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Comparison of aortic arch repair using the endovascular technique, total arch replacement and staged surgery†

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Abstract

OBJECTIVES: We evaluated the operative and long-term outcomes of various approaches for aortic arch repair.

METHODS: A total of 436 consecutive patients who underwent aortic arch repair from January 2001 to March 2016 in our centre were evaluated. Of these, 276 underwent conventional total arch replacement (TAR), and 118 underwent thoracic endovascular repair (TEVAR). The remaining 42 patients underwent staged thoracic endovascular repair (STEVAR). A total of 72 patients in the TEVAR group were matched to 72 patients who underwent open surgery including TAR or STEVAR by using propensity score analysis.

RESULTS: Surgical outcomes showed shorter ICU and hospital stay in the TEVAR group ($P < 0.001$ and $P < 0.001$, respectively). The 30-day mortality and neurologic dysfunction showed no significant difference among the three groups (2.8 and 5.4% in TAR group, 1.7 and 8.5% in TEVAR group and 0 and 2.4% in STEVAR group; $P = 0.500$ and $P = 0.297$, respectively). Long-term survival was not significantly different among the three groups (78% in TAR group, 67% in TEVAR group and 81% in STEVAR group at 5 years; $P = 0.123$). Freedom from aortic reintervention was lower in the TEVAR group than in other groups (98% in TAR, 92% in TEVAR and 97% in STEVAR at 5 years, $P = 0.040$).

CONCLUSIONS: Operative outcomes showed no significant differences between the groups except for early recovery after TEVAR. Long-term survival was similar between groups; however, TEVAR had inferior reintervention free rate.

Keywords: Aortic arch aneurysm • Total arch replacement • Hybrid arch repair • Endovascular procedures

INTRODUCTION

With the recent development of surgical techniques and managements, the conventional total arch replacement (TAR) method has become the standard surgical option for aortic arch aneurysms. The thoracic endovascular aortic repair (TEVAR) is widely recognized as an alternative option for thoracic aortic aneurysms, especially for high-risk patients. By combining TAR with an elephant trunk or arch vessel debranching or by improving devices, TEVAR can be extended to aortic arch pathologies [1, 2].

In this study, we used TEVAR including supra-aortic vessel debranching or fenestrated graft in patients who had a high risk for conventional TAR. We used staged thoracic endovascular repair (STEVAR) with TAR as the first stage and TEVAR as the second stage in patients with extended aortic arch pathology. The aim of this study was to evaluate the short-term and long-term outcomes of these approaches in a single centre.

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METHODS

Between January 2001 and March 2016, 436 consecutive patients underwent aortic arch repair at our centre. Of these, 276 patients underwent conventional TAR, and 118 patients underwent TEVAR. The remaining 42 patients underwent STEVAR. The exclusion criteria included acute aortic dissection and hemi-arch or partial arch repair. The patient characteristics of three groups are listed in Table 1. We performed open surgery as the first choice, particularly inpatients with shaggy aortic syndrome, Marfan syndrome, or aortic dissection. TEVAR is essentially indicated for elderly high-risk patients or those with comorbidity including severe frailty. The mean ages were 67.8 ± 10.1 years in the TAR group, 74.7 ± 10.4 years in the TEVAR group and 72.4 ± 8.3 years in the STEVAR group ($P < 0.001$). It was found that 36.4% patients in the TEVAR group, 5.4% patients in TAR group and 11.9% patients in STEVAR group were octogenarian (age > 80) ($P < 0.001$). The Japan SCORE (30 days operative mortality) was higher in the TEVAR group than in TAR or STEVAR groups (9.5 ± 8.6, 6.3 ± 5.1 and 5.5 ± 3.3, respectively; $P < 0.001$).

Table 1: Patients characteristics

Variables	Overall cohorts			P-value	Matched pairs (sensitivity analysis)		P-value
	TAR n = 276	TEVAR n = 118	STEVAR n = 42		OPEN (TAR + STEVAR) n = 72	TEVAR n = 72	
Age, years	67.8 ± 10.1	74.7 ± 10.4	72.4 ± 8.3	<0.001	72.8 ± 8.8	73.0 ± 10.6	0.871
Age >80 years	15 (5.4)	43 (36.4)	5 (11.9)	<0.001	18 (25.0)	17 (23.6)	0.846
Gender (male)	225 (81.5)	99 (83.9)	36 (85.7)	0.725	64 (88.9)	63 (87.5)	0.796
Prior PTCA/CABG	82 (29.7)	39 (33.1)	13 (31.0)	0.805	23 (31.9)	27 (37.5)	0.484
COPD	26 (9.4)	19 (16.1)	7 (16.7)	0.105	8 (11.1)	11 (15.3)	0.460
CKD requiring haemodialysis	6 (2.2)	1 (0.8)	1 (2.4)	0.643	4 (5.6)	1 (1.4)	0.183
Cerebrovascular disease	34 (12.3)	18 (15.3)	3 (7.1)	0.385	11 (15.3)	14 (19.4)	0.509
Rupture/impending rupture	16 (5.8)	11 (9.3)	1 (2.4)	0.226	8 (11.1)	6 (8.3)	0.574
Prior sternotomy	30 (10.9)	17 (14.4)	4 (9.5)	0.545	7 (9.7)	7 (9.7)	1.000
Emergency/urgent	13 (4.7)	10 (8.5)	0 (0)	0.085	6 (8.3)	5 (6.9)	0.754
Marfan syndrome	6 (2.2)	0 (0)	0 (0)	0.171	0	0	NA
Aortic pathology							
Atherosclerosis	225 (81.5)	96 (81.4)	38 (90.5)	0.347	69 (95.8)	70 (97.2)	0.500
Dissection	48 (17.4)	19 (16.1)	1 (2.4)	0.043	0	0	NA
Pseudoaneurysm	3 (1.1)	3 (2.5)	3 (7.1)	0.030	3 (4.2)	2 (2.8)	0.500
Extend of aneurysm							
Ascending-arch	57 (24.2)	1 (0.9)	3 (7.5)	0.000	2 (2.8)	1 (1.4)	0.500
Arch	134 (56.8)	84 (79.2)	20 (50.0)	0.003	52 (72.2)	55 (76.4)	0.567
Arch-descending	32 (13.6)	20 (18.9)	15 (37.5)	<0.001	17 (23.6)	15 (20.8)	0.688
Ascending-descending	13 (5.5)	1 (0.9)	2 (5.0)	0.162	1 (1.4)	1 (1.4)	0.752
Japan SCORE (30 days operative mortality)	6.3 ± 5.1	9.5 ± 8.6	5.5 ± 3.3	0.000	8.4 ± 7.4	9.9 ± 9.6	0.405

Data are presented as number (%) or mean ± SD.

PTCA: percutaneous transluminal coronary angioplasty; CABG: coronary artery bypass grafting; COPD: chronic obstructive pulmonary disease; CKD: chronic kidney disease; TAR: total arch replacement; TEVAR: thoracic endovascular aortic repair; STEVAR: staged thoracic endovascular.

OPERATIVE TECHNIQUES

The procedural details of the three groups are given in Table 2.

Open arch repair (TAR)

All patients underwent a median sternotomy. A left thoracotomy was added for 27 patients in whom the aneurysms extended further distally. The patients were cooled until the rectal or bladder temperature reached between 25 and 28 °C. Three supra-aortic vessels were cannulated from their openings inside the incised aortic arch with balloon-tipped cannulas for selective cerebral perfusion (SCP). The initial total perfusion rate in supra-aortic vessels was regulated to maintain at 10 ml kg^{-1} min^{-1}. The target pressure measured at the tip of the left carotid cannula was 30 to 50 mmHg. The supra-aortic vessels were reconstructed using only a polyethylene terephthalate fiber (Dacron) graft with three branches for reconstruction. Most patients underwent open distal anastomosis, and the stepwise technique was applied for deep anastomoses.

Thoracic endovascular repair (TEVAR)

The details of our surgical technique of TEVAR with aortic arch vessel debranching have been previously reported [3]. Initially, we used the handmade stent graft devices, but then we used the commercially available TEVAR devices after their introduction in Japan in 2008. For spinal cord protection, we adopted cerebrospinal fluid drainage and motor evoked potential, particularly for patients with ≥20 cm of aortic coverage or previous abdominal aortic surgery.

Zone 0

In the early phase of our series, total debranching with TEVAR was performed in patients with proximal zone 0 landing. To avoid median sternotomy and clamping of the ascending aorta, the surgical strategy was changed to the chimney technique or a fenestrated graft was used.

Zone 1

After bilateral axillary arteries and left common carotid artery (LCCA) bypass, a stent-graft was deployed through the femoral artery and positioned such that the proximal end of the covered stent-graft was in the aortic arch between the brachiocephalic artery and left common carotid artery (LCCA).

Zone 2

After the creation of the bilateral axillary arteries bypass, a stent-graft was deployed through the femoral artery and positioned such that the proximal end of the covered stent-graft was in the aortic arch between left common carotid artery (LCCA) and left subclavian artery (LSA).

Staged thoracic endovascular repair (STEVAR)

The first stage involving the elephant trunk technique was performed similarly to the above-described standard TAR. Distal anastomosis was performed at the proximal side of the aneurysm. The length of the elephant trunk was between 5 and 7 cm. For patients with very large aneurysms, we performed a

CONVENTIONAL AORTIC SURGERY

Table 2: Details of procedure

	TAR	STEVAR	*P*-value
Total arch replacement + FET	7 (2.5)		
Approach			
Median sternotomy	251 (90.9)	42 (100)	
Median sternotomy + thoracotomy	27 (9.1)		
Concomitant procedure			
CABG	52 (18.8)	9 (21.4)	
Bentall	11 (4.0)		
Remodelling	1 (0.4)		
Mitral valve replacement	1 (0.4)		
Tricuspid valve replacement	1 (0.4)		
Aortic valve replacement	12 (4.3)		
Operation time, min	452 ± 147	370 ± 123	0.002
CPB time, min	225 ± 65	186 ± 41	<0.001
Cross-clamp time, min	145 ± 42	119 ± 28	<0.001
SCP time, min	101 ± 28	86 ± 16	<0.001
TEVAR	*n*	Bypass design	
Zone 0	33		
Total debranching bypass with TEVAR	12	Ascending aorta to BCA, LCCA and LAxA: 12	
Chimney graft technique and supra-aortic bypass	6	RAxA to LCCA and LAxA: 6	
Fenestrated graft and supra-aortic bypass	15	RAxA to LCCA and LAxA: 3	
		RAxA to LAxA: 5	
		No bypass: 7	
Zone 1	29	RAxA to LCCA and LAxA: 29	
Zone 2	56	RAxA to LAxA: 27	
		No bypass: 22	
		Branched graft: 7	

Data are presented as number (%) or mean ± SD.

FET: frozen elephant trunk; CABG: coronary artery bypass grafting; TAR: total arch replacement; TEVAR: thoracic endovascular aortic repair; STEVAR: staged thoracic endovascular aortic repair; BCA: brachiocephalic artery; LCCA: left common carotid artery; LAxA: left axillary artery; RAxA: right axillary artery.

second-stage operation during the same hospitalization period. However, most patients were discharged after the first stage, and they underwent the second stage of STEVAR at a later period. The median duration between the two operations was 2 months [interquartile range (IQR: 1–3)]. In the second stage, a stent graft main body was deployed inside the elephant trunk. In STEVAR group, the first stage operation had shorter operation time (370 ± 123 vs 452 ± 147 min; $P = 0.002$), cardiopulmonary bypass (CPB) time (186 ± 41 vs 225 ± 65 min; $P \leq 0.001$), aortic cross-clamp time (119 ± 28 vs 145 ± 42; $P < 0.001$) and SCP time (86 ± 16 vs 101 ± 28; $P < 0.001$).

