Endovascular treatment of chronic aortic dissection with fenestrated and branched stent grafts

Marek K. Kuzniar, MD, Anders Wanhainen, MD, PhD, Gustaf Tegler, MD, PhD, *and* Kevin Mani, MD, PhD, *Uppsala, Sweden*

ABSTRACT

Objective: Chronic aortic dissection with aneurysm development that includes the aortic arch and/or thoracoabdominal aorta (TAAA) is traditionally treated with open or hybrid surgery. Total endovascular treatment with fenestrated and branched aortic repair (F/B-EVAR) has recently been introduced as a less invasive alternative. The aim was to report the short- and midterm outcomes from a single tertiary vascular center.

Methods: All patients with chronic aortic dissection treated with F/B-EVAR from 2010 to 2019 at Uppsala University Hospital were identified. Perioperative and postoperative parameters were analyzed, with focus on short- (<30 days) and midterm survival, complication, and reintervention rates.

Results: F/B-EVAR was performed on 26 patients (median age, 63 years; range, 33-87 years; 18 men; median aortic diameter, 70 mm; range, 50-98 mm); with a median follow-up of 23 months (range, 0.5-118.0 months). One patient underwent both arch and TAAA repair. Overall, 13 arch repairs (arch group) after type A (n = 8) and type B (n = 5) dissection (all elective) were performed, and 14 TAAA repairs (TAAA group) after type A (n = 5) and type B (n = 9) dissection (one rupture). A total of 72 aortic branches were targeted (22 arch, 50 TAAA). Short-term technical success was achieved in 24 of 27 procedures (89%). Failures were related to one intraoperative retrograde type A dissection (RTAD) requiring open conversion (arch group), one persistent type IC endoleak on completion angiography (arch group), and one persistent type III endoleak (TAAA group). Mortality was 4% (n = 1) at 30 days and related to a second RTAD that occurred after discharge and was found on autopsy. Both RTADs occurred in patients with chronic type B dissection undergoing fenestrated arch repair. Paraplegia occurred in three cases (two arch, one TAAA) (11%), none permanent, and stroke in three cases (one arch, one TAAA) (11%); one was permanent. In the midterm, endoleaks were detected in 12 patients (44%); persistent false lumen flow (n = 3), type IB (n = 1), type IC (n = 3), type II (n = 7), and type IIIC (n = 2). The 3-year survival (Kaplan-Meier) of the arch repair was 75% and for the TAAA, 93%. Freedom from reintervention at 3 years were 100% for arch repairs and 48% for TAAA. In patients with a follow-up of more than 6 months (n = 23), all had stable or decreased aortic diameters and complete false lumen thrombosis at the level of stent graft was present in 65% (n = 15).

Conclusions: Endovascular treatment of postdissection aneurysms is feasible, with acceptable short-term and midterm outcomes. RTAD after fenestrated and branched endovascular arch repair warrants caution when performed on patients with native ascending aortas, and reinterventions are frequent in TAAA repair. (J Vasc Surg 2021;73:1573-82.)

Keywords: Chronic dissection; Endovascular repair; Arch repair; Fenestrated branched stent grafts

A large proportion of patients surviving an aortic dissection develop an aneurysmal degradation of the outer wall of the false lumen, requiring further intervention.[1] Geirsson et al[2] showed that the risk for reintervention, predominantly owing to aortic dilatation, in the aorta distal to the replaced segment following type A dissections, was 25% at 6 years. Juvonen et al[3] reported 38% aneurysmal rupture or progression requiring aortic repair in patients who underwent medical therapy alone for type B aortic dissections. Despite advances in medical therapy the intervention-free survival is only 60% at 6 years in patients managed with medical therapy alone, underlining the need of subsequent surgical repair.[1]

Traditionally, postdissection aneurysms of the arch or thoracoabdominal aorta (TAAA), were primarily treated with open or hybrid surgery. These major procedures involve a substantial surgical trauma to the patient, and even in the modern era, with surgical advances and improved postoperative care, the morbidity and mortality after open repair[4] and hybrid repair[5] remain high.

In our institution open or hybrid repair was the primary mode of treatment for postdissection aneurysms, in visceral segment until 2010, and in arch segment until

From the Section of Vascular Surgery, Department of Surgical Sciences, Uppsala University.

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Correspondence: Marek Kuzniar, MD, Vascular Surgery, Department of Surgical Sciences, Uppsala University, 751 85 Uppsala, Sweden (e-mail: marek.kuzniar@surgsci.uu.se).

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2014, after which we have adopted a preference for a total endovascular approach when possible.[6-8] Early favorable outcomes after endovascular treatment of postdissection aneurysms have been reported, with comparable results with those achieved with atherosclerotic TAAAs.[9-17] However, a fenestrated-branched endovascular approach remains a relatively new technique, particularly in a dissection setting, and its long-term results are uncertain. The aim of this study was to report short-term and midterm outcomes after endovascular repair of chronic aortic dissection with fenestrated and branched stent grafts in a tertiary vascular center.

