0.041$). After propensity score matching, the study cohort included 114 patients. There were 57 patients (50%) in the OAR group and 57 patients (50%) in the a-BEVAR group. See *Fig. S1* and *Table 2*.

Procedural data

In the unmatched OAR group, 66 patients (74.1%) were treated with the Thoraflex hybrid graft (Vascutek Terumo, Inchinnan, UK) and 23 patients (25.9%) were treated with the Gelweave Siena graft (Terumo Aortic, Inchinnan, UK). Distal anastomosis for OAR was in zone 2 in 31 patients (34.8%) and in zone 3 in 58 patients (65.2%). The mean (s.d.) cardiopulmonary bypass time was 212.9 (42.7) min.

The aortic arch endograft used was a custom-made branched device (Cook Medical, Bloomington, IN, USA) in all cases. In the unmatched a-BEVAR group, 48 patients (51.1%) underwent total endovascular arch repair using a three-branch device, while 46 patients (48.9%) were treated using a two-branch device and associated supra-aortic trunk debranching procedure. The debranching was left subclavian artery transposition in 5 cases (10.8%) and left carotid-subclavian bypass in 41 cases (89.2%). The mean (s.d.) total volume of the contrast agent was 108.8 (42.6) ml, the mean (s.d.) fluoroscopy time was 31.8 (22.3) min, and the mean (s.d.) indirect dose area product was 57.84 (39.4) Gy/cm^2.

Perioperative results

In the propensity score-matched cohorts, the intraoperative mortality rate was 1.8% (1 patient) for OAR *versus* 0% for a-BEVAR ($P = 0.310$) (*Table 3*). Intraoperative complications were observed in 7 patients (12.3%) in the OAR group *versus* 2 patients (3.5%) in the a-BEVAR group ($P = 0.081$). These included six cases (10.5%) of prolonged bleeding and one case (1.7%) of acute pulmonary oedema with cardiac arrest in the OAR group; on the other hand, two cases (3.5%) of right subclavian artery dissection were observed in the a-BEVAR group without related clinical complications.

There was no difference in the 30-day mortality rate between the OAR group and the a-BEVAR group (3.5% *versus* 5.3%

Table 2 Anatomical characteristics of the patients

	Unmatched cohorts (*n* = 183)		P	Propensity score-matched cohorts (*n* = 114)		P
	OAR (*n* = 89)	a-BEVAR (*n* = 94)		OAR (*n* = 57)	a-BEVAR (*n* = 57)	
Previous aortic graft diameter (mm), mean(s.d.)	30(3)	36(2)	0.060	30(3)	38(4)	0.140
Previous aortic graft outer curvature length (mm), mean(s.d.)	55(18)	62(21)	0.040	55(18)	60(17)	0.140
Right arch	0 (0)	0 (0)	NE	0 (0)	0 (0)	NE
Bovine arch	14 (16.3)	9 (9.8)	0.201	6 (10.5)	3 (5.3)	0.303
Arch origin of LVA	5 (5.8)	3 (3.3)	0.422	4 (7.0)	2 (3.6)	0.410
BCT dissection	30 (35.7)	31 (33.7)	0.780	20 (35.1)	23 (40.4)	0.561
LCCA trunk dissection	18 (22.0)	17 (18.8)	0.621	13 (23.6)	13 (22.8)	0.921
LSA dissection	33 (40.7)	25 (27.8)	0.070	26 (47.3)	17 (29.8)	0.058

Values are *n* (%) unless otherwise indicated. *Significant. OAR, open arch repair; a-BEVAR, branched endovascular aortic repair; NE, not evaluable; LVA, left vertebral artery; BCT, brachiocephalic trunk; LCCA, left common carotid artery; LSA, left subclavian artery.

respectively; $P = 0.220$); in the OAR group, two patients died as a result of multiple organ failure, while, in the a-BEVAR group, three patients died as a result of cardiac arrest, multiorgan failure, and brain death respectively.

