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Early and mid-term outcomes of endovascular and open surgical repair of non-dissected aortic arch aneurysm†

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Abstract

OBJECTIVES: With the introduction of endovascular stent graft technology, a variety of surgical options are available for patients with aortic aneurysms. We sought to evaluate early-term and mid-term outcomes of patients undergoing endovascular and open surgical repair for non-dissected aortic arch aneurysm.

METHODS: Overall, 200 patients underwent treatment for isolated non-dissected aortic arch aneurysm between January 2008 and February 2016: 133 patients had open surgery and 67, endovascular repair. Early-term and mid-term outcomes were compared.

RESULTS: Seventy percent (n = 47) needing endovascular repair underwent fenestrated stent graft and 30% (n = 20) underwent the debranched technique. Patients in the open surgery group were younger (71 vs 75 years, P < 0.001) and had a lower prevalence of ischaemic heart disease (11% vs 35%, P < 0.001). Intensive care unit stay (1 vs 3 days, P < 0.001), hospital stay (11 vs 17 days, P < 0.001) and surgical time (208 vs 390 min, P < 0.001) were lower in the endovascular repair group than in the open surgery group. There were 3 in-hospital deaths each in the open surgery and endovascular groups (2% vs 5%, respectively, P = 0.40). Mid-term survival (P < 0.001) and freedom from reintervention (P = 0.009) were better in the open surgery than in the endovascular repair group. No aneurysm-related deaths were observed. The propensity-matched comparison (n = 58) demonstrated that survival was better in the open surgery group (P = 0.011); no significant difference was seen in the reintervention rate (P = 0.28).

CONCLUSIONS: Close follow-up for re-intervention may reduce the risk for aneurysm-related deaths and provide acceptable outcomes in patients undergoing endovascular repair.

Keywords: Aortic arch aneurysm • Fenestrated stent graft • TEVAR • Open surgery

INTRODUCTION

Despite improvements in perioperative care and surgical strategies, the incidence of morbidity and mortality in patients undergoing conventional open thoracic aortic surgery ranges from 2.7 to 28.6% [1–4]. These data include cerebral infarction, transient brain dysfunction, multiple organ failure, respiratory problems and infections [5]. The aging population has increased; owing to their frailness, these patients are at higher risk if they have an operation and may need a less-invasive treatment.

The treatment of patients with aortic arch aneurysms involves the supra-aortic branches and the aortic arch curvature, which is challenging in endovascular treatment. Strategies to obtain an appropriate landing zone without sacrificing the aortic branches are needed. To accommodate for this anatomical complexity, several surgical techniques have been suggested, including open surgical repair, the frozen elephant trunk technique, chimney techniques, branched thoracic endovascular aneurysm repair (TEVAR), debranched TEVAR, fenestrated TEVAR or a combination of these techniques. Using the frozen elephant trunk technique allows for a more proximal site for anastomosis in patients undergoing open surgical repair [2, 6–11]. Branched TEVAR, debranched TEVAR and the chimney technique provide proximal extension of the stent graft while preserving the supra-aortic branch blood flow via additional adjunctive procedures [7, 8, 10, 12]. Fenestrated TEVAR allows for the preservation of the aortic branches by providing added covered bridging stents in the supra-aortic trunks or simply deploying the endograft [8, 13].

The 30-day mortality rate of patients undergoing debranched TEVAR ranges from 2 to 19% [14], whereas the mortality rate of those undergoing other hybrid methods ranges from 9% to 23.7% [3, 15, 16]. The early results of strategies involving endovascular techniques are comparable to those of conventional open

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repair. Although endovascular techniques are less invasive than open surgical repair, they have a risk for endovascular-specific complications, including endoleaks and migrations, which may require additional treatment during the follow-up period.

The goal of this study was to evaluate the early-term and mid-term results of endovascular treatment compared with open surgical repair in patients with non-dissected aortic arch aneurysm.