ARTICLE HIGHLIGHTS

- **Type of Research:** A single-center, retrospective cohort study
- **Key Findings:** Twenty-six patients with postdissection aneurysms underwent total fenestrated-branched endovascular repair of the arch and thoracoabdominal aorta with 89% technical success and 4% perioperative mortality. Two of six patients with native ascending aortas undergoing arch fenestrated repair developed retrograde type A dissection. The 3-year survival was 75% for arch and 93% for thoracoabdominal cases, and reinterventions occurred in 0% and 52% of patients, respectively.
- **Take Home Message:** Endovascular treatment of postdissection aneurysms has acceptable short- and midterm outcomes. The results suggest an increased risk of retrograde type A dissection when performing fenestrated and branched arch repair of chronic dissection aneurysms in patients with native ascending aorta.

METHODS

Prospectively collected data were analyzed for all patients with chronic aortic dissection aneurysms who underwent fenestrated and/or branched endovascular aortic repair (F/B-EVAR) of the arch and/or TAAA between January 2010 and November 2019 at Uppsala University Hospital. The study was approved by the ethical committee of the Uppsala region.

All patients were discussed on multidisciplinary rounds consisting of vascular and cardiac surgeons, angiologists, and radiologists. All patients underwent high-resolution computed tomography (CT) imaging, with arterial and venous contrast-enhanced phases and 1-mm slice thickness. Sizing and planning were performed using 3D workstations (3mensio, Medical Pie Imaging, Maastricht, the Netherlands) with multiplanar reconstruction and centerline analysis. All patients were treated with custom-made devices (CMD) or off-the-shelf Cook Medical stent grafts (Bloomington, Ind).

For arch reconstruction, in cases where dissections involved the arch and the arch was aneurysmal, typically after a type A dissection repair, the repair was done using arch branch device with two inner side branches for the brachiocephalic trunk (BCT) and left common carotid (LCC) artery, landing with the main graft proximally in the ascending graft. Because this graft design involves covering the left subclavian artery (LSA) a bypass from LCC was always performed as a staged procedure or in the same setting as arch repair (Supplementary Fig, online only). In cases where dissections extended into abdominal aorta, a distal landing in the true lumen of the dissected descending thoracic aorta was accepted. False lumen embolization techniques were only used selectively, on relatively large and/or fast expanding aneurysms, where the risk of leaving retrograde flow in thoracic false lumen was deemed too high. The stent graft was sized on the long axis of the true lumen, and oversizing was avoided at the distal end to minimize the risk of stent graft-induced reentries. Additionally, in selected cases, when landing in dissected aorta (typically arch repair), a modified stent graft design with low distal radial force was used.[18] Cardiac output control upon stent graft deployment was achieved with inferior vena cava occlusion. BCT stenting was performed through the exposed right common carotid (RCC) artery, with distal clamp to decrease the risk for embolization. For patients with a distal arch or proximal descending aortic aneurysm requiring a landing zone in the arch (typically after a type B dissection), arch fenestrated devices were planned, with single fenestration for the LSA or LCC and scallop for the proximal supra-aortic vessel when necessary. Patients in need of arch branch reconstruction but with no previous ascending repair were refused total endovascular repair, because landing in a native ascending aorta in a dissection setting was considered a contraindication. However, implantation of arch fenestrated devices was accepted in postdissection setting in case of normal ascending aorta and arch landing zone. All arch stent grafts were flushed with carbon dioxide before saline flushing, and procedures were performed with target activated clotting time of more than 250 seconds during stent graft insertion.

For TAAA repair, we aimed for complete false lumen exclusion by extending the distal repair beyond the dissection, landing in healthy or previously grafted abdominal aortic or iliac zones. Patients with dissections extending distally beyond the iliac bifurcation underwent adjunctive open surgical external to hypogastric iliac bypasses, transposing the iliac bifurcation distally, beyond the dissection, which facilitated landing in a nondissected iliac segment while maintaining the hypogastric perfusion. Reinforced fenestrations were preferably used but in cases of a more adequate lumen diameter (>25 mm) revascularization with branches was considered. Spinal drainage was used when more than 20 cm of the thoracic aorta was covered and/or in any patient that had undergone previous surgery of descending aorta or abdominal aorta. In cases LSA had been sacrificed during a previous repair, bypass from LCC was always performed to maximize spinal cord perfusion.

Preoperative variables collected included patient demographics, largest aneurysm diameter, indication for treatment, presence of connective tissue disease, and previous aortic surgery. Perioperative data included operation and fluoroscopy time, blood loss, main graft design, and technical success. Postoperative follow-up consisted of CT angiography and clinical evaluation at 1 month and CT angiography at 12 months and then yearly. Data presented on aneurysm sac behavior, endoleaks, and branch patency were based on the last available CT angiography images.

Outcomes included technical success, defined on an intent-to-treat basis by successful introduction and deployment of the main graft, successful incorporation of target vessels to main graft, in the absence of type I or III endoleaks (unless planned staged procedure), graft obstruction, and conversion to open repair or death within 24 hours of surgery.[19] In cases of distal landing in dissected aorta (typically when performing repair of an arch aneurysm with distal landing in the descending thoracic aorta), retrograde flow in the false lumen from distal uncovered entry tears was not regarded as type 1B endoleak/technical failure. All-cause mortality at 30 and 90 days and Kaplan-Meier survival estimates up to 3 years were calculated. Morbidity included spinal cord ischemia (SCI), stroke, myocardial infarction, renal failure, abdominal compartment syndrome, and bowel ischemia. Reinterventions were categorized as early (<30 days or in hospital) and late (>30 days). Kaplan-Meier estimates of freedom from reintervention up to 3 years was calculated including all unplanned reintervention in patients surviving 30 days. Reason for reintervention and postinterventional outcome was investigated. Follow-up CT images were scrutinized for late endoleaks (>30 days), branch patency, and aneurysmal sac behavior (changes in maximal aneurysm diameter and false lumen patency at the level of the stent graft).

Data analyses were performed with SPSS (v 26.0; SPSS, Inc, Chicago, Ill). Normality was assessed with histograms. Continuous variables are presented as median with range. Categorical variables are presented as percentage. Comparison between categorical variables were performed using the χ^2 test or Fischer exact test. Comparisons between continuous variables were performed with Mann-Whitney test because data were non-normally distributed and sample size was small. Survival and freedom from reintervention was assessed with Kaplan-Meier curves and presented with standard error. A P value of less than .05 was considered significant.

RESULTS

A series of 26 patients were treated for chronic dissection arch aneurysms and TAAAs with F/B EVAR from 2010 to 2019. Thirteen arch procedures were performed and 14 TAAA repairs. One patient underwent both arch and TAAA endografting, and was initially repaired with arch FEVAR to provide a proximal landing zone as the dissection extended into the arch, and later (after 12 months) had TAAA repair with FEVAR. This patient is included in both groups for the procedural data and short-term outcomes, but for the long-term outcomes he is included only once in the TAAA cohort as the main indication for treatment was TAAA. Patient characteristics are presented in Table I.

The indication for treatment was a postdissection aneurysm of greater than 55 mm in all cases. Elective repair was performed in 25 patients and emergent repair in one patient (TAAA rupture repaired with FEVAR CMD that was anatomically prepared for another patient, but had a configuration where three of the four fenestrations were acceptable in an acute setting. One elective patient was treated with an off-the-shelf T-branch device. The remaining patients were treated with CMDs.

Overall, there were seven patients (27%) with connective tissue disease, three in the arch group and four in the TAAA group. All seven patients had a previous aortic repair offering a proximal landing zone in a surgical graft.

Intraoperative data. The 13 arch repairs consisted of 7 FEVARs and 6 BEVARs. The 14 TAAA repairs involved 3 BEVARs and 11 FEVARs. Procedural data are summarized in Table II. Adjunctive and staged procedures were carried out in 16 patients (62%) with a total of 28 procedures; carotid-LSA bypass (n = 12), external iliac-hypogastric artery (HA) bypass (n = 8), iliacofemoral bypass as conduits for access (n = 3), iliacorenal bypass (n = 1), staged EVAR (n = 2), staged thoracic endovascular aortic repair (TEVAR) (n = 1), and delayed stenting of branch for spinal protection (n = 1).

In total 72 arteries were targeted: 22 arteries in aortic arch (6 BCT, 11 LCC, and 5 LSA) and 50 arteries in visceral aorta (13 celiac arteries, 14 superior mesenteric arteries, 19 renal arteries, 3 accessory renal arteries, and 1 lumbar artery). Although no branch vessels were perfused from the false lumen in the aortic arch, 4 of 14 patients (29%) in the TAAA group had 12 of the 50 (24%) target arteries that were perfused by a false lumen. Four arteries were cannulated through an existing entry tear in the dissection membrane at the level of target vessel. Five arteries were treated by placing the main fenestrated/branched stent graft in the false lumen (two patients in the TAAA group), creating a neofenestration distal to the stent graft to maintain limb perfusion. Two arteries were cannulated by creating a neofenestration in the dissection membrane, one with transjugular intrahepatic

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Table I. Baseline characteristics of the 26 study patients