Major stroke was observed in three patients (5.3%) after OAR *versus* two patients (3.5%) after a-BEVAR ($P = 0.650$). There were two right-side strokes in the OAR group; the other three strokes were bilateral. SCI occurred in two patients (3.5%) in the OAR group and no patients (0%) in the a-BEVAR group ($P = 0.151$). Compared with OAR patients, a-BEVAR patients had significantly lower rates of AKI (8.8% *versus* 31.6%; $P = 0.002$) and temporary dialysis (7.0% *versus* 22.8%; $P = 0.002$), with no difference in the rate of permanent dialysis. Similarly, a-BEVAR patients had a significantly lower rate of prolonged (>48 h) intubation (3.5% *versus* 28.1%; $P < 0.001$). Early reinterventions were performed in 18 patients (31.6%) in the OAR group *versus* 10 patients (17.5%) in the a-BEVAR group ($P = 0.082$). In the OAR group, there were 16 cases of re-sternotomy for haematoma evacuation, 1 case of proximal anastomotic pseudoaneurysm repair, and 1 case of DTA replacement through a left thoracotomy for renal and visceral malperfusion syndrome; in the a-BEVAR group, early reinterventions were evacuation of a cervical haematoma in 5 cases, femoral pseudoaneurysm repair in 4 cases, and evacuation of a femoral haematoma in 1 case. Vascular access complications were observed in one patient (1.8%) in the OAR group and seven patients (12.5%) in the a-BEVAR group ($P = 0.028$).

The median ICU length of stay was 7 (i.q.r. 3–12) days in the OAR group and 2 (i.q.r. 1–3) days in the a-BEVAR group ($P < 0.001$). The median hospital length of stay was 21 (i.q.r. 13–29) days in the OAR group and 10 (i.q.r. 8–16) days in the a-BEVAR group ($P < 0.001$). A significantly higher number of patients were discharged home directly in the a-BEVAR group (50 patients (86.5%)) than in the OAR group (26 patients (34%)) ($P < 0.001$). In case of transfer to rehabilitation facilities, the median length of stay in rehabilitation facilities was 17 (i.q.r. 13–40) days.

Mid-term outcomes

The median follow-up time in the total matched population was 30 (i.q.r. 7–59) months; median of 37 (i.q.r. 10–59) months in the OAR group and 23 (i.q.r. 7–49) months in the a-BEVAR group ($P = 0.470$). No patients were lost to follow-up. Mid-term results are reported in *Table 4*.

Thirteen late deaths were observed during follow-up (13 of 114 patients (11.4%)), three of which were aortic-related deaths (3 of 114 patients (2.6%)). Late mortality occurred in six patients (10.5%) after OAR *versus* seven patients (12.3%) after a-BEVAR ($P = 0.770$). In the OAR group, the causes of late death were thoracoabdominal aortic rupture (2 patients), respiratory failure (2 patients), stroke (1 patient), and cardiac failure (1 patient). In the a-BEVAR group, endograft infection with aorto-oesophageal fistula (1 patient), respiratory failure (4 patients), cardiac failure (2 patients), stroke (1 patient), and other (3 patients) were noted.

Overall survival at 36 months was 86.1% (95% c.i. 76.3% to 95.9%) for the OAR group and 80.0% (95% c.i. 67.1% to 92.9%) for the a-BEVAR group ($P = 0.430$) (*Fig. 1*).

Seven arch-related reinterventions were performed in the OAR group (7 of 57 patients (12.3%)) and eight arch-related reinterventions were performed in the a-BEVAR group (8 of 57 patients (14.0%)) ($P = 0.900$). In the OAR group, the reinterventions were unplanned second-stage thoracic endovascular stent-graft completion for symptomatic aortic diameter progression (4 patients), thoracic endovascular aortic repair for graft infection with descending aorta rupture (1 patient), open repair for anastomotic pseudoaneurysm (1 patient), and left subclavian artery embolization (1 patient). In the a-BEVAR group, the reinterventions were false lumen embolization (5 patients) and bridging stent relining of the brachiocephalic trunk (2 patients) or left carotid artery (1 patient) for type Ic endoleak.

The cumulative incidence using Gray's test of aortic-related mortality and arch-related reinterventions at 36 months was 0% for OAR *versus* 2% for a-BEVAR ($P = 0.620$) and 41% for OAR *versus* 42% for a-BEVAR ($P = 0.800$) respectively (*Fig. S2*).

Discussion

Open surgical repair has been the 'gold standard' intervention for aortic arch disease progression after initial TAAD repair. However, endovascular arch repair using a-BEVAR has emerged as a novel alternative in the past decade. In this study, the short- and mid-term outcomes for the first propensity score-matched comparison between OAR and a-BEVAR in a multicentre cohort are reported, with no difference in operative and mid-term mortality between the two groups.

The lack of direct comparisons between OAR and a-BEVAR in the literature is due to the relative novelty of the endovascular approach and significant patient heterogeneity, as those undergoing open repair are typically younger and with fewer comorbidities[21]. In the present study, preoperative age, CKD, connective tissue disease, and coronary disease were all balanced in the propensity score-matched population.

The outcomes of redo OAR in the present study were comparable to those reported in the literature, where redo OAR

Table 3 Perioperative outcome comparison for the unmatched and matched OAR and a-BEVAR groups

	Unmatched cohorts (n = 183)		P	Propensity score-matched cohorts (n = 114)		P
	OAR (n = 89)	a-BEVAR (n = 94)		OAR (n = 57)	a-BEVAR (n = 57)	
Intraoperative complications	10 (11.2)	4 (4.3)	0.080	7 (12.3)	2 (3.5)	0.081
Intraoperative death	1 (1.1)	2 (2.1)	0.591	1 (1.8)	0 (0)	0.310
Total operating time (min), median (i.q.r.)	360 (315–476)	255 (183–310)	<0.001*	375 (333–488)	271 (201–325)	<0.001*
Thirty-day mortality	2 (2.2)	5 (5.3)	0.280	2 (3.5)	3 (5.3)	0.220
In-hospital mortality	4 (4.5)	5 (5.3)	0.800	3 (5.3)	3 (5.3)	0.990
Major Stroke	5 (5.6)	4 (3.3)	0.671	3 (5.3)	2 (3.5)	0.650
TIA	3 (3.4)	1 (1.1)	0.293	1 (1.8)	0 (0)	0.320
SCI	3 (3.4)	0 (0)	0.073	2 (3.5)	0 (0)	0.151
Cardiac complications	3 (3.4)	3 (3.2)	0.950	3 (5.3)	1 (1.8)	0.310
Prolonged (>48 h) intubation	24 (27)	3 (3.2)	<0.001*	16 (28.1)	2 (3.5)	<0.001*
Reintubation	7 (7.9)	3 (3.2)	0.160	5 (8.8)	3 (5.3)	0.460
ARI	12 (13.5)	6 (6.4)	0.110	8 (14.0)	4 (7.0)	0.220
AKI	20 (22.5)	9 (9.6)	0.017*	18 (31.6)	5 (8.8)	0.002*
Temporary dialysis	15 (16.8)	5 (5.3)	0.002*	13 (22.8)	4 (7.0)	0.002*
Permanent dialysis	2 (2.2)	3 (3.2)	0.690	2 (3.5)	3 (5.3)	0.650
Other complications	20 (22.5)	21 (22.3)	0.980	18 (31.6)	13 (22.8)	0.290
Vascular access complications	3 (3.4)	16 (17.4)	0.002*	1 (1.8)	7 (12.5)	0.028*
Early reintervention	26 (29.2)	17 (18.1)	0.076	18 (31.6)	10 (17.5)	0.082
ICU length of stay (days), median (i.q.r.)	6 (2–12)	2 (2–4)	<0.001*	7 (3–12)	2 (1–3)	<0.001*
Hospital length of stay (days), median (i.q.r.)	19 (12–28)	9 (7–17)	<0.001*	21 (13–29)	10 (8–16)	<0.001*
Discharge to rehabilitation facilities	50 (67.6)	15 (18.1)	<0.001*	31 (66.0)	7 (13.5)	<0.001*

Values are n (%) unless otherwise indicated. *Significant. OAR, open arch repair; a-BEVAR, branched endovascular aortic repair; i.q.r., interquartile range; TIA, transient ischaemic attack; SCI, spinal cord ischaemia; ARI, acute respiratory injury; AKI, acute kidney injury.

Table 4 Mid-term outcome comparison for the unmatched and matched OAR and a-BEVAR groups