METHODS

Overall, 281 patients were treated for non-dissected aortic arch aneurysms at our institution between January 2008 and February 2016. Eighty-one patients had comorbidities, including coronary artery or valvular disease requiring additional surgical treatment and were excluded from the study. The remaining 200 patients underwent isolated aortic arch aneurysm repair via open surgical or endovascular repair and were included in this study. Patient selection criteria for this study are shown in Fig. 1. All patients underwent the eyeball frailty evaluation, which was performed by a physician at the time of the outpatient clinic visit. Patients who were considered fit for open surgery underwent the procedure, whereas frail patients were considered for endovascular repair. Follow-up examinations were performed in the outpatient clinic, via mail or via the telephone. The study was approved by the Institutional Review Board of Saitama Medical Center, Jichi Medical University.

Open surgery

Cardiopulmonary bypass was established under general anaesthesia, with a cannula to the ascending aorta or via the subclavian artery, superior vena cava and the inferior vena cava. Cardiopulmonary bypass was maintained using non-pulsatile flow between 2.0 and 2.4 l/min/body surface area (m^2) and a membrane oxygenator. Cerebral perfusion was managed by antegrade cerebral perfusion under mild hypothermia at 25°C. Direct cannulation of the arch vessels was performed followed by catheter balloon inflation. Reconstruction of the left subclavian artery was performed following a distal anastomosis, and a proximal anastomosis was subsequently performed. The remaining arch vessels were reconstructed after the aortic clamp was released.

Endovascular surgery

Inclusion criteria for patients undergoing endovascular aortic arch repair with the precurved fenestrated endograft, Najuta (Kawasumi Laboratories Inc. Shinagawa, Tokyo, Japan), were (i) proximal and distal landing zone >15 mm in length and 20–38 mm in diameter; (ii) adequate access route with a diameter >7 mm; and (iii) supra-aortic branches not originating from the aneurysm, except for the left subclavian artery. Aneurysms originating from the lesser curvature or those from the anterior wall of the aortic arch were considered a great indication for the precurved fenestrated endograft. All of the patients were evaluated via enhanced computed tomography; over-sizing of the sealing zone was +20% of the landing aortic diameter. Patients who were not indicated for the fenestrated stent graft were treated via debranched TEVAR. Extra-anatomical bypass was established from the right to the left subclavian artery followed by the left common carotid artery when needed. This procedure was dependent on the extensiveness of the landing zone, which was anywhere distal to the right innominate artery. All endovascular procedures were performed with the patient under general anaesthesia. The common femoral artery was exposed and used as the access vessel. The 'tug-of-wire' method [11] was used for patients undergoing precurved fenestrated endograft deployment, and a simple stiff wire was used in those undergoing debranched TEVAR. Endografts were deployed in the aortic arch under fluoroscopic guidance without additional circulatory support or rapid pacing. Post-deployment balloon dilatation and occlusion of the left subclavian artery were performed selectively. Computed tomographic imaging was performed 1 week postoperatively.

Data analysis

Normal distribution of the data was performed using the Kolmogorov–Smirnov test. When comparing 2 groups, we analysed continuous data that were normally distributed using the Student *t*-test (mean ± SD); data that were not normally distributed were analysed using the Mann–Whitney test [median, interquartile range (IQR)]. The Fisher exact test was used (*n*, %) for categorical variables. Early-term and mid-term outcomes were compared between patients who underwent open surgical repair and those who underwent endovascular surgery. Early-term results included intensive care unit (ICU) stay, postoperative hospital stay,