Characteristics	Arch aneurysm (n = 12)	Thoracoabdominal aneurysm (n = 14)	Total (N = 26)
Body mass index	25 (16-34)	25 (21-38)	25 (16-38)
Male sex	8 (66)	10 (71)	18 (69)
Age	69 (51-87)	62 (33-80)	62 (33-87)
Largest aneurysm diameter, mm	60 (54-77)	72 (55-98)	70 (54-98)
Hypertension	12 (100)	13 (93)	25 (96)
Preoperative creatinine, µmol/L	85 (44-166)	91 (52-119)	85 (44-166)
Diabetes mellitus	0	0	
Prior cerebral event	5 (42)	1 (7)	6 (23)
Prior paraplegia (with rest symptoms)	1 (8)	1 (7)	2 (8)
COPD	1 (8)	2 (14)	3 (12)
Congestive heart failure	2 (17)	0	2 (8)
Coronary disease	1 (8)	3 (21)	4 (15)
Smoking			
Current	2 (17)	1 (7)	3 (12)
Prior	8 (67)	6 (43)	14 (54)
Never	2 (17)	7 (50)	9 (35)
Connective tissue disease	3 (25)	4 (29)	7 (27)
Marfan	3 (25)	3 (21)	6 (23)
Loey-Dietz	0	1 (7)	1 (4)
Indication for F/B-EVAR			
Aneurysm elective	12 (100)	13 (93)	25 (96)
Aneurysm rupture	0	1 (7)	1 (4)
Original aortic dissection			
Debakey type			
I	7 (58)	5 (36)	12 (46)
II	0	0	0 (0)
IIIA	2 (17)	0	2 (8)
IIIB	3 (25)	9 (64)	12 (46)
Previous aortic surgery			
Ascending aortic/arch repair	8 (67)	7 (50)	15 (58)
Ascending aortic repair	8	7	15 (58)
Ascending aortic and arch repair	0	5	5 (19)
Frozen elephant trunk	0	4	4 (15)
Descending aortic repair	1 (8)	10 (71)	11 (42)
TEVAR	1	9	10 (38)
Open repair	0	2	2 (8)
Abdominal aortic repair	0	3 (21)	3 (12)
EVAR	0	2	2 (8)
Open repair	0	1	1 (4)

COPD, Chronic obstructive pulmonary disease; *EVAR*, endovascular aortic repair; *F/B-EVAR*, fenestrated/branched endovascular aortic repair; TEVAR, thoracic endovascular aortic repair.
Values are median (range) or number (%).
One patient had both arch and thoracoabdominal aneurysm (TAAA) repair. This patient is only included in the TAAA group as the aneurysm indicating treatment was located thoracoabdominally.

Table II. Perioperative data of the 27 fenestrated and branched procedures

Variable	Arch aneurysm (n = 13)	Thoracoabdominal aneurysm (n = 14)	Total (N = 27)
Operation time, minutes	281 (165-587)	355 (140-613)	353 (140-613)
Fluoroscopy time, minutes	46 (34-106)	110 (42-200)	78 (34-200)
Contrast volume, mL	235 (143-460)	254 (135-460)	252 (135-460)
Blood loss, mL	450 (350-3500)	1000 (400-3000)	800 (350-3500)
Main stent graft			
CMD fenestrated	7	11	18
CMD branched	6	2	8
T-branch	0	1	1
Fenestrations, no	6	36	42
Branches, no	12	13	25
Scallops, no	4	1	5
Concomitant aortic repair			
TEVAR	3 (23)	6 (43)	9 (33)
TEVAR (dissection modified)[a]	7 (54)	0 (0)	7 (26)
EVAR	0 (0)	9 (64)[b]	9 (33)
False lumen embolization			
Candy plug	1 (8)	0 (0)	1 (4)
Knickerbocker	1 (8)	0 (0)	1 (4)
Preemptive selective embolization			
Inferior mesenteric artery	0 (0)	1 (8)	1 (4)
Renal artery	0 (0)	1 (8)	1 (4)
Distal landing zone			
Descending aorta (zones 4-5)	13 (100)	0 (0)	13 (48)
Abdominal aorta (zones 7-9)	0 (0)	5 (36)	5 (19)
Iliac arteries (zones 10-11)	0 (0)	9 (64)	9 (33)
State of distal landing zone			
Nondissected	0 (0)	9 (86)[c]	12 (44)
Dissected	12 (92)	1 (7)	13 (48)
Prior graft	1 (8)	3 (21)	4 (15)
Spinal drainage	11 (85)	12 (86)	23 (85)
Technical success	11 (85)	13 (93)	24 (89)

CMD, Custom-made device; *EVAR*, endovascular aortic repair; *TEVAR*, thoracic endovascular aortic repair.
Values are median (range) or number (%). One patient underwent both arch and thoracoabdominal aortic aneurysm repair, the procedural data of each procedure is reported.
[a] Modified stent graft design with low distal radial force.
[b] Including two staged EVARs.
[c] Five patients underwent staged hypogastric artery debranching enabling distal landing in healthy iliac segment.

portosystemic shunt needle, the other with an outback catheter. Finally, one false lumen perfused renal artery was treated with a staged iliacorenal bypass.

Overall technical success was achieved in 24 of 27 procedures (89%). The lack of technical success was due to:

1. Arch FEVAR in a patient with chronic type B dissection and native ascending aorta was found to have a retrograde type A dissection (RTAD) on completion angiography, which led to immediate open conversion with sternotomy and ascending repair with a good result.
2. Arch BEVAR in a patient with a residual dissection flap extending deep in the supra-aortic vessel, resulting in type IC endoleak (distal attachment of side branch) from the false lumen of the RCC; unfortunately, this patient died from a descending aortic rupture on postoperative day 45.
3. TAAA FEVAR in a patient with rupture that had a persistent type III endoleak from a renal artery fenestration, which was successfully sealed 48 hours after repair, and the patient was discharged on postoperative day 30.