	Unmatched cohorts (n = 183)		P	Propensity score-matched cohorts (n = 114)		P
	OAR (n = 89)	a-BEVAR (n = 94)		OAR (n = 57)	a-BEVAR (n = 57)	
Late death	9 (10.1)	10 (10.6)	0.911	6 (10.5)	7 (12.3)	0.770
Aortic-related death	3 (3.4)	1 (1.1)	0.200	2 (3.5)	1 (1.8)	0.310
Stroke	5 (5.6)	9 (9.6)	0.310	2 (3.5)	7 (12.3)	0.082
TIA	1 (1.1)	0 (0)	0.300	0 (0)	0 (0)	NE
SCI	0 (0)	1 (1.1)	0.331	0 (0)	0 (0)	NE
Cardiac complications	7 (7.9)	5 (5.3)	0.490	6 (10.5)	1 (1.8)	0.051
Respiratory complications	8 (9.0)	9 (9.6)	0.890	5 (8.8)	5 (8.8)	0.990
Nephrological complications	3 (3.4)	6 (6.4)	0.351	1 (1.8)	5 (8.8)	0.093
Other complications	10 (11.5)	11 (11.8)	0.940	5 (9.1)	10 (17.5)	0.190
Arch-related reintervention	10 (11.2)	12 (12.8)	0.821	7 (12.3)	8 (14.0)	0.900
Aortic diameter shrinkage	21 (23.6)	22 (23.4)	0.800	15 (26.3)	16 (28.1)	0.900

Values are n (%). OAR, open arch repair; a-BEVAR, branched endovascular aortic repair; TIA, transient ischaemic attack; NE, not evaluable; SCI, spinal cord ischaemia.

with FET and ET is associated with a mortality rate ranging from 0% to 17.5%[22]. Ram *et al.*[23] reported an operative mortality rate of 3.3% for redo total arch repair after previous TAAD repair, while Urbanski *et al.*[24] reported an in-hospital mortality rate of 12% after FET. Redo surgery was identified as a risk factor for early mortality in both studies[23,24]. On the other hand, Verscheure *et al.*[4] reported an early mortality rate of 1.4% after branched endograft for residual dissection. Similarly, Tsilimparis *et al.*[10] reported a mortality rate of 5%. In the present study, the total 30-day mortality rate was 4.4%, with no significant difference between the OAR group and the a-BEVAR group.

Given the complex nature of this kind of aortic surgery and the frequent involvement of the supra-aortic trunks, stroke remains a significant risk for both approaches. In the OAR group of the present study, the stroke rate was 5.3%, which is comparable to previous studies. In a meta-analysis of 3154 patients treated with FET, the overall stroke rate was 7.6%[25]. Kreibich *et al.*[26] reported a stroke rate of 15% for 237 patients treated with redo FET for residual type A aortic dissection. In the literature, wire and catheter manipulation in supra-aortic vessels during a-BEVAR for chronic aortic arch dissection has a low stroke rate of 2.9%[4]. Interestingly, in the present study, the endovascular group and the OAR group had a similar stroke rate (3.5% *versus* 5.3% respectively; $P = 0.650$). This can be explained by the absence of thrombus or atheromatous plaque in this disease, the proximal landing zone in a previous prosthetic graft, and the consequent lower risk of embolization; moreover, except for brief intervals of carotid clamping, supra-aortic vessels are perfused during the whole endovascular repair.

A notable finding in the present study is the significantly higher rate of AKI in the OAR group (31.6% *versus* 8.8%; $P = 0.002$). This is consistent with a recent meta-analysis showing that OAR procedures are associated with a higher rate of renal complications compared with endovascular techniques (7.54%

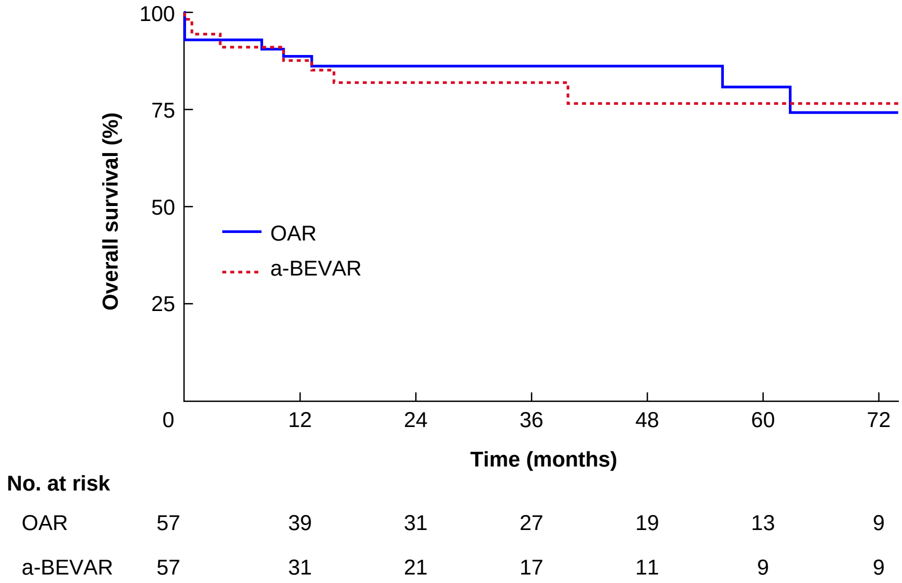

Fig. 1 Kaplan–Meier analysis of overall survival for the propensity score-matched cohorts