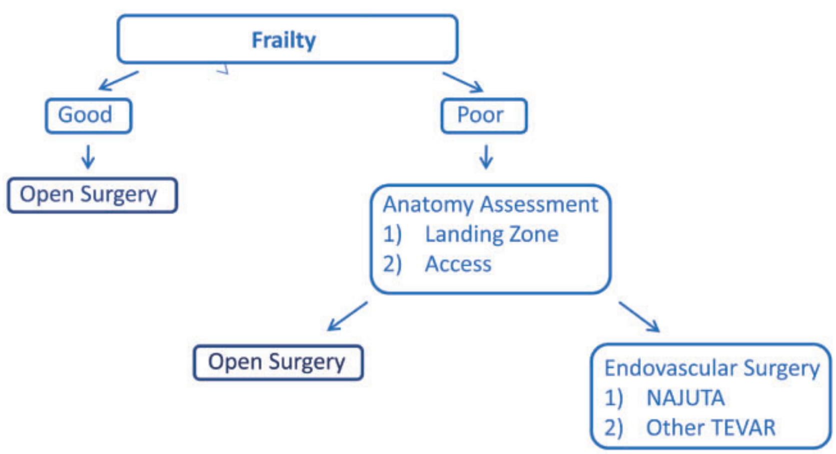

Figure 1: Patient selection criteria. Patient frailty was evaluated by a physician at the out-patient clinic.

prolonged ventilation (>48 h), acute kidney injury, cerebral vascular event (cerebral infarction or clinical symptoms including seizure or paralysis) and the 30-day mortality rate. Mid-term results, including all-cause mortality and aneurysm-related events (i.e. reoperation, reintervention and aneurysm rupture), were evaluated using the Kaplan–Meier curve and the log-rank test.

Propensity score matching was used to adjust for baseline characteristics to further compare the outcomes of patients from similar backgrounds. The variables included in the analysis were age; sex; and prevalence of ischaemic heart disease, hypertension, diabetes, chronic occlusive pulmonary disease, cerebral vascular disease and peripheral vascular disease. These variables were matched in a 1:1 nearest neighbour matching search by building a propensity score by performing logistic regression. Early-term and mid-term results were also compared in the propensity matched group population. *P*-values <0.05 were considered significant. All analyses were performed using Stata (version 13.1, Stata Corp, College Station, TX, USA) and IBM SPSS Statistics, version 23.0 (IBM Corp, Armonk, NY, USA).

RESULTS

Altogether, 133 patients underwent open surgery; 67, endovascular repair. Of the patients in the latter group, 70% ($n = 47$) received fenestrated stent grafts and 30% ($n = 20$), debranched TEVAR. Six patients were not able to undergo endovascular repair despite their frailty. The reasons for this patient selection included an anatomical limitation for the endovascular repair, including large diameter, and a short landing zone. All patients were followed up (median, 45 months; IQR, 19.3–82.8). Patient demographics are shown in Table 1. Patients who underwent open surgical repair were younger (71 ± 7.5 vs 75 ± 7.8, $P < 0.001$) and had a lower prevalence of ischaemic heart disease (11% vs 35%, $P < 0.001$). Statin (34% vs 55%, $P = 0.006$) and aspirin (20% vs 42%, $P = 0.001$) use was also lower in patients who had open surgery compared with those who had endovascular repair. Most patients in the endovascular group had aneurysms that included zone 3, whereas none involved zone 0. However, 24.1% of the patients in the open surgery group had aneurysms involving zone 0. After initial treatment with the Najuta, 13% ($n = 6$) of patients had a type 1 endoleak and 6% ($n = 3$) had a type 2 endoleak. Comparatively, 10% ($n = 2$) of the patients had a type 1 endoleak and 10% (n = 2), a type 2 endoleak after debranched TEVAR treatment. One week post endovascular repair, 4% ($n = 2$) of the patients who received the Najuta continued to have a type 1 endoleak.

Early results of the unadjusted data are shown in Table 2. Compared with the open-surgery group, the endovascular group had a shorter stay in the ICU (1 day, IQR 1–1 vs 3 days, IQR 2–5; $P < 0.001$), shorter hospital stay (11 days, IQR 10–15 vs 17 days, IQR 14–26; $P < 0.001$), and shorter surgery time (208 ± 103 vs 390 ± 87.5 min; $P < 0.001$). There was no significant difference in in-hospital deaths (2% vs 5%; $P = 0.4$). A significant decrease in

Table 1: Patient demographics and medical information for the patients undergoing open surgery compared with those having endovascular repair