Early outcomes. Short-term outcomes are presented in Table III. Overall, mortality was 4% (n = 1) at 30 days. One patient in the arch group died suddenly 12 days after repair after an uneventful arch FEVAR (fenestration for LSA and scallop for LCC). Autopsy confirmed RTAD with tamponade. This patient originally had a type B

Table III. Short-term results of the 27 fenestrated and branched procedures

Variable	Arch aneurysm (n = 13)	Thoracoabdominal aneurysm (n = 14)	Total (N = 27)
Mortality 30 days	1 (7)	0	1 (4)
Mortality 90 days	2 (15)	1 (7)[a]	3 (11)
Spinal cord ischemia	2 (14)	1 (7)	3 (11)
Permanent	0	0	0
Transient	2 (14)	1 (7)	3 (11)
Stroke	2 (14)	1 (7)	3 (11)
Permanent	1 (7)	0	1 (4)
Transient	1 (7)	1 (7)	2 (7)
Myocardial infarction	0	0	0
Renal failure (requiring dialysis)	0	1 (7)[a]	1 (4)
ACS (requiring laparotomy)		1 (7)[a]	1 (4)
ICU stay	1 (0-20)	1 (0-56)	1 (0-56)
Hospital stay	7 (4-32)	8 (4-87)	8 (4-87)
Reinterventions (in hospital)	2 (15)	3 (21)	5 (19)

ACS, Abdominal compartment syndrome; *ICU*, intensive care unit.
Values are median (range) or number (%). One patient had both arch and thoracoabdominal repair, the short-term outcomes of each procedure are reported.
[a]Same patient suffering multiple complications.

dissection with native ascending aorta and descending aortic aneurysm with proximal extension to the left subclavian, requiring treatment with arch FEVAR for adequate landing zone.

Two more deaths occurred within 90 days accounting for a mortality of 11% (n = 3). First was the above-mentioned patient with a persistent type IC endoleak from a residual dissection in the RCC after arch BEVAR, resulting in sudden death owing to descending aortic rupture confirmed on autopsy. The second patient treated with TAAA FEVAR suffered a renal artery branch bleed that was successfully embolized the same day. He subsequently developed multiorgan failure, abdominal compartment syndrome, and colonic ischemia, and eventually succumbed 87 days after repair.

vTransient SCI occurred in 11% of cases (n = 3), two in the arch group (one treated with FEVAR and the other with BEVAR) and one in the TAAA group (FEVAR). All these patients had a prophylactic spinal drainage already installed preoperatively and presented with lower extremity paraparesis on the second postoperative day. Management included increasing the spinal drainage and blood pressure and resulted in full recovery at discharge.

Three patients suffered a minor stroke (11%), two were transient, after TAAA FEVAR and arch BEVAR, and one was permanent, after arch FEVAR.

Early secondary procedures were performed in five patients (19%) with eight procedures. One patient required relining of the BCT branch after arch-BEVAR procedure owing to stent kinking and stenosis at the branch origin detected on an early in-hospital CT. Coiling of renal artery bleeding in two patients from TAAA group was required. One patient was emergently treated for ruptured TAAA with a TEVAR and four FEVAR, and two early reinterventions were required to achieve complete aneurysm seal; for treatment of type II (IMA coiling), IIIA (attachment between aortic stent graft components), and IIIC (attachment between aortic stent graft and side branch) endoleaks. Additionally, one open conversion with ascending aortic replacement owing to RTAD (mentioned elsewhere in this article) and one resection of a pseudoaneurysm in the groin was performed.

Late outcomes. The median follow-up time was 23 months (range, 0.5-118.0 months). Only one patient died beyond 90 days, owing to an accidental traumatic subdural hematoma that occurred 14 months after the initial procedure (arch FEVAR).

During follow-up, endoleaks were detected in 12 patients (44%). In the arch group, this consisted of three cases of persistent retrograde false lumen flow at level of the stent graft owing to distal landing in dissected aorta, and one case of endoleak type IB owing to distal stent graft attachment failure. Two of these patients are pending a distal prolongation with TEVAR and two are treated conservatively with surveillance owing to favorable aneurysm sac behavior. Three Ic and two IIIc endoleaks were diagnosed, all in the TAAA group, and all related to leakage from visceral branches, namely, celiac arteries and SMAs. Seven endoleaks type II were detected, five in the TAAA group and two in the arch group.