Definition of outcomes

Mortality was reported as 30-day mortality, and hospital death was defined as any death prior to hospital discharge. Late mortality is defined as all-cause mortality, and the time origin is the time of surgery. In the STEVAR group, the time origin is first stage operation. Permanent neurologic deficit is defined as a new neurological deficit persistent at the time of discharge, and temporary neurologic deficit is defined as a new neurological deficit with complete resolution by discharge. Aortic reintervention was defined as reintervention for the previously repaired arch segment.

Endpoints and follow-up

Primary end-points were hospital morality and late mortality. Data were recorded prospectively. The patients were followed by the outpatient unit of our institution. In the case of patient follow-ups in other hospitals, telephonic conversations were conducted. The final date of follow-up was March 2016, and the mean duration of the follow-up was 48.3 ± 3.3 months, and it was completed for 91% of our cohort.

Statistical analysis

Continuous data were expressed as means ± standard deviation or median with interquartile range. Among the three groups, continuous data were compared by one-way analysis of variance (ANOVA), and categorical data were compared by the χ^2 test. Risk factors for in-hospital mortality was evaluated using logistic regression analysis. Clinically relevant variables with $P < 0.25$ in univariable analysis were included in multivariable regression analyses as candidates for backward stepwise variable selections. Cox proportional hazards regression was performed to estimate the hazard ratio (HR) for risk factors on late mortality and aortic reintervention. Survival and aortic reintervention free rates were estimated using the Kaplan–Meier method and were compared among groups using log-rank test. In addition, sensitivity analyses by means of propensity score matching (PSM) were performed. By PSM, the number of STEVAR group was too small compared to the other two groups. Since STEVAR involved TAR followed by TEVAR, TEVAR was compared with open surgery, which included TAR and STEVAR. The PSM was estimated using a logistic regression model (eight factors and covariates: age, gender, octogenarian, rupture, prior sternotomy, aortic pathologies and extend of

Table 3: Surgical outcomes

Variables	Overall cohorts			P-value	Matched pairs (Sensitivity analysis)		P-value
	TAR n = 276	TEVAR n = 118	STEVAR n = 42		OPEN (TAR+STEVAR) n = 72	TEVAR n = 72	
30-day death	7 (2.5)	1 (0.8)	0 (0)	0.337	0 (0)	1 (1.4)	0.500
In-hospital death	14 (5.1)	3 (2.5)	0 (0)	0.192	3 (4.2)	3 (4.2)	0.660
Neurologic dysfunction	15 (5.4)	10 (8.5)	1 (2.4)	0.297	5 (6.9)	8 (11.1)	0.383
PND	7 (2.5)	6 (5.1)	1 (2.4)	0.4	2 (2.8)	3 (4.2)	0.500
TND	8 (2.9)	4 (3.4)	0 (0)	0.499	3 (4.2)	5 (6.9)	0.359
Spinal cord deficits	1 (0.4)	1 (0.8)	0 (0)	0.726	0 (0)	1 (1.4)	0.500
Renal failure on HD	8 (2.9)	1 (0.8)	0 (0)	0.259	0 (0)	1 (1.4)	0.500
Prolonged intubation (≥48 h)	74 (28.1)	6 (5.3)	2 (5.4)	<0.001	21 (30.9)	5 (7.5)	0.001
Tracheostomy	4 (1.4)	5 (4.2)	0 (0)	0.125	4 (5.6)	4 (5.6)	0.641
ICU stay, days	3.0 (2.0–5.0)	1.0 (1.0–1.8)	3.0 (3.0–3.0)	<0.001	3.0 (2.0–5.0)	1.0 (1.0–2.0)	<0.001
Postoperative hospital stay, days	22.0 (17.0–33.0)	10.5 (7.0–21.0)	24.0 (20.0–33.5)	0.001	25.0 (18.0–36.0)	10.0 (7.0–21.8)	0.005

Data are presented as number (%) or median (IQR: interquartile range).
PND: permanent neurologic deficit; TND: temporary neurologic deficit; HD: haemodialysis; ICU: intensive care unit; TAR: total arch replacement; TEVAR: thoracic endovascular aortic repair; STEVAR.

