Homemade fenestrated physician-modified stent-grafts for arch aortic degenerative aneurysms

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ABSTRