Ann Thorac Cardiovasc Surg 2022; 28: 193–203
Online December 22, 2021
doi: 10.5761/atcs.oa.21-00206

Original Article

Early and Mid-Term Outcomes of Open versus Endovascular Left Subclavian Artery Debranching for Thoracic Aortic Diseases

Philip Dueppers, MD,[1] Lorenz Meuli, MD,[1] Benedikt Reutersberg, MD,[1] Michael Hofmann, MD,[1] Florian Messmer, MD,[2] and Alexander Zimmermann, MD[1]

Purpose: To compare open versus endovascular left subclavian artery debranching for thoracic endovascular aortic repair of thoracic aortic pathologies.
Methods: This is a retrospective study of patients receiving left subclavian artery debranching in our institution from October 2009 to January 2020. The primary outcome was freedom from aortic reintervention. Secondary outcomes were type I endoleaks, left subclavian artery (LSA) debranching failure, stroke, technical or clinical success, procedure-related reintervention, as well as 30-day or overall all-cause and aorta-related mortality.
Results: Forty-eight patients received parallel graft-based (n = 24, ENDO; median age 75 years [70–80 years]) or open (n = 24, OPEN; median age 71 years [59–75 years]) debranching for type B aortic dissection (n = 25), degenerative aneurysm (n = 12), type IA endoleak (n = 6), suture-associated (n = 3) or ostial LSA aneurysm (n = 1), or penetrating aortic ulcer (n = 1). The median follow-up was 36 months (13–61 months). After 16 months, aortic reintervention-free survival in groups OPEN and ENDO was 91% (95% confidence interval [CI]: 79 to 100%) and 86% (73 to 100%) (p = 0.71), respectively. After 36 months, all-cause survival in groups OPEN and ENDO was 74% (95% CI: 55 to 99%) and 79% (95% CI: 64 to 97%) (p = 0.74), respectively; freedom from aorta-related mortality was 81% (95% CI: 62 to 100%) and 91% (95% CI: 80 to 100%) (p = 0.78), respectively. Group OPEN presented less type I endoleaks (OPEN/ENDO = 3/19, p <0.001) and higher technical (OPEN/ENDO = 81/36%, p = 0.003) and clinical success rates (OPEN/ENDO = 67/36%, p = 0.047). No statistical differences were found for other outcomes.
Conclusion: Both strategies achieved comparable reintervention and mortality rates, but open debranching should be preferred due to its higher technical and clinical success and less type I endoleaks.

Keywords: thoracic aortic aneurysm, aortic dissection, TEVAR, parallel grafts, endoleak

[1]*Department of Vascular Surgery, University Hospital Zurich, Zurich, Switzerland*
[2]*Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, Zurich, Switzerland*

Received: September 8, 2021; Accepted: November 7, 2021
Corresponding author: Philip Dueppers, MD, MHBA. Department of Vascular Surgery, University Hospital Zurich, Rämistrasse 100, Zurich 8091, Switzerland
Email: dr.dueppers@gmail.com

Introduction

Thoracic endovascular aneurysm repair (TEVAR) has widely replaced open conventional surgery in the treatment of the descending aorta due to its reduced morbidity and mortality.[1] Distal aortic arch and left subclavian artery (LSA) ostium involvement however challenges standard TEVAR as it requires proximal landing in Ishimaru zone.[2] Overstenting the LSA risks ischemia of the arm, cerebellum, and even spinal cord, if multiple intercostal arteries are occluded by long aortic stent grafts.[2–4] Therefore, current clinical guidelines recommend LSA debranching in elective zone 2 TEVAR while in urgent repair; it should be performed based on the patients' anatomy (patent left mammary to coronary bypass grafting, functioning hemodialysis access, and dominant left vertebral artery).[3,5]

Open LSA debranching procedures involve left carotid-axillary or -subclavian bypasses as well as subclavian-carotid-transposition enabling hybrid arch repair without opening the thoracic cavity.[2,4,6] Especially, carotid-subclavian bypasses have widely been used for LSA debranching with excellent long-term patency but require general anesthesia and may cause nerve, lymphatic, or bleeding complications and stroke.[4]

On the other hand, the use of minimally invasive parallel grafts for LSA debranching has meanwhile been confirmed as one promising endovascular option for zone 2 TEVAR in several clinical studies.[7–10] Conventional peripheral stent grafts are implanted parallel to the aortic stent graft and classified depending on their configuration: "chimney" when extending to the proximal and "periscope" when extending to the distal part of the aortic stent graft (involving retrograde blood flow).[7,11] Due to their "off-the-shelf" availability, their lower cost compared to arch-specific devices, and their minor surgical trauma compared to open debranching, some centers rely on this technique even in elective cases.[7–9] However, concerns about gutter-related endoleaks arising from blood flow between the parallel and aortic graft and graft occlusion have impeded this technique to become the first-choice therapy for elective cases in many centers.[12]

An international consent whether to use parallel grafts or open techniques (or even other endovascular techniques) for LSA debranching for zone 2 TEVAR still does not exist. This single-center retrospective cohort study aimed to compare early and mid-term results of open techniques versus parallel grafts for LSA debranching during zone 2 TEVAR.