Table 4: Multivariate regression analysis for in-hospital mortality

Variables	Univariable OR (95% CI)	P-value	Multivariable OR (95% CI)	P-value
Age >80 years	0.36 (0.05–2.76)	0.267		
Gender (male)	0.49 (0.17–1.43)	0.184		
Marfan syndrome	5.18 (0.57–46.91)	0.213	8.79 (0.93–83.11)	0.058
Atherosclerotic	0.69 (0.22–2.16)	0.352		
Dissection	1.71 (0.54–5.40)	0.265		
Rupture	5.06 (1.53–16.71)	0.018	5.02 (1.42–17.79)	0.013
Emergency/urgent	2.53 (0.54–11.78)	0.224		
Prior cerebral infarction	1.51 (0.42–5.44)	0.365		
CAD	2.65 (1.00–7.02)	0.043		
COPD	0.98 (0.22–4.43)	0.670		
Renal dysfunction (on HD)	3.68 (0.43–31.71)	0.274		
Previous sternotomy	2.45 (0.76–7.78)	0.125		
TEVAR (reference: TAR+STEVAR)	0.57 (0.16–2.01)	0.279		
Concomitant procedure	2.39 (0.89–6.44)	0.077		
Perioperative neurologic dysfunction	7.90 (2.55–24.49)	0.002	8.05 (2.48–26.13)	0.001

PTCA: percutaneous transluminal coronary angioplasty; CAD: coronary artery disease; COPD: chronic obstructive pulmonary disease; HD: haemodialysis; TAR: total arch replacement; TEVAR: thoracic endovascular aortic repair; STEVAR: staged thoracic endovascular.

aneurysm) and greedy matching (ratio = 1:1 without replacement) with a calliper of width 0.25 standard deviations of the logit of the estimated PS was applied. After the matching, survival curves were compared between the two groups with log rank test. All data were analysed using SPSS 22.0 software (IBM Corp., Armonk, NY, USA).

RESULTS

The perioperative outcomes are listed in Table 3. The overall hospital mortality was 3.9% (17/436), including 5.1, 2.5 and 0% in the TAR, TEVAR and STEVAR groups, respectively ($P = 0.192$). The cause of death in all cases was as follows: pulmonary-related in 10 patients, stroke in 2, multiple organ failure in 1, low output syndrome in 1, hepatic failure in 1, arrhythmia in 1 and residual thoracoabdominal aortic aneurysm rupture in 1 patient. Neurologic dysfunction developed in 15 (5.4%) patients in the TAR group, in 10 (8.5%) patients in TEVAR group and in 1 (2.4%) patient in the STEVAR group ($P = 0.297$). Spinal cord injury (SCI) developed in 1 patient each in TAR (0.4%) and TEVAR (0.8%) groups; however, there were no such deficits in the STEVAR group ($P = 0.726$). Prolonged intubation for longer than 48 h was required for 74 (28.1%) patients in the TAR group, 6 (5.3%) patients in TEVAR group and 2 (5.4%) patients in STEVAR group ($P < 0.001$). The ICU length of stay ($P < 0.001$) and the duration of postoperative hospital stay ($P = 0.001$) were significantly shorter in the TEVAR group. Table 4 shows that the risk factors for hospital mortality were rupture [odds ratio (OR), 5.02; $P = 0.013$] and perioperative neurologic dysfunction [odds ratio (OR), 8.05; $P < 0.001$].