	Open surgery	Endovascular repair	*P*-value
	n = 133	*n* = 67	
Age, years[a]	71 ± 7.5	75 ± 7.8	0.0003
Gender, male, *n* (%)	99 (74)	58 (87)	0.07
EuroSCORE II[b]	2.80 (1.84–4.54)	3.19 (2.19–4.89)	0.09
Hypertension, *n* (%)	119 (90)	60 (90)	1
Dyslipidemia, *n* (%)	48 (36)	33 (49)	0.09
Diabetes, *n* (%)	21 (16)	13 (19)	0.55
COPD, *n* (%)	8 (6)	7 (10)	0.27
Previous smoker, *n* (%)	100 (75)	51 (76)	1
Cerebral vascular disease, *n* (%)	21 (16)	5 (8)	0.12
Peripheral vascular disease, *n* (%)	2 (2)	3 (5)	0.34
Ischaemic heart disease, *n* (%)	14 (11)	23 (34)	<0.001
Prior cardiac surgery, *n* (%)	4 (3)	9 (13)	0.011
Ca-Channel blocker, *n* (%)	92 (69)	45 (67)	0.87
ACE inhibitor, *n* (%)	30 (23)	13 (19)	0.72
Angiotensin receptor blocker, *n* (%)	51 (38)	20 (30)	0.27
Beta-blocker, *n* (%)	39 (29)	22 (33)	0.63
HMG-CoA reductase inhibitor, *n* (%)	45 (34)	37 (55)	0.0059
Antiplatelet, *n* (%)	27 (20)	29 (43)	<0.001
Left ventricular ejection fraction, *n*[a]	64 ± 7.6	63.3 ± 9.7	0.45
Creatinine, mg/dl[b]	0.88 (0.71–1.10)	0.87 (0.78–1.16)	0.32
Haemoglobin, g/dl[b]	13.1 (12.2–14.2)	12.6 (11.2–13.8)	0.038
Origin of aneurysm			<0.001
Zone 0, *n* (%)	32 (24)	0 (0)	
Zone 1, *n* (%)	31 (23)	14 (21)	
Zone 2, *n* (%)	26 (20)	17 (25)	
Zone 3, *n* (%)	44 (33)	36 (54)	

ACE: angiotensin converting enzyme; COPD: chronic obstructive pulmonary disease.
[a]Mean ± SD.
[b]Median (25th percentile to 75th percentile).

aneurysm size was observed in patients who underwent endovascular repair 1-year postoperatively versus preoperatively (56.0 ± 11.63 vs 59.5 ± 9.44 mm; $P < 0.001$).

Table 2: Early results for the patients undergoing open surgery compared with those having endovascular treatment

	Open surgery n = 133	Endovascular repair n = 66	P-value
Operation time, min[a]	390.3 ± 87.5	208.1 ± 103	<0.001
ICU stay, days[b]	3 (2–5)	1 (1–1)	<0.001
Postoperative hospital stay, days[b]	17 (14–26)	11 (10–15)	<0.001
Acute kidney injury, n (%)	23 (17)	6 (9)	0.14
Prolonged ventilation, n (%)	19 (14)	3 (5)	0.05
Cerebral infarction, n (%)	14 (11)	2 (3)	0.09
In-hospital deaths, n (%)	3 (2)	3 (5)	0.4

[a]Mean ± SD.
[b]Median (25th percentile to 75th percentile).

Three in-hospital deaths occurred in each group (open surgery group, 2%; endovascular repair group, 5%; $P = 0.40$). Causes of deaths in the open surgery group included multiple organ failure ($n = 1$), heart failure ($n = 1$) and mediastinitis ($n = 1$), whereas those in the endovascular group included shower emboli ($n = 2$) and endograft infection ($n = 1$). Compared with the endovascular repair group, the open surgery group had better mid-term survival (log rank $P < 0.001$) and freedom from reintervention ($P = 0.009$) rates (Fig. 2A and C).

Table 3 shows a propensity score matched group comparison; 58 pairs were matched. No significant differences were observed between the open surgery and endovascular groups. Compared with the open surgery group, the endovascular repair group had a shorter hospital stay (11 days, IQR 10–14 vs 18 days, IQR 14–24; $P < 0.001$) and shorter operative time (202 ± 95.5 vs 392 ± 87.4 min; $P < 0.001$) (Table 4). Further, incidence of cerebral infarction was higher in the open surgery group than in the endovascular repair group (14% vs 2%; $P = 0.032$).