Materials and Methods

Patients

All patients were enrolled into this retrospective single-center cohort study that received endovascular or open LSA debranching plus TEVAR with proximal landing in Ishimaru zone 2 from October 2009 to January 2020. Vascular pathologies included aortic dissection, degenerative or postoperative aortic aneurysm, type IA endoleak, penetrating aortic ulcer, and proximal LSA aneurysm. Proximal landing in zone 0/1, secondary debranching due to complications, and refusal of trial participation led to exclusion.

We screened the institutional clinical information system and collected demographic, perioperative, and follow-up data. If required, latest follow-up data were transferred from external hospitals. Pre- and postoperative computed tomography angiography (CTA) were reviewed using a three-dimensional workstation (XERO Viewer 8.1.2; Agfa Healthcare N.V., Mortsel, Belgium) and a center line-based method for measurement. Endoleaks were analyzed independently by the first and senior author, and inconsistencies were discussed before reaching an agreement.

The regional review board provided ethical approval. Written informed consent was obtained from all patients or their enrollment was provided by the Federal Human Research Act.

Outcomes

The primary outcome was freedom from aortic reintervention. Secondary outcomes involved technical and clinical success, early procedure-related reinterventions, type I endoleaks, debranching failure, perioperative strokes, as well as early and overall all-cause and aorta-related mortality.

Definitions

Procedure-related reinterventions included all secondary procedures directly attributable to the primary TEVAR and debranching procedure during 30 days from surgery. Aortic reinterventions included all secondary procedures for endoleaks, rupture, or dissection related to the initially treated aortic pathology. Endoleaks were described according to the current reporting standards involving parallel grafts.[13] According to that, a type IC endoleak was defined as retrograde blood flow between the arterial wall of the LSA and the implanted parallel graft. Gutter-related endoleaks were described separately but classified as type IA or IB endoleak.[12,13] LSA debranching failure was defined as LSA graft occlusion or performance of LSA-related reinterventions. Technical success was defined as deployment of all stent grafts at the intended location with maintained patency of all stent grafts and the LSA as well as absence of type I or III endoleak on the first CTA after >30 days postoperative.[13] Clinical success additionally required absence of aneurysm rupture, progressive dissection, disabling stroke or death from primary or secondary procedures or any thoracic aorta-related cause, and freedom from aortic reintervention.[13] Aorta-related mortality included deaths due to early procedure-related or late thoracic aortic complications or due to complications of aortic reinterventions.[13,14]

Statistical analysis

The patient cohort was subdivided into groups ENDO and OPEN according to the used debranching technique. Continuous variables were summarized by mean ± standard deviation if normally distributed or by median (interquartile range) if skewed. Continuous variables were compared using the student's t-test if normally distributed or the Mann–Whitney U test if skewed. Normality was tested using the Shapiro–Wilk test. Categorical variables were summarized with counts and percentages for each level of the variable and compared using the Pearson's chi-squared test. Kaplan–Meier curves were used for estimation of freedom from aortic reintervention and survival. The log-rank test was used for comparison of survival and reinterventions between groups. All analyses were done with R-Studio version 3.6.3 for MacOS or SPSS version 26 for Windows; all p-values were two sided with an alpha level of 5%.

Results

Patients

After excluding 113 patients (proximal landing zone <2 = 98, rejection of trial participation = 8, secondary LSA debranching = 7), we enrolled 48 patients with endovascular (n = 24; group ENDO) or open LSA debranching (n = 24; group OPEN). Except from a higher rate of combined anticoagulation and platelet inhibitor therapy preoperatively in group ENDO, no statistical difference of demographic or disease-specific data was found (**Table 1**). Median follow-up was 36 months (13–61 months) for survival.

Primary procedures

Each patient underwent cardiopulmonary assessment before elective surgery. In frail patients with a high risk for open surgery, an endovascular approach using parallel grafts was defined in an interdisciplinary consensus. A percutaneous transfemoral TEVAR (TAG; W. L. Gore & Associates, Newark, DE, USA) was implanted in all patients who received LSA debranching.

Endovascular debranching (17 periscopes, 7 chimneys) was performed using self-expandable stent grafts (VIABAHN; W. L. Gore & Associates). To ensure that the parallel graft exceeded the length of the aortic stent graft, 17 patients required more than one stent graft (two or three: n = 16/1). Long self-expandable bare-metal stents (WALLSTENT; Boston Scientific, Marlborough, MA, USA) were used for additional stent graft reinforcement in 15 (63%) patients, of which two required two stents for reinforcement of very long periscope grafts.

Open debranching was achieved by carotid-axillary bypasses (n = 20, 83%) or rarely by carotid-subclavian bypasses or subclavian-to-carotid transposition (each n = 2). The LSA remained open (n = 15, 63%) or was plug embolized (n = 6, 25%) or ligated (n = 3, 13%) proximal to the vertebral artery. The different debranching techniques are demonstrated in the **Supplementary Fig. 1** (available Online). More complications occurred during endovascular (n = 3; iliac artery rupture = 2 and parallel graft dislocation = 1) than during open debranching (iliac artery rupture = 1). There were significantly more emergency procedures in the group ENDO. The median cumulated operation time as well as the length of stay in the hospital and intermediate/intensive care unit was significantly longer in the group OPEN – even if comparing single-staged procedures only. Detailed operative data are presented in **Table 2**. Early and mid-term results after primary procedures are summarized in **Table 3**.