No late reinterventions were performed in the arch group, but nine late reinterventions were performed in 7 of 14 patients from the TAAA group. A type IC endoleak

Table IV. Late reinterventions and outcomes during follow-up in patients (N = 14) treated with fenestrated and branched aortic repair (F/B-EVAR) of thoracoabdominal aorta (TAAA) (no late reinterventions in patients treated in arch segment)

Cause for reintervention	No.	Type of procedure	Follow-up imaging after reintervention
Endoleaks			
Type IC	3	Distal extension CA, SMA	No endoleaks
		Distal extension CA	No endoleaks
		Distal extension CA, SMA, RRA	Type II LRA (not stented)
Type II	3	Coiling lumbar artery	Type II lumbar artery persistent
		Coiling lumbar artery (second intervention)	Type II lumbar artery persistent
		Open ligation LRA (second intervention)	No endoleak
Type IIIC	1	Prox extension CA, SMA	Type II IMA
Type IIIC + II combined	1	Prox extension RRA, coiling lumbar	Type II lumbar artery persistent
Proximal progression of dissection	1	TEVAR aorta descendens	No endoleaks

CA, Celiac artery; *IMA*, internal mammary artery; *LRA*, left renal artery; *RRA*, right renal artery; *SMA*, superior mesenteric artery; *TEVAR*, thoracic endovascular aortic repair.

was treated by distal stent prolongation in the respective leaking visceral artery, type IIIC was treated by proximal stent prolongation, and type II by coiling lumbar arteries (two patients required multiple procedures). One patient was treated with a proximal TEVAR extension after developing a new type B dissection in a previously healthy aorta with an entry tear remote from the graft edge. All target vessels remained patent during follow-up. All the reinterventions and their outcomes are presented in Table IV.

Of the 23 patients with a follow-up of more than 6 months (13 arch, 10 TAAA) all had stable or decreased aortic diameters. Overall, mean sac regression was 7 mm (range, 0-25 mm). Complete false lumen thrombosis at the level of the stent graft was present in 65% of patients (8 arch, 7 TAAA).

The estimated combined survival at 3 years was 84.2% ± 7.2%; stratified for arch 75.0% ± 12.5%, and for TAAAs 92.9% ± 6.9% (log-rank $P = .22$; Fig, *A*). Freedom from reintervention at 3 years was for the entire cohort was 71% ± 10.1%; in the arch group, it was 100% and in the TAAA group, 48% ± 15.1% (log-rank $P = .01$; Fig, *B*).

DISCUSSION

Endovascular repair by means of fenestrated and branched technology offers a possibility to treat patients with complex postdissection aneurysms involving the aortic arch and visceral segment without the requirement for circulatory arrest or thoracoabdominal incision. However, the procedures remain extensive. In this study, depicting our early experience, the technical success rate was 89% with 30- and 90-day mortality of 4% and 11%, respectively, which is comparable with previous reports. A summary of the current literature on endovascular treatment of postdissection aneurysms is presented in Table V.

It is important to critically assess the failures occurring in patient series when a new technique is being expanded into treatment of new patient cohorts. The occurrence of RTAD in two patients in this cohort warrants further discussion. Fenestrated arch stent grafts, designed to achieve seal in midaortic arch, can serve as a treatment option for patients with thoracoabdominal diseases involving the arch. Although recent reports show promising early results with fenestrated repair for mainly nondissected arch pathologies, the literature on the use of arch fenestrated stent grafts in chronic dissections remains very limited.[20,21] In our center, implantation of arch fenestrated devices was accepted in a postdissection setting in case of normal native ascending aorta and arch landing zone. Results now reveal that, among six patients treated in this setting (arch FEVAR without previous ascending repair), two developed RTAD. This occurrence of RTAD in our series is indeed a major concern and seems to be higher than what has previously been reported in the literature after TEVAR for chronic dissections. In a recent meta-analysis,[22] the pooled incidence of RTAD after standard TEVAR for chronic dissection was 3% and the odds ratio of RTAD relative to degenerative aneurysm was 10 for an acute dissection and 3.4 for a chronic dissection.[22,23] Deployment of the stent graft in proximal aortic arch zones 0 to 2 seems to be a significant risk factor for RTAD.[22,23] Another potential risk factor could be guide wire and/or sheath manipulation in the arch. Eggebrecht et al[24] captured 63 cases of RTAD in patients undergoing TEVAR for mainly aortic dissections; majority of cases (75%) were associated with the stent graft itself or with manipulation of guidewire, with a fatal outcome in 42% of patients.

The introduction of fenestrated devices might further aggravate the risk of RTAD in patients with chronic dissections, with the rationale being that fenestrated stent grafts require substantially more snare and wire manipulations than standard TEVARs, potentially inflicting damage on the underlying fragile aortic wall. During the deployment process of a fenestrated stent graft, a preloaded guidewire is snared in the arch from left brachial