For the mid-term results, patients who underwent open surgery had better survival rates than those who underwent endovascular repair (log rank, $P = 0.012$) (Fig. 2B). Causes of death included cardiac events, cerebral events and pneumonia (Table 5). One patient from the open surgery group had a re-intervention because of a pseudoaneurysm of the anastomosis site, whereas 3 patients from

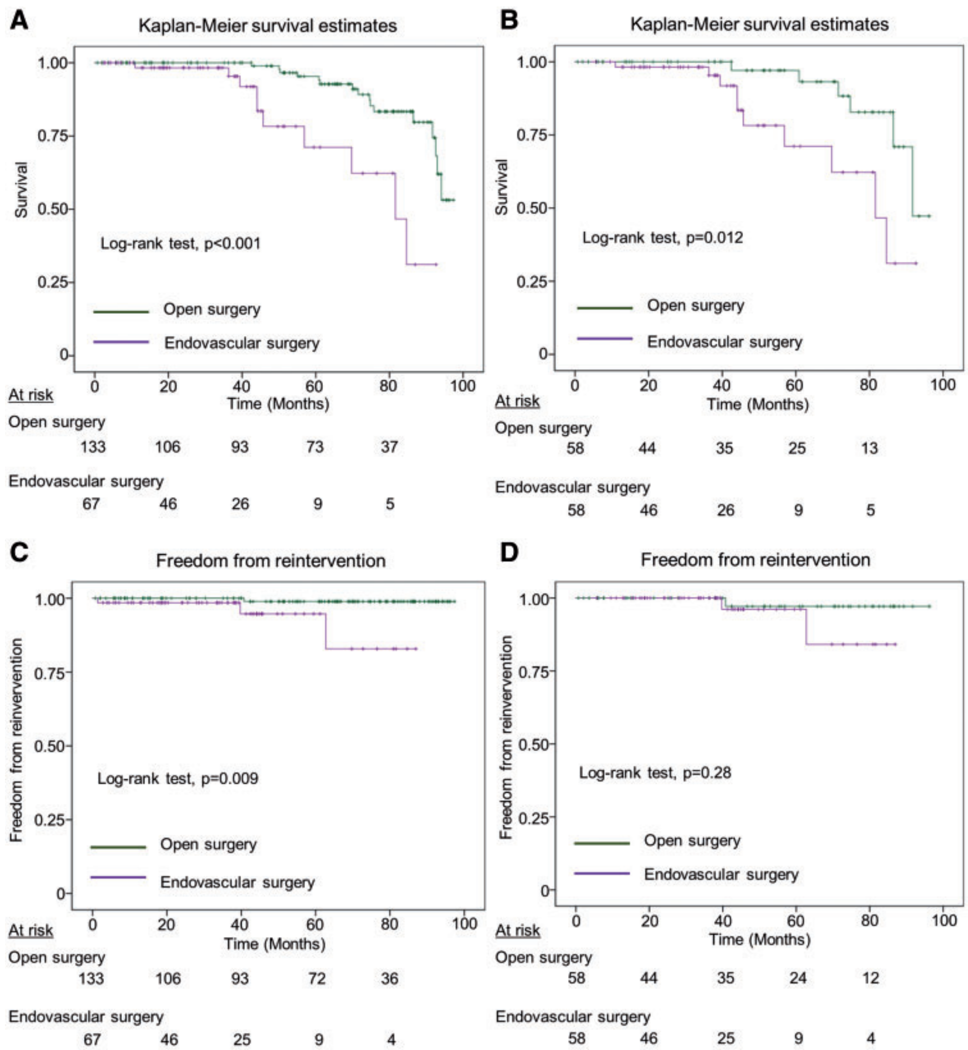

Figure 2: Kaplan–Meier survival curve and log-rank test for all-cause mortality in (**A**) all and (**B**) propensity score-matched patients, and Kaplan–Meier survival curve and log-rank test for reintervention in (**C**) all and (**D**) propensity score-matched patients undergoing an open operation and endovascular repair of an aortic arch aneurysm.