Aortic reinterventions

Early aortic reinterventions included one implantation of a second LSA plug for type II endoleak after primary plug embolization (4%; OPEN) and one frozen elephant trunk procedure for retrograde type A aortic dissection (TAAD; 4%; ENDO). During follow-up, seven patients in the group ENDO required aortic reinterventions due

Table 1 Demographic and disease-specific data

Characteristics	ENDO (n = 24)	OPEN (n = 24)	p value
Female	8 (33%)	9 (38%)	0.763
Median age, years (IQR)	75 (70-80)	71 (59-75)	0.103
ASA Class 2	1 (4%)	0 (0%)	0.312
ASA Class 3	18 (75%)	17 (71%)	0.745
ASA Class 4	5 (21%)	7 (29%)	0.505
Arterial hypertension	19 (79%)	17 (71%)	0.505
Tobacco use	10 (42%)	6 (25%)	0.221
Lipid disorder	9 (37%)	5 (21%)	0.204
Chronic kidney injury	8 (33%)	4 (17%)	0.182
Coronary artery disease	4 (17%)	2 (8%)	0.383
Stroke	4 (17%)	2 (8%)	0.383
Cancer	3 (13%)	2 (8%)	0.637
Chronic obstructive pulmonary disease	2 (8%)	2 (8%)	1.00
Prior myocardial infarction	1 (4%)	2 (8%)	0.551
Diabetes mellitus type II	0 (0%)	3 (13%)	0.074
Peripheral arterial occlusive disease	1 (4%)	2 (8%)	0.551
Cerebral vascular disease	0 (0%)	1 (4%)	0.312
Congestive heart failure	0 (0%)	1 (4%)	0.312
Preoperative antithrombotic medication			0.113
None	9 (37%)	9 (37%)	1.00
APT	6 (25%)	9 (37%)	0.350
OAC + APT	6 (25%)	1 (4%)	0.041*
OAC	2 (8%)	5 (21%)	0.220
DAPT	1 (4%)	0 (0%)	0.312
Earlier thoracic aortic procedures	8 (33%)	11 (46%)	0.546
Ascending aorta repair	3 (13%)	5 (21%)	0.439
Alone	2 (8%)	4 (17%)	0.383
+ Hemiarch repair	0 (0%)	1 (4%)	0.312
+ TEVAR	1 (4%)	0 (0%)	0.312
TEVAR	3 (13%)	4 (17%)	0.683
Patchplasty for aortic isthmus stenosis	2 (8%)	0 (0%)	0.149
Thoraco-abdominal aortic replacement	0 (0%)	1 (4%)	0.312
Type B aortic dissection	13 (54%)	12 (50%)	0.773
Acute	7 (29%)	4 (17%)	0.303
Chronic	6 (25%)	8 (33%)	0.525
Degenerative aortic aneurysm	6 (25%)	6 (25%)	1.00
Thoracic aorta	6 (25%)	4 (17%)	0.477
Thoraco-abdominal aorta	0 (0%)	2 (8%)	0.149
Type IA endoleak	3 (13%)	3 (13%)	1.00
Patchplasty-associated aneurysm	2 (8%)	0 (0%)	0.149
Penetrating aortic ulcer	0 (0%)	1 (4%)	0.312
Para-anastomotic aneurysm	0 (0%)	1 (4%)	0.312
Left subclavian artery branch aneurysm	0 (0%)	1 (4%)	0.312
Mean maximum aortic diameter	56 ± 14	58 ± 14	0.687

* Statistical significance

ASA: American Society of Anesthesiologists; (D)APT: (dual) antiplatelet therapy; IQR: interquartile range; OAC: oral anticoagulants; TEVAR: thoracic endovascular aneurysm repair

to each two gutter-related type IA or type IB endoleaks, one type IC endoleak, one non-gutter-related type IA endoleak, and one retrograde TAAD. In the group OPEN, late aortic reintervention was required for each one type IA, IB, and III endoleak as well as for two type II endoleaks due to retrograde blood flow via non-occluded LSA branches. Overall, there was no difference of aortic reinterventions in both groups (n = 8 vs. n = 6; p = 0.525). A stratified analysis of the aortic reintervention rate is presented in **Table 3**. After a median follow-up of 16 months, aortic reintervention-free survival was 91% (95% confidence interval [CI]: 79 to 100%) in the group