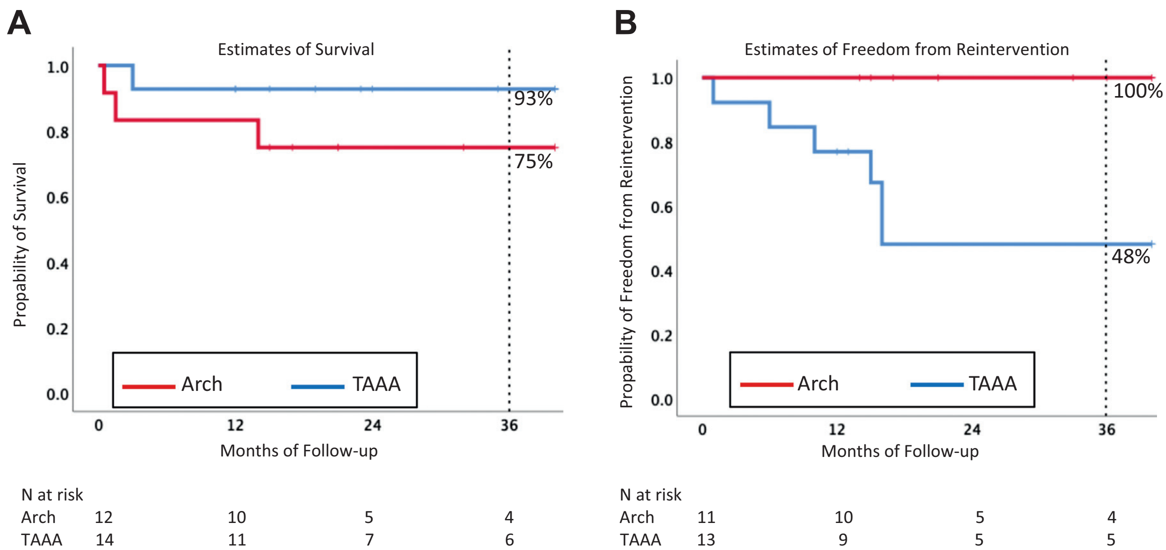

Fig. Kaplan-Meier estimates of survival **(A)** and freedom from reintervention **(B)** for patients undergoing branched and fenestrated procedure in the aortic arch and thoracoabdominal aorta (*TAAA*).

access. Under tension on the through-and-through wire, the stent graft is deployed in the correct position and the friction between the stretched wire and the aortic wall can potentially cause damage to the wall. In addition, because all fenestrations are reinforced with bridging stents there is a potential risk of aortic wall damage at the level LSA orifice upon bridging stent deployment. In their early experience, Tsilimparis et al[25] reported outcomes following endovascular arch repair, comparing fenestrated vs branched stent grafts in 29 patients (38% with postdissecting aneurysms) and found that arch fenestrated repair was associated with higher mortality (20% vs 0%). There is positive association between patients with Marfan syndrome and RTAD[24,26]; however, none of the two patients in our series suffering RTAD had diagnosed connective tissue disease.

In their early experience, Spear et al[11] in 2015 reported a series of 23 postdissection aneurysms, seven treated with arch branched stent grafts.[11] Interestingly, six of those seven patients had had previous ascending aorta replacements and the only patient that died had a native ascending aorta and iatrogenic type A dissection was suspected. In our modest opinion, we believe that endovascular arch repair with fenestrated/branched stent grafts for postdissection aneurysms in patients with native ascending aortas should be avoided.

In contrast with arch fenestrated stent grafts, the arch inner branched stent grafts are designed to land proximally in the ascending aorta. In 2019, Verscheure et al[13] presented excellent results in using arch branched stent grafts in 70 patients with post type A chronic aortic arch dissection, with a technical success rate of 94% and combined mortality and stroke rate of 4%. In another cohort of 43 procedures, including 19 repairs with arch branched stent grafts, the technical success rate was 93% and in-hospital mortality rate 4.7%.[14] Patient selection is indeed critical, and patients with a prior type A dissection with graft replacement of the ascending aorta, providing a secure proximal landing zone, may be the best candidates for endovascular arch repair. A recent analysis shows that more than two-thirds of patients after a type A dissection are technically eligible for endovascular repair with arch branched stent grafts.[8,27]

Endoleaks and reintervention rates remain an inherent challenge with the endovascular technique. In this report, reinterventions were common; however, they occurred solely in the TAAA group, with more than one-half of patients (52%) undergoing reinterventions at 36 months. Looking at the entire cohort, the estimated reintervention was 29% at 36 months, which is in accord with previous reports with reintervention rates ranging from 20% to 47%, as summarized in Table V. Apart from one case of proximal disease progression, all reinterventions were performed for endoleaks, most commonly proximal or distal attachment of side branches (type IC and IIIC leakage). Although some investigators might consider reinterventions as failures, they can also be regarded as complementary procedures and a part of the endovascular methodology. The most recent and largest report to date, by Oikonomou et al[12] notes a reintervention rate of 53% at 3 years among 71 patients treated with F/B-EVAR for postdissection aneurysms. Type IC endoleaks were the most common reason for reintervention and the authors conclude that longer bridging stents are advised. In our series, five of seven reinterventions were performed for type IC (n = 3) and IIIc (n = 2) leakage from target vessels. Indeed, in a dissection setting, bridging stents need to extend deeper

Table V. Summary of outcomes after total endovascular repair for postdissection aneurysms in arch and thoracoabdominal aorta (*TAAA*)