VASCULAR

Table 3: Demographic and medical information for the patients having open surgery compared with those having endovascular treatment in a propensity matched group

	Open surgery $n = 58$	Endovascular repair $n = 58$	P-value
Age, years[a]	74 ± 4.9	74 ± 7.6	0.73
Gender, male, *n* (%)	51 (88)	51 (88)	1
EuroSCORE II[b]	3.06 (2.09–4.63)	3.16 (2.20–4.89)	0.77
Hypertension, *n* (%)	55 (95)	52 (90)	0.49
Dyslipidemia, *n* (%)	26 (45)	27 (47)	1
Diabetes, *n* (%)	9 (16)	12 (21)	0.63
COPD, *n* (%)	7 (12)	7 (12)	1
Previous smoking, *n* (%)	47 (81)	44 (76)	0.65
Cerebral vascular disease, *n* (%)	6 (10)	4 (7)	0.74
Peripheral vascular disease, *n* (%)	1 (2)	2 (3)	1
Ischaemic heart disease, *n* (%)	11 (19)	15 (26)	0.51
Prior cardiac operation, *n* (%)	1 (2)	7 (12)	0.06
Ca-Channel blocker, *n* (%)	45 (78)	39 (67)	0.3
ACE inhibitor (%), *n* (%)	13 (22)	9 (16)	0.48
Angiotensin receptor blocker, *n* (%)	23 (40)	17 (29)	0.33
Beta-blocker, *n* (%)	15 (26)	17 (29)	0.84
HMG-CoA reductase inhibitor, *n* (%)	24 (41)	29 (50)	0.46
Antiplatelet, *n* (%)	15 (26)	21 (36)	0.32
Left ventricular ejection fraction, (%)[a]	64 ± 8.2	64 ± 9.4	0.64
Creatinine level, mg/dl[b]	0.95 (0.80–1.19)	0.86 (0.78–1.16)	0.5
Hemoglobin level, g dl[b]	12.8 (11.8–14.2)	12.6 (11.2–13.8)	0.25

ACE: angiotensin-converting enzyme-inhibitor; COPD: chronic obstructive pulmonary disease; SMD: standard mean difference.
[a]Mean ± SD.
[b]Median (25th percentile to 75th percentile).

Table 4: Early results for the patients undergoing open surgery compared with those having endovascular treatment in the propensity score matched group

	Open surgery $n = 58$	Endovascular repair $n = 58$	P-value
Operation time, min[a]	392.2 ± 87.4	201.6 ± 95.5	<0.001
ICU stay, days[b]	3 (2–5)	1 (1–1)	<0.001
Postoperative hospital stay, days[b]	18 (14–24)	11 (10–14)	<0.001
Acute kidney injury, *n* (%)	14 (24)	6 (10)	0.08
Prolonged ventilation, *n* (%)	7 (12)	2 (3)	0.16
Cerebral vascular event, *n* (%)	8 (14)	1 (2)	0.032
In-hospital deaths, *n* (%)	0 (0)	3 (5)	0.24

[a]Mean ± SD.
[b]Median (25th percentile to 75th percentile).

Table 5: Cause of deaths in patients undergoing open surgery and endovascular treatment

	All		Matched group	
	Open surgery	Endovascular repair	Open surgery	Endovascular repair
Cardiac event, *n* (%)	7 (29)	2 (20)	1 (17)	1 (11)
Cerebral event, *n* (%)	7 (29)	1 (10)	3 (50)	1 (11)
Pneumonia, *n* (%)	4 (17)	2 (20)	1 (17)	2 (22)
Gastrointestinal event, *n* (%)	3 (13)	2 (20)	0 (0)	2 (22)
Multiple organ failure, *n* (%)	1 (4)	2 (20)	1 (17)	2 (22)
Malignancy, *n* (%)	0 (0.0)	1 (10)	0 (0)	1 (11)
Other, *n* (%)[a]	2 (8)	0 (0)	0 (0)	0 (0)

[a]Pulmonary embolism and abdominal aortic aneurysm rupture.

the endovascular repair group had a reintervention because of a type 1 endoleak (log rank, $P = 0.28$; Fig. 2D). No deaths from aneurysm rupture occurred in either group.

In the univariate analysis, variables that were associated with mid-term results in the endovascular and open surgery groups included acute kidney injury (12% vs 90%, respectively; $P = 0.034$), cerebral infarction (6% vs 19%; $P = 0.043$), sepsis (3% vs 35%; $P < 0.001$) and prolonged ventilation (8% vs 35%; $P < 0.001$). In addition, more patients taking angiotensin receptor blockers were likely to survive than patients without (39% vs 15%, respectively; $P = 0.017$). The treatment strategy was not associated with patient outcomes. Variables that were independently associated with mid-term mortality rates in the multivariate analysis included sepsis [odds ratio (OR) 6.82, 95% confidence interval (CI) 1.57–29.6, $P = 0.011$], prolonged ventilation (OR 4.14, 95% CI 1.37–12.5, $P = 0.012$) and angiotensin receptor blocker use (OR 0.26, 95% CI 0.07–0.87, $P = 0.028$). (Table 6).

DISCUSSION

Although patients who had endovascular aortic arch repair were older and had a higher prevalence of ischaemic heart

Table 6: Multivariate analysis for mid-term outcomes

	Odds ratio	95% CI	*P*-value
Angiotensin receptor blocker	0.26	(0.07–0.87)	0.028
Sepsis	6.82	(1.57–29.60)	0.011
Prolonged ventilation	4.14	(1.37–12.50)	0.012

disease, the stays in the ICU and hospital were shorter than for those who had open surgical repair. The all-cause mortality rate (log rank, $P < 0.001$) and re-intervention rate ($P = 0.009$) were higher in the endovascular repair group; however, there were no aneurysm-related deaths in either group. In a propensity-matched comparison, the all-cause mortality rate was higher in the endovascular repair group (log rank, $P = 0.011$); however, there was no significant difference in the re-intervention rate (log rank, $P = 0.28$).

Preservation of cerebral perfusion while avoiding stroke is an important aspect in treating patients with aortic arch aneurysms. The anatomy of the aortic arch comprises complex spatial geometric curves and 3-D angulations. Obtaining a sufficient proximal sealing zone while preserving the three major supra-aortic branches makes it difficult to treat the aneurysm with endografts. Furthermore, endografts in the aortic arch are subjected to dynamic strain due to its curved configuration. High blood flow and the pulsatile movement of the aorta may also cause migration, fractures and damage to the device components [17].

In their series of 55 consecutive patients, Kang *et al*. [18] reported hybrid repair of proximal aortic disease and showed similar perioperative and late outcomes compared with open surgical repair, despite a higher re-intervention rate during follow-up. Bavaria *et al*. [19] reported a series of aortic arch aneurysms treated by a hybrid approach involving zone 0, which also resulted in good mid-term results in a cohort of older patients with significant comorbidity. This surgical technique, however, requires open sternotomy.

Bosiers *et al*. reported a series of 96 patients treated with the chimney technique. Technical success was 89.5% with a 30-day mortality rate of 9.5%. Although no aorta-related deaths were observed, type Ia endoleak occurred in 10.5% of the patients and a major stroke, in 2%; 5.2% of the treated patients required a re-intervention. Gutter-related type I endoleaks and risk for embolic stroke related to arterial access remained a major issue [20]. Maurel *et al*. reported a small series comparing fenestrated TEVAR and branched TEVAR. The 30-day mortality rate was 20% in the fenestrated TEVAR group ($n = 3$) vs 0% in the branched TEVAR group. Causes of early death were major stroke, access complications and myocardial infarction. There was one late non-aneurysm–related death in each group [7]. In a more recent report by Spear *et al*., inner branched endograft use was associated with a major stroke in 7.4% of the patients and with a minor stroke in 3.7%. Although this technique requires catheterization from the target supra-aortic branches, the authors concluded that it may be feasible for patients who cannot undergo open surgery [21].