Table 2 Operative data

Characteristics	ENDO (n = 24)	OPEN (n = 24)	p value
Procedures			
Single staged	24 (100%)	11 (46%)	<0.001*
Two staged	0 (0%)	13 (54%)	<0.001*
Emergency procedures	7 (29%)	1 (4%)	0.020*
Median operation time, cumulated, min (IQR)	117 (105–149)	207 (170–284)	<0.001*
Only single-staged procedures	117 (105–149)	195 (155–225)	0.001*
Median length of in-hospital stay, cumulated, days (IQR)	6 (5–10)	15 (10–20)	<0.001*
Only single-staged procedures	6 (5–10)	15 (8–20)	0.008*
Median intensive/intermediate care, cumulated, days (IQR)	0 (0–1)	2 (1–9)	0.002*
Only single-staged procedures	0 (0–1)	6 (1–10)	0.002*
Debranching technique			n.a.
Sandwich	10 (42%)	–	n.a.
Periscope	7 (29%)	–	n.a.
Chimney	7 (29%)	–	n.a.
Carotid-axillary bypass	–	20 (83%)	n.a.
Carotid-LSA bypass	–	2 (8%)	n.a.
LSA-to-carotid transposition	–	2 (8%)	n.a.
Planned additional/adjunctive procedures	3 (13%)	1 (4%)	0.394
EVAR	1 (4%)	0 (0%)	0.312
EIA stent grafting for distal entry occlusion	1 (4%)	0 (0%)	0.312
Iliac-femoral conduit	1 (4%)	1 (4%)	1.00
Intraoperative complications	3 (13%)	1 (4%)	0.296
Postoperative antithrombotic medication	24 (100%)	24 (100%)	1.00
OAC + APT	14 (58%)	10 (42%)	0.248
APT	7 (29%)	11 (46%)	0.233
OAC	2 (8%)	2 (8%)	1.00
DAPT	1 (4%)	1 (4%)	1.00

* Statistical significance
(D)APT: (dual) antiplatelet therapy; IQR: interquartile range; LSA: left subclavian artery; n.a.: not applicable; OAC: oral anticoagulants; EVAR: endovascular aortic repair; EIA: external iliac artery

OPEN and 86% (CI: 73 to 100%) in the group ENDO (p = 0.71) (**Fig. 1**).

Secondary outcomes

Both groups presented similar numbers of procedure-related reinterventions (including early aortic reinterventions) (n = 6 vs. n = 3; p = 0.267) that were mostly related to access sites (each = 2). Further reinterventions (ENDO) included abdominal exploration for intestinal ischemia, frustrate recanalization of an occluded periscope, and change from chimney to periscope configuration (each = 1). Strokes occurred in the group OPEN only (n = 2; p = 0.149) and were related to staged TEVAR (multiple cerebral areas) or carotid-subclavian bypass and TEVAR (left hemisphere). Both technical success (36% vs 81%; p = 0.003) and clinical success (36% vs. 67%; p = 0.047) were significantly lower in the group ENDO, mainly due to more type I endoleaks. Reasons for failure are listed in **Table 3**. Early type I endoleaks (59% vs. 10%; p = 0.001) were detected significantly more often in the group ENDO (**Table 3**). Except four type IA endoleaks, all type IA (n = 6) and IB (n = 8) endoleaks in the group ENDO were gutter related. There was one type IC endoleak via the LSA (ENDO). During follow-up, 58% of type I endoleaks sealed spontaneously and one type IB endoleak developed (both ENDO). Early debranching failure was only observed in the group ENDO (n = 2; p = 0.149) due to periscope graft occlusion. During follow-up, each one additional carotid-axillary bypass and sandwich–periscope graft occluded. Overall LSA debranching failure was 13% after endovascular and 5% after open debranching (p = 0.317).

Mortality

Thirty-day as well as overall all-cause and aorta-related mortality rates were not statistically different in both groups (**Table 3**). Early aorta-related deaths were related to postoperative type IA endoleak and persistent hemorrhage after type B aortic dissection-related aortic rupture (n = 1; ENDO) or intestinal ischemia after celiac

Table 3 Early and late results of open versus endovascular debranching

Characteristics	ENDO (n = 24)	OPEN (n = 24)	p value
30-day results			
Median follow-up for first CTA, days (IQR)	2 (1–4)	1 (1–2)	0.121
Type I endoleaks	19 (79%)	3 (13%)	<0.001*
Type IA	10 (42%)	2 (8%)	0.008*
Type IB	8 (33%)	1 (4%)	0.010*
Type IC	1 (4%)	–	n.a.
Procedure-related reinterventions	6 (25%)	3 (13%)	0.267
LSA debranching failure	2 (8%)	0 (0%)	0.149
Stroke	0 (0%)	2 (8%)	0.149
30-days mortality, all-cause	2 (8%)	3 (13%)	0.637
30-days mortality, aorta-related	1 (4%)	1 (4%)	1.00
First CTA follow-up >30 days			
Patients available	22 (92%)	21 (87%)	0.637
Median follow-up for first CTA >30 days, months (IQR)	3 (2–4)	2 (2–3)	0.438
Technical success	8 (36%)	17 (81%)	0.003*
Type I endoleak	13 (59%)	2 (10%)	0.001*
Type IA	7 (32%)	1 (5%)	0.023*
Type IB	5 (23%)	1 (5%)	0.089
Type IC	1 (5%)	–	n.a.
Type III endoleaks	0 (0%)	2 (10%)	0.138
Clinical success	8 (36%)	14 (67%)	0.047*
LSA debranching failure	2 (8%)	0 (0%)	0.157
Latest CTA follow-up			
Patients available	21 (88%)	20 (83%)	0.683
Median follow-up for last CTA, months (IQR)	52 (33–71)	21 (14–59)	0.062
Persisting type I endoleaks	9 (43%)	0 (0%)	0.001*
Type IA	5 (24%)	0 (0%)	0.020*
Type IB	3 (14%)	0 (0%)	0.079
Type IC	1 (5%)	–	n.a.
Median follow-up for survival, months (IQR)	52 (22–68)	16 (8–48)	0.061
Median follow-up for CTA, months (IQR)	48 (22–68)	16 (8–48)	0.093
Median follow-up for aortic reintervention, months (IQR)	26 (4–57)	15 (3–31)	0.458
Overall aortic reinterventions	8 (33%)	6 (25%)	0.525
Type I endoleak	6 (25%)	2 (8%)	0.121
Type II endoleak	0 (0%)	3 (13%)	0.074
Type III endoleak	0 (0%)	1 (4%)	0.312
Retrograde type A aortic dissection	2 (8%)	0 (0%)	0.149
Overall LSA debranching failure	3 (13%)	1 (5%)	0.317
Overall mortality, all-cause	9 (38%)	6 (25%)	0.393
Overall mortality, aorta-related	4 (17%)	3 (13%)	1.00