Author, year of publication	Number and type of procedures	Follow-up, months	Technical success, %	Perioperative mortality, %	Stroke, %	SCI, %	Reinterventions during follow-up, %
Kitagawa et al,[9] 2013	1 arch BEVAR, 29 TAAA F/B-EVARs	20	100	0[a]	0	0	27[b]
Spear et al,[14] 2018	19 arch BEVARs, 24 TAAA F/B-EVARs	26	93	2.3[a]	4.7	7	20[b]
Tsilimparis et al,[17] 2018	20 arch BEVARs, 0 TAAA F/B-EVARs	17	95	5	5	0	30[b]
Oikonomou et al,[12] 2019	0 arch F/B-EVARs, 71 TAAA F/B-EVARS	25	94	5.6[c]	0	16	47[d]
Law et al,[16] 2019	0 arch F/B-EVARs, 20 TAAA F/B-EVARS	12	100	5[a]	0	10	30[b]
Verscheure et al,[13] 2019	70 arch BEVARs, 0 TAAA F/B-EVARs	10	94	2.8[c]	2.8	0	29[b]
Current study, 2020	13 arch F/B-EVARs, 14 TAAA F/B-EVARs	21	89	3.7[a]	11[e]	11	29[d]

BEVAR, Branched endovascular aortic repair; *F/B-EVAR*, fenestrated/branched endovascular aortic repair; *SCI*, spinal cord ischemia; *TAAA*, thoracoabdominal aortic aneurysm.
[a]Thirty-day mortality.
[b]Percentage of patients requiring interventions during follow-up.
[c]In-hospital mortality.
[d]Three-year estimates (Kaplan-Meier).
[e]Permanent stroke 4% (n = 1).

into target vessel well beyond the dissection flap, overcoming the distance between stent graft and target vessel created by the false lumen.

Despite the high reintervention rate, most series,[9,12,14,15] including ours, report favorable aortic remodeling with false lumen thrombosis and aneurysm regression. All reintervention in this series were successful with no mortalities and with a cessation of type I and III endoleaks on follow-up CT, as summarized in Table IV. In addition, a recent report by Tenorio et al[15] showed comparable reintervention rates to that achieved with atherosclerotic TAAAs treated with F/B-EVAR.

Cerebrovascular insults remain a major concern, not exclusive to, but especially after endovascular arch repair. In the arch group, only one patient (8%) suffered a stroke with a permanent deficit after arch FEVAR repair. Spear et al[14] reported a stroke rate of 2 of 19 patients (11%) after arch repair, whereas Verscheure et al[13] reported remarkably low stroke rate of 3% among patients after type A dissections.

SCI remains a significant problem, with our rates of 11% being in accord with previous studies, ranging from 0% to 16% (Table V). Among three patients in the current study (11%) with SCI, none developed permanent symptoms. The spinal protective strategies applied can be summarized by the data in this study: routine preservation of the LSA and HA when needed (42% patients had LSA and 19% HA debranching), spinal drainage was used in 85% patients for 48 to 72 hours, and adjunctive and/or staged procedures were carried out in 62% of patients. The blood loss and operative time for TAAA repair are relatively high in our study; however, improvements in surgical techniques have been adopted over time: retrograde cannulation of target vessels with steerable sheaths, usage of DrySeal (W. L. Gore & Associates, Flagstaff, Ariz) introducers, and leaving only guidewires behind (not sheaths) in target vessels. The use of fusion guidance and cone beam CT may further decrease operation time and decrease the need for reintervention.[11,28]

Endovascular repair of extensive arch and thoracoabdominal postdissection aneurysms is feasible with acceptable results considering the gravity of the disease and extension of the aneurysms involved. However, distinct patient selection and surgical technique can possibly contribute to future improvements of outcome. Based on the current cases series and existing literature, we suggest that fenestrated and branched endovascular repair of the arch should be avoided in patients with chronic dissection with a native ascending aorta, owing to the risk for RTAD. In thoracoabdominal endovascular repair of postdissection aneurysms, meticulous technique should be applied with regard to securing seal of the bridging stent grafts in the fenestrations/branches as well as in the target vessels. Reinterventions after TAAA repair can be regarded as part of the surgical strategy, and patients should thus be informed of this possibility in advance.

AUTHOR CONTRIBUTIONS

Conception and design: MK, AW, GT, KM
Analysis and interpretation: MK, KM
Data collection: MK
Writing the article: MK, AW, GT, KM
Critical revision of the article: MK, AW, GT, KM
Final approval of the article: MK, AW, GT, KM
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Supplementary Fig (online only). A 77-year-old woman with a 60-mm arch aneurysm after type A dissection underwent endovascular repair using arch branch device with two inner side branches for brachiocephalic and left common carotid (LCC) artery landing proximally in previously prosthetically replaced ascending aorta. Left carotid-subclavian artery bypass with Amplatzer plug implantation was performed in the same setting as the arch repair. Computed tomography (CT) angiography 24 months after repair showing aortic remodeling and aneurysm regression at the level of the stent graft. Rest-dissection distally to the stent graft can be seen.