The Najuta is a semi-customized fenestrated TEVAR device consisting of a self-expandable, stainless-steel Z stent with an expanded polytetrafluoroethylene graft sutured around the stent frame [22]. Yokoi *et al*. reported a series of 383 patients treated with the Najuta. Technical success was achieved in 380 cases and initial success, in 364. Complications included stroke (1.8%), permanent paralysis (0.7%) and perioperative death (1.6%) [11]. Kurimoto *et al*. [23] also reported on the use of the Najuta stent graft. There were no aorta-related late deaths. Survival and aorta-related, event-free rates at 2 years were 86.3 and 88.8%, respectively. These results were similar to the results in this study, where most of the endovascular repairs in our series were performed using Najuta stent grafts.

It was suggested that determinants for the occurrence of post-operative neurological dysfunction in patients undergoing open surgical repair for aortic arch aneurysm are age and duration of the arrest period [24]. Although the effects of these factors could be avoided using endovascular repair, the use of a complex endovascular technique should be limited because excessive manipulation of catheters, wires and intravascular devices in the aortic arch may cause the formation of a thrombus or dissection leading to cerebral embolization or malperfusion [25]. A fenestrated stent graft may be an appropriate option because it is associated with minimal manipulation of the catheter, where cerebral perfusion is preserved after simple deployment of the endograft in the aortic arch. Furthermore, a precurved Najuta stent graft provides less manipulation of the aortic arch intima. By putting tension on the wire using the 'tug-of wire' technique, the precurved stent graft is stretched and inserted until it approaches the brachiocephalic artery. The tension on the wire is then gradually released to get the stent graft in its semi-customized precurved shape while the whole system is advanced into the ascending aorta. This procedure creates less friction on the intima of the aortic arch, which may result in a lower risk of cerebral embolization.

The mid-term, all-cause mortality rate was higher in patients who underwent endovascular repair; however, the major causes of death were unrelated to the aneurysm. Although endovascular repair may be associated with a higher re-intervention rate related to endoleak, device migration and fractures, no aneurysm-related deaths occurred in either group. Only 1 patient in the open surgery group ($n = 133$) had re-intervention due to the formation of a pseudoaneurysm. Three patients from the endovascular treatment group had endovascular re-intervention owing to a type 1 endoleak. Close follow-up after endovascular treatment may have provided timely assessment of the endografts leading to no aneurysm-related death in our series.

Although endovascular repair provided shorter stays in the ICU and hospital and no aneurysm-related deaths, there was a trend toward higher in-hospital deaths. The causes of in-hospital deaths in the endovascular repair group were infection and shower emboli. Although endovascular repair provides less invasive treatment, patients with a shaggy aorta are still at risk if they undergo an operation. The indications for surgical treatment itself or for the development of a new method should also be considered on the basis of the anatomy and physiology of each patient [26].

This study had several limitations. It is a retrospective study with a relatively small number of patients. A study with a larger number of patients should be performed. There was also patient selection bias. Because of the way the operative strategy was chosen, patients who underwent endovascular repair were much more likely to be frail than those who underwent open surgery. Furthermore, there were anatomical differences between the 2 groups, which may have had some impact on the outcomes. However, all patients included in the study would have had the same operation when treated via open surgical repair, which is a total arch replacement under cardiopulmonary bypass. In addition, although propensity-matching scoring was performed, the possibility of other hidden variables contributing to patient outcomes cannot be excluded. Lastly, there was no objective measurement for frailty, which may have been associated with postoperative outcomes.

Although we observed a higher risk for re-intervention in the endovascular group, no aneurysm-related deaths were observed in either group. Endovascular repair may be a less invasive treatment, which provides benefits, especially in elderly patients at high risk if they undergo open surgical treatments. Confinement to simple endovascular techniques and close patient follow-up postoperatively may reduce the risk for aneurysm-related death and provide acceptable outcomes in patients with aortic arch aneurysms undergoing endovascular repair.

Conflict of interest: none declared.

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