Percentages are based on the number of patients available for follow-up. Overall rates and corresponding percentages are calculated based on the initial patient number
*Statistical significance
CTA: computed tomography angiography; IQR: interquartile range; LSA: left subclavian artery; n.a.: not applicable

trunk overstenting (n = 1; OPEN). Late aorta-related deaths were caused by type IA or IB endoleak-related reintervention or type IB endoleak-related rupture in the group ENDO (n = 3), or by stent graft infection and type IA endoleak-related rupture in the group OPEN (n = 2). After a median follow-up of 36 months, freedom from overall all-cause mortality was 74% (CI: 55 to 99%) in the group OPEN and 79% (CI: 64 to 97%) in the group ENDO (p = 0.74), while freedom from aorta-related mortality was 81% (CI: 62 to 100%) and 91% (CI: 80 to 100%) (p = 0.78), respectively (**Fig. 1**).

Discussion

Main findings of this study included significantly higher technical and clinical success and lower type I

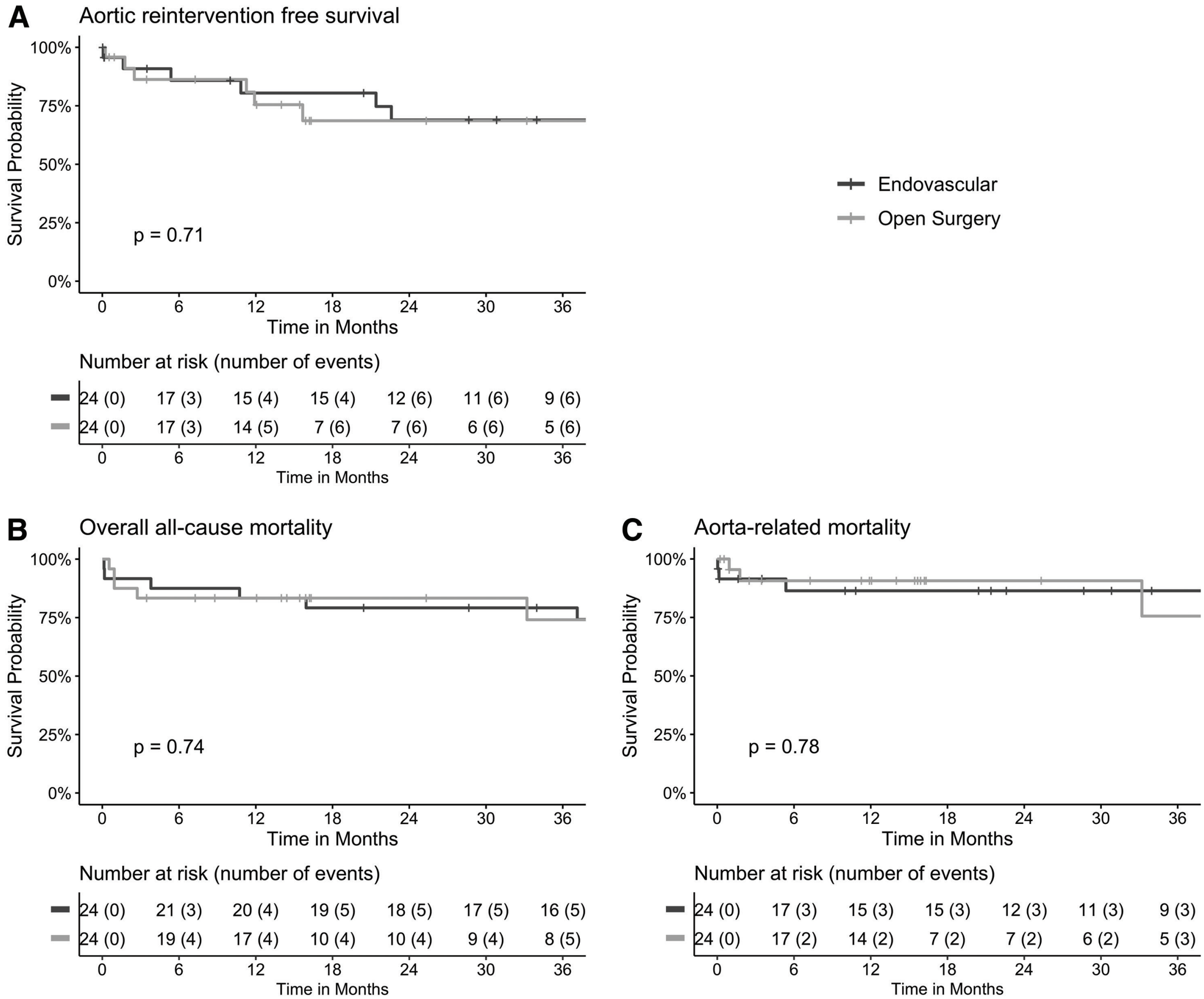

Fig. 1 Kaplan–Meier analysis of freedom from overall aortic reintervention (**A**), overall all-cause mortality (**B**), and aorta-related mortality (**C**).

endoleak rates after open LSA debranching. Aortic reinterventions and aorta-related mortality were similar in both groups.