OAR, open arch repair; a-BEVAR, branched endovascular aortic repair.

versus 5.17%; $P = 0.03$)[21]. The reported rate of AKI after FET ranges from 7.5% to 77.6% and AKI is associated with older age, extended cardiopulmonary bypass duration, male sex, and elevated BMI[21,27]. AKI is a well-documented concern in complex aortic surgeries and the results of the present study suggest that endovascular repair, with its less invasive approach, may reduce the risk of this complication. Furthermore, the higher rate of prolonged intubation in the OAR group (28.1% *versus* 3.5%; $P <$ 0.001), the longer ICU length of stay (median of 7 *versus* 2 days; $P < 0.001$), the longer hospital length of stay (median of 21 *versus* 10 days; $P < 0.001$), and the higher rate of discharge to rehabilitation facilities (66.0% *versus* 13.5%; $P < 0.001$) also underscore the benefits of endovascular repair in terms of quicker recovery and reduced perioperative morbidity. Notably, vascular access complications were significantly more frequent in the a-BEVAR group compared with the OAR group (12.5% *versus* 1.8%; $P = 0.028$), reflecting the technical challenges of vascular access and the need for large introducer sheaths of at least 20 Fr during complex endovascular aortic arch procedures.

In patients previously treated for TAAD, the prosthetic graft offers an ideal proximal endovascular landing zone if its length is adequate with parallel edges, without a conical configuration and free of thrombus or calcifications[4]. In this setting, type 1a endoleak is very rare for a-BEVAR[4]. Indeed, in the present study, reinterventions for endoleak after a-BEVAR were primarily for type 1c endoleak, which was not unexpected, particularly in dissected supra-aortic trunks[4]. Distally, the reported false lumen patency rate of the downstream aorta after arch replacement is generally high, ranging from 43% to 77.5%, and it is associated with enlargement of the downstream aorta, leading to distal aortic events[28,29]. Kimura *et al.*[28] reported a distal reoperation rate of 8% after arch repair, with a false lumen patency rate of 92% in this group. In the literature, the reported distal reintervention rate after branched repair is comparable to that after open surgery (29% *versus* 22% respectively)[4,30]. This was corroborated in the present study, where both groups presented with a similar rate of arch-related reinterventions (12.3% in the OAR group and 14.0% in the a-BEVAR group), with most cases involving unplanned second-stage completion due to aortic diameter progression. Early and late aortic diameter progression as well as adverse aortic events requiring elective or even emergency reintervention are unpredictable[12]. Long-term follow-up with regular imaging is essential to detect these potential evolutions and ensure that reinterventions are performed promptly.

The retrospective, non-randomized design of the present study introduces potential selection bias despite the use of propensity score matching. The number of patients excluded due to unsuitable anatomy for endovascular repair was not recorded. Open and endovascular aortic arch repair were available in all of the participating centres; however, no prospectively maintained database allowing access to OAR data was available in three of the centres. Evaluation by a neurologist and postoperative diffusion-weighted MRI were not routinely performed. Distal thoracic and thoracoabdominal completion were not assessed, as the study focused on arch repair outcomes. Differences in median follow-up between the cohorts may have limited the assessment of mid-term outcomes. Further studies with longer follow-up and prospective designs are needed. The cost-effectiveness analysis of a-BEVAR *versus* OAR should be explored in future studies.

Collaborators

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Disclosure

G.T. is a consultant for Terumo Aortic, Medtronic, and Artivion, J.S. is a consultant for Cook Medical, Abbott Vascular, Boston Scientific, and GE Healthcare, A.S. is a consultant for Cook Medical, Artivion, and Phillips, with all compensation going to the UMass Memorial Foundation, Y.T. is a consultant for Terumo Aortic, Medtronic, and Artivion, and S.H. is a consultant for and has intellectual property with Cook Medical, GE Healthcare, and Bentley. The authors declare no other conflict of interest.

Supplementary material

Supplementary material is available at *BJS* online.

Data availability

The data that support the findings of this study are available from the corresponding author, upon request.

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