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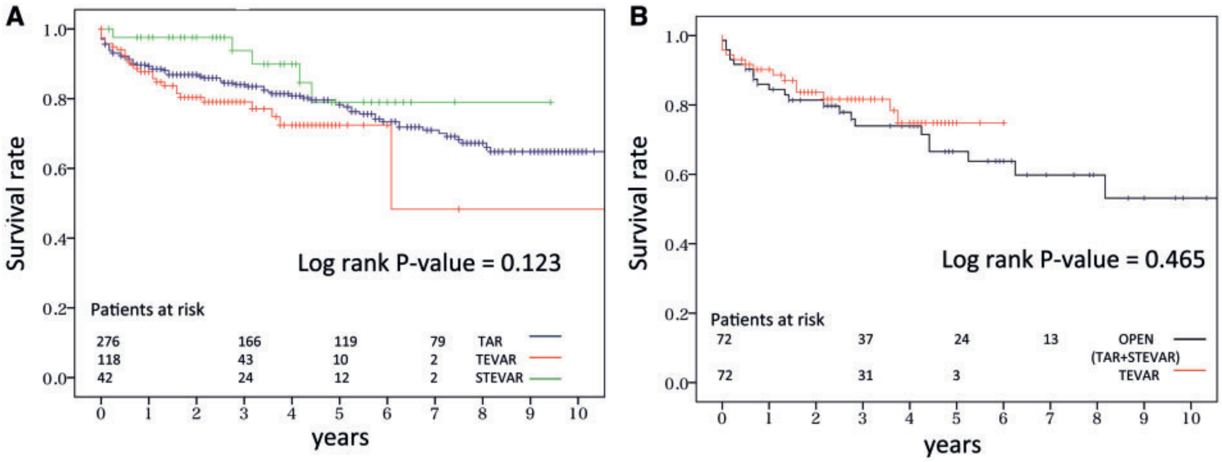

Figure 1: Survival curve: (**A**) for unmatched patients, (**B**) for patients after propensity matching.

Table 5: Cox proportional hazards regression analysis for mortality after surgery

Variables	Univariable HR (95% CI)	Univariable *P*-value	Multivariable HR (95% CI)	Multivariable *P*-value
Age >80 years	1.86 (1.04–3.32)	0.034	2.49 (1.53–4.05)	<0.001
Gender (male)	0.95 (0.53–1.70)	0.865		
Marfan syndrome	1.69 (0.31–9.40)	0.542		
Atherosclerotic	0.89 (0.50–1.58)	0.689		
Dissection	1.84 (0.49–6.98)	0.284		
Rupture	2.32 (1.05–5.13)	0.033	2.07 (1.07–4.01)	0.032
Emergency/urgent	1.51 (0.60–3.77)	0.379		
Prior cerebral infarction	2.15 (1.18–3.93)	0.011	1.86 (1.13–3.04)	0.014
CAD	1.29 (0.80–2.07)	0.292		
COPD	1.76 (0.94–3.30)	0.075		
Renal dysfunction (on HD)	5.84 (1.37–24.89)	0.018	2.45 (0.94–6.38)	0.068
Previous sternotomy	1.32 (0.68–2.55)	0.414		
TEVAR (reference: TAR+STEVAR)	0.93 (0.56–1.55)	0.786		
Concomitant procedure	0.90 (0.53–1.54)	0.707		
Perioperative neurologic dysfunction	1.86 (0.80–4.30)	0.144		

PTCA: percutaneous transluminal coronary angioplasty; CAD: coronary artery disease; COPD: chronic obstructive pulmonary disease; HD: haemodialysis; TAR: total arch replacement; TEVAR: thoracic endovascular aortic repair; STEVAR: staged thoracic endovascular.

Figure 1A shows the overall long-term survival assessed by the Kaplan–Meier method. Survival at 3 and 5 years after surgery was 84.0 ± 2.3 and 78.3 ± 2.8% in the TAR group, 79.1 ± 4.0 and 72.4 ± 5.2% in TEVAR group and 93.8 ± 4.3 and 79.0 ± 8.8% in STEVAR group, respectively. There was no significant difference between the three groups ($P = 0.123$). Late deaths occurred in 84 patients (19.3%). Of these, 17 (20.2%) were aorta-related deaths, including rupture of a descending thoracic or thoraco-abdominal aneurysm in 9 cases, an aortic arch aneurysm in 1, brachiocephalic aneurysm in 2, aortic dissection in 1 and sudden death in 4 patients. Cardiac-related deaths occurred in 8 patients (9.5%), including congestive heart failure in 6 and acute myocardial infarction in 2 patients. Other deaths occurred as follows: respiratory failure in 14 patients (16.7%), cancer in 13 (15.5%), cerebral accident in 7 (8.3%), sepsis in 5 (6.0%), gastrointestinal complications in 3 (3.6%), renal failure in 1 (1.2%) and unknown in 16 patients (19.0%). Multivariable analysis demonstrated that the risk factors for mortality after surgery were octogenarian (HR, 2.49; $P < 0.001$), prior cerebral infarction (HR, 1.86; $P = 0.014$) and rupture (HR, 2.07; $P = 0.032$) (Table 5).

Late aortic reintervention occurred in 12 (2.8%) patients, including 5 in the TAR group, 6 in TEVAR group and 1 in STEVAR group. Figure 2A shows freedom from reintervention at 3 and 5 years after surgery was 99.5 ± 0.5 and 97.8 ± 1.3% in the TAR group, 95.2 ± 2.1 and 91.9 ± 3.8% in TEVAR group and 97.1 ± 2.8 and 97.1 ± 2.8% in STEVAR group ($P = 0.040$). In the TAR group, re-open surgery was performed in 2 patients due to pseudoaneurysm of the anastomotic site and in 2 patients due to graft infection. TEVAR was performed in 1 patient due to distal anastomotic pseudoaneurysm. In the TEVAR group, reoperations were performed in 4 patients due to endoleak and in 2 patients due to retrograde aortic dissection. In the STEVAR group, only 1 patient required open descending aortic replacement for aortobronchial fistula due to endoleak. Univariable analysis demonstrated that TEVAR exhibited a tendency towards higher aortic reintervention, but the difference was not statistically significant (Table 6).

According to the propensity matching analysis, ICU stay and postoperative hospital stay were shorter in the TEVAR group than in OPEN (TAR and STEVAR) group ($P < 0.001$ and $P < 0.001$, respectively). The survival rates in the OPEN and TEVAR groups

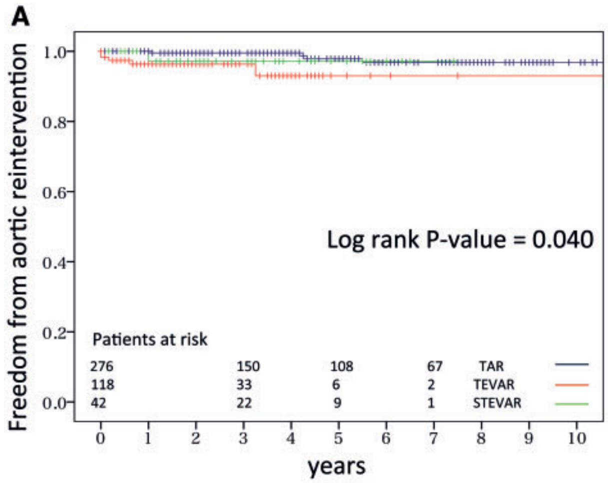

Figure 2: Freedom from aortic reintervention: (**A**) for unmatched patients, (**B**) for the patients after propensity matching.

Table 6: Cox proportional hazards regression analysis for aortic reintervention

Variables	Univariable HR (95% CI)	*P*-value
Age >80 years	3.09 (0.90–10.60)	0.080
Gender (male)	2.36 (0.30–18.60)	0.351
Marfan syndrome	7.62 (0.82–70.77)	0.155
Atherosclerotic	0.63 (0.17–2.40)	0.358
Dissection	1.84 (0.49–6.98)	0.284
Rupture	NA	NA
Emergency/urgent	NA	NA
Prior cerebral infarction	0.62 (0.080–4.92)	0.540
CAD	0.75 (0.20–2.80)	0.469
COPD	0.67 (0.08–5.26)	0.570
Renal dysfunction (on HD)	5.42 (0.61–47.87)	0.202
Previous sternotomy	1.53 (0.33–7.19)	0.417
TEVAR (reference: TAR+STEVAR)	2.79 (0.88–8.82)	0.070
Concomitant procedure	1.09 (0.29–4.12)	0.560
Perioperative neurologic dysfunction	NA	NA

PTCA: percutaneous transluminal coronary angioplasty; CAD: coronary artery disease; COPD: chronic obstructive pulmonary disease; HD: haemodialysis; TAR: total arch replacement; TEVAR: thoracic endovascular aortic repair; STEVAR: staged thoracic endovascular.

were 66.6 ± 6.4 and 74.6 ± 6.4% at 5 years, respectively ($P = 0.465$) (Fig. 1B). The freedom from reintervention in the OPEN group and TEVAR group were 100% and 91.0 ± 5.1% at 5 years, respectively ($P = 0.031$) (Fig. 2B).

DISCUSSION

In the present study, the in-hospital mortality was 3.9% for all patients, including 5.1% of TAR group, 2.1% of TEVAR group and 0% of STEVAR group. Contemporary studies [4–11] have reported an early mortality rate of 4 to 10% in aortic arch operation with SCP and 2 to 6% in hybrid procedures with a stent graft [12–14]. Our early outcomes after the aortic arch operation can be compared favourably with those of the previous reports. In our study, the risk factors for hospital mortality were perioperative neurologic dysfunction and rupture at admission. Octogenarian is not a surgical risk factor in our study. We recommend TAR even for octogenarians without severe frailty. The neurologic dysfunction rates were 5.4% in the TAR group and 2.1% in STEVAR group, and these values are comparable with the results of others [6, 7]. We used moderate hypothermic circulatory arrest with antegrade SCP. Okita *et al.* [15] described that antegrade SCP might be preferred for brain protection in the cases of complicated aortic arch procedures. In the TEVAR group, the neurologic dysfunction rate was 8.5%, which is a matter of concern. At the beginning of our series, most of the strokes occurred in vertebral/basilar lesions. We, therefore, introduced left subclavian artery occlusion before deploying the stent graft main body, resulting in decreased stroke rate [16].

The management of extensive aortic aneurysm is still a challenge [17]. In TAR, distal anastomosis is a challenge if it is very deep from the median sternotomy and the aneurysm is large. However, in the STEVAR, distal anastomosis is proximal to the aneurysm and an ostium of left subclavian artery, and is easier and less invasive than the conventional TAR. It may result in shorter cardiopulmonary bypass (CPB) time, SCP time and operation time than the TAR group in our study. However, there is the risk of rupture between the two stages. In our study, 1 patient died after the first-stage operation while waiting for the next operation. The frozen elephant trunk technique allows single-stage repair of extensive aortic arch disease [18, 19]. However, it needs to be accepted that the risk of SCI is as low as that of conventional TAR. We performed FET technique only on patients whose aneurysm can be treated by the short length of the stent graft or with small access for stent graft delivery. This point led to the low rate of SCI, i.e. 0.4% in TAR group and 0% in STEVAR group.

Aortic reintervention free rate was lower in the TEVAR group than in other groups, and there was no significant difference between the groups in terms of long-term survival. In our report, the superiority of debranching with TEVAR compared with total arch or STEVAR was not evident except for shorter ICU length of stay and postoperative hospital stay and lesser long intubation time. Cao *et al.* [20] concluded that there are no reliable long-term data to ascertain the durability of hybrid arch repair (HAR). Our own results presented herein reflected similar findings. HAR procedures have been proposed as a means to circumvent perioperative morbidity and mortality associated with conventional

TAR in high-risk patients [20, 21]. The results of the current study suggest that HAR is generally safe and effective for patients believed to be inappropriate for conventional open arch repair [22, 23]. However, regarding to native zone 0 landing, HAR is still controversial [24, 25]. There are a few new commercial devices for zone 0 landing [26]. Although these devices may be promising, they are yet to be approved for general use. Under these circumstances, open surgery remains the gold standard for aortic arch pathology.

Limitation

The study was a retrospective analysis. Other limitations of this study include the small sample size and smaller size of each cohort. Therefore, further investigations with a larger cohort and follow-ups are required.

CONCLUSIONS

Aortic arch aneurysm was repaired with acceptable mortality and morbidity in each type of operation. The postoperative outcomes of the three groups were similar, except that the TEVAR group had shorter ICU stay and hospital stay compared to the other two groups. There was no significant difference between the groups in terms of long-term survival. However, TEVAR had inferiority of freedom from aortic reintervention compared to TAR.

Conflict of interest: none declared.

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