Perioperative outcomes of open (n = 721) and endovascular LSA debranching (n = 116) were recently compared using prospectively collected registry data from the Vascular Quality Initiative, but only 20% (n = 23) of endovascularly treated patients received parallel grafts.[6] In fact, there are only four studies exclusively comparing carotid–subclavian bypasses or subclavian–carotid transposition to chimney or periscope–sandwich grafts for LSA debranching.[8,15–17] **Table 4** demonstrates their results along with studies that examined either open or parallel graft-based LSA debranching only.[2,4,6,9,18] A former study from the reporting institution also described results of periscope–sandwich grafts for LSA debranching, but as only some of the patients were included into the presented cohort, their results were not used for comparison.[7] Follow-up for parallel grafts in these four studies was 8–21.3 months and much shorter than the 52 months in the presented study. As in our study, statistical differences were neither detected for strokes, mortality, or reintervention rate.[8,15–17]

Nevertheless, all comparative studies reported more aortic reinterventions after parallel grafts than after open procedures.[8,15–17] Our rate of 33% for parallel grafts is in line with Johnson et al., but others have reported much lower rates of 0.6%–12.5%.[8,15,17,18] Reasons for aortic reinterventions involved type IA and IB endoleaks, type II endoleak via non-occluded LSA branches, aorto-bronchial fistula, stent graft migration, and distal stent-induced new entry tear.[8,15–17] Type II endoleaks

Table 4 Published results of open and parallel graft-based left subclavian artery debranching during zone 2 TEVAR

Group	Technique	Author	Design	Year	Patients	Median FU	30-day mortality		Stroke	Primary EL I	Technical success	Overall aortic reintervention	Overall mortality, all-cause	Primary EL I
							All-cause	Aorta related						
OPEN	CSB + SCT	Luehr et al.[2)]	Single cohort	2019	55	16.8	4 (7.3)	n.d.	3 (5.5)	7 (12.8)	n.d.	7 (12.8)	7 (12.7)	n.d.
OPEN	CSB + SCT	D'Oria et al.[6)]	Single cohort[c]	2020	721	1	24 (3.3)	16 (2.2)	36 (5.0)	19 (2.6)	n.d.	n.d.	n.d.	n.d.
OPEN	CSB	Xiang et al.[17)]	Comparative	2018	14	–(39.9[a])	1 (7.1)	0 (0)	0 (0)	1 (7.1)	13 (92.9)	1 (7.7)	1 (7.1)	0 (0)
OPEN	CSB	Piffaretti et al.[8)]	Comparative	2018	42	15	n.d.	1 (2.4)	1 (2.4)	n.d.	41 (97.6)	2 (4.8)	n.d.	n.d.
OPEN	CSB + SCT	Johnson et al.[15)]	Comparative	2021	35	26.2	0 (0)	0 (0)	1 (2.9)	0 (0)	n.d.	9 (25.7)	1 (2.9)	0 (0)
OPEN	CSB	Ramdon et al.[16)]	Comparative	2020	64	14.5	2 (3.1)	n.d.	4 (6.3)	3 (4.6)	n.d.	n.d.	n.d.	n.d.
OPEN	CSB + CAB + SCT	Own study	Comparative	2021	24	16	3 (13)	1 (4)	2 (8)	3 (13)	17 (81)	6 (25)	6 (25)	0 (0)
ENDO	Chimney	Xue et al.[9)]	Single cohort	2015	59	16.5	0 (0)	0 (0)	2 (3.4)	5 (8.5)	58 (98.3)	n.d.	3 (5.1)	5 (8.5)
ENDO	Chimney	Ding et al.[18)]	Single cohort	2019	159	–(23[a])	3 (1.9)	1 (0.6)	3 (1.9)	36 (22.6)	129 (81)	1 (0.6)	6 (3.8)	4 (3.3)
ENDO	Chimney	Piffaretti et al.[8)]	Comparative	2018	31	15	n.d.	2 (6.4)	1 (3.2)	n.d.	31 (100)	2 (6.5)	n.d.	4 (13)
ENDO	Chimney	Xiang et al.[17)]	Comparative	2018	24	–(21.3[a])	0 (0)	0 (0)	0 (0)	10 (41.7)	24 (100)	3 (12.5)	0 (0)	5 (20.8)
ENDO	Chimney	Ramdon et al.[16)]	Comparative	2020	17	8	0 (0)	n.d.	1 (5.9)	0 (0)	n.d.	n.d.	n.d.	n.d.
ENDO	Periscope	Johnson et al.[15)]	Comparative	2021	18	11	0 (0)	0 (0)	0 (0)	7 (39)	n.d.	6 (33.3)	3 (16.7)[b]	2 (11.1)
ENDO	Both	Own study	Comparative	2021	24	36	2 (8)	1 (4)	0 (0)	19 (79)	8 (36)	8 (33)	9 (38)	9 (43)

Results are given as numbers (percentage) or months for follow-up

[a] Mean; [b] Aorta-specific; [c] Endovascular group was not used for comparison, because only 20% received parallel grafts and subgroup analysis was not performed

CAB: carotid-axillary bypass; CSB: carotid-subclavian bypass; EL I: type I endoleak; FU: median follow-up; n.d.: not described; SCT: subclavian-carotid transposition; TEVAR: thoracic endovascular aneurysm repair caused by retrograde blood flow via non-occluded LSA branches after open debranching (reported in 21%–23% of patients) deserve special consideration, as this is a truly evitable cause for reintervention.[15,17] Although some cases of spontaneous occlusion have been reported, most patients suffer from persisting type II endoleak and require embolization.[8,15] One third of all aortic reinterventions after open debranching in this study was related to these type II endoleaks. Because of our experience and learning curve, we meanwhile performed primary LSA occlusion as a standard, which we considered crucial for preventing aortic reintervention. If not considering these type II endoleaks, the difference of aortic reintervention rates between both groups as the primary outcome would have been higher, but still without statistical significance ($p = 0.182$). Also secondary endpoints were not affected by these type II endoleaks.

In addition, most of these studies described more type I endoleaks for parallel grafts, for which this study and Xiang et al. even found statistical significance.[17] The majority of these endoleaks were gutter related, which is a well-known, parallel graft-unique source of endoleakage.[8,12,15,17] No remaining endoleak was detected after open debranching in the latest CTA.[15,17] In line with our results, 11.1%–20.8% of primary endoleaks were still present after endovascular debranching.[15,17] However, these endoleaks did not lead to a significantly higher rate of aortic reintervention or mortality compared to open techniques in our or comparable studies.[8,15,17]

The reported technical success rate was much lower for parallel grafts compared to open procedures and results of other studies (**Table 4**). However, comparison of technical and clinical success rates among studies is impaired by the use of different definitions.

As a result of this and other studies, perioperative strokes of both techniques did not show a significant difference and were comparable to the reported 5.4% pooled stroke rate in a large meta-analysis of LSA revascularization and stroke as the primary outcome (**Table 4**).[19]

Graft occlusion with required reintervention was not a major issue in this nor in other studies as they mainly remained asymptomatic and showed no statistical significance between both groups.[16,17] However, presented occlusion rates after open procedures (5%) and parallel grafts (13%) were higher than the reported 0%–3% after open[4,8,15–17] and 0%–4.2% after parallel graft procedures.[8,9,15–18]

The observed mortality of both groups is comparable to literature results, but 30-day and overall all-cause mortality was higher in our patients (**Table 4**). Piffaretti et al. estimated the freedom from TEVAR-related mortality of 93% at 12 and 36 months and freedom from all-cause mortality of 83% and 81% at 12 and 36 months, respectively.[8]

Parallel grafts were used significantly more frequently in emergency settings in this and other studies.[8] To maintain graft patency, antithrombotic medication was prescribed more aggressively in the presented patients when using parallel grafts (especially oral anticoagulation + antiplatelet therapy). Piffaretti et al. also reported significantly more patients with double antiplatelet therapy after using parallel grafts and consequently described a significantly less freedom from endoleak in this subgroup compared to patients with single antiplatelet therapy.[8]

Endovascular alternatives to parallel grafts are custom-made single-branched[20,21] or scalloped devices[22] that are only available for elective repair due to the required time for manufacturing. Physician-made fenestrations or scallops are another alternative for either elective or emergent repair, but require advanced endovascular expertise and may not be permitted in every country due to its off-label nature.[5,23] Larger studies with longer follow-up are not yet existent.

Limitations

Due to this study's single-center retrospective observational design with a univariate analysis, observed differences may not be associated with the debranching technique and statistical power may be reduced by the small-sized patient cohort. Results may – especially in urgent cases – also be biased by the treatment selection based on patients' individual risk assessment by the treating surgeon. Heterogeneity of our cohort is increased due to the inclusion of elective and urgent cases as well as different aortic pathologies, especially aortic degenerative aneurysms and aortic dissections. However, these subgroups were also mixed into patient cohorts in comparable studies, and heterogeneity seems to be a general issue.[6,8]

Conclusion

Both open and parallel-graft-based LSA debranching achieved comparable results regarding aortic reintervention and mortality. When treating high-risk patients, the longer procedure time of open debranching should be kept in mind, but apart from that, open debranching (including mandatory proximal LSA occlusion) should be the preferred technique due to significantly less type I endoleaks and a higher technical and clinical success.

Disclosure Statement

Alexander Zimmermann is a proctor for CryoLife/Jotec and for Cook Medical. He is member of an advisory board for Medtronic. Benedikt Reutersberg is a proctor for Terumo Aortic. There are no further conflicts of interest.

Supplementary Information

Contrast-enhanced computed tomography scans demonstrating performed endovascular (chimney [**A**], periscope [**B**]) and open (carotid-subclavian bypass [**C**], LSA transposition [**D**]) techniques for debranching of the LSA.

References

1) Geisbüsch S, Kuehnl A, Salvermoser M, et al. Increasing incidence of thoracic aortic aneurysm repair in germany in the endovascular era: secondary data analysis of the nationwide German DRG microdata. Eur J Vasc Endovasc Surg 2019; **57**: 499–509.
2) Luehr M, Etz CD, Berezowski M, et al. Outcomes after thoracic endovascular aortic repair with overstenting of the left subclavian artery. Ann Thorac Surg 2019; **107**: 1372–9.
3) Riambau V, Böckler D, Brunkwall J, et al. Editor's choice - management of descending thoracic aorta diseases: clinical practice guidelines of the European Society for Vascular Surgery (ESVS). Eur J Vasc Endovasc Surg 2017; **53**: 4–52.
4) Voigt SL, Bishawi M, Ranney D, et al. Outcomes of carotid-subclavian bypass performed in the setting of thoracic endovascular aortic repair. J Vasc Surg 2019; **69**: 701–9.
5) Bradshaw RJ, Ahanchi SS, Powell O, et al. Left subclavian artery revascularization in zone 2 thoracic endovascular aortic repair is associated with lower stroke risk across all aortic diseases. J Vasc Surg 2017; **65**: 1270–9.
6) D'Oria M, Kärkkäinen JM, Tenorio ER, et al. Perioperative outcomes of carotid-subclavian bypass or transposition versus endovascular techniques for left subclavian artery revascularization during nontraumatic zone 2 thoracic endovascular aortic repair in the vascular quality initiative. Ann Vasc Surg 2020; **69**: 17–26.
7) Lachat M, Mayer D, Pfammatter T, et al. Periscope endograft technique to revascularize the left subclavian artery during thoracic endovascular aortic repair. J Endovasc Ther 2013; **20**: 728–34.
8) Piffaretti G, Pratesi G, Gelpi G, et al. Comparison of two different techniques for isolated left subclavian artery revascularization during thoracic endovascular aortic repair in zone 2. J Endovasc Ther 2018; **25**: 740–9.
9) Xue Y, Sun L, Zheng J, et al. The chimney technique for preserving the left subclavian artery in thoracic endovascular aortic repair. Eur J Cardiothorac Surg 2015; **47**: 623–9.
10) Dueppers P, Reutersberg B, Rancic Z, et al. Long-term results of total endovascular repair of arch-involving aortic pathologies using parallel grafts for supra-aortic debranching. J Vasc Surg 2022; **75**: 813–823.e1.
11) Criado FJ. Chimney grafts and bare stents: aortic branch preservation revisited. J Endovasc Ther 2007; **14**: 823–4.
12) Ohrlander T, Sonesson B, Ivancev K, et al. The chimney graft: a technique for preserving or rescuing aortic branch vessels in stent-graft sealing zones. J Endovasc Ther 2008; **15**: 427–32.
13) Oderich GS, Forbes TL, Chaer R, et al. Reporting standards for endovascular aortic repair of aneurysms involving the renal-mesenteric arteries. J Vasc Surg 2021; **73**: 4S–52S.
14) Fillinger MF, Greenberg RK, McKinsey JF, et al. Reporting standards for thoracic endovascular aortic repair (TEVAR). J Vasc Surg 2010; **52**: 1022–33, 1033.e15.
15) Johnson CE, Zhang L, Magee GA, et al. Periscope sandwich stenting as an alternative to open cervical revascularization of left subclavian artery during zone 2 thoracic endovascular aortic repair. J Vasc Surg 2021; **73**: 466–75.e3.
16) Ramdon A, Patel R, Hnath J, et al. Chimney stent graft for left subclavian artery preservation during thoracic endograft placement. J Vasc Surg 2020; **71**: 758–66.
17) Xiang Y, Huang B, Zhao J, et al. The strategies and outcomes of left subclavian artery revascularization during thoracic endovascular repair for type B aortic dissection. Sci Rep 2018; **8**: 9289.
18) Ding H, Zhu Y, Wang H, et al. Management of type B aortic dissection with an isolated left vertebral artery. J Vasc Surg 2019; **70**: 1065–71.
19) Huang Q, Chen XM, Yang H, et al. Effect of left subclavian artery revascularisation in thoracic endovascular aortic repair: a systematic review and meta-analysis. Eur J Vasc Endovasc Surg 2018; **56**: 644–51.
20) Patel HJ, Dake MD, Bavaria JE, et al. Branched endovascular therapy of the distal aortic arch:

preliminary results of the feasibility multicenter trial of the gore thoracic branch endoprosthesis. Ann Thorac Surg 2016; **102**: 1190–8.
21) Zhang H, Huang H, Zhang Y, et al. Comparison of chimney technique and single-branched stent graft for treating patients with type B aortic dissections that involved the left subclavian artery. Cardiovasc Intervent Radiol 2019; **42**: 648–56.
22) Ben Abdallah I, El Batti S, Sapoval M, et al. Proximal scallop in thoracic endovascular aortic aneurysm repair to overcome neck issues in the arch. Eur J Vasc Endovasc Surg 2016; **51**: 343–9.
23) Chassin-Trubert L, Mandelli M, Ozdemir BA, et al. Midterm follow-up of fenestrated and scalloped physician-modified endovascular grafts for zone 2 TEVAR. J Endovasc Ther 2020; **27**: 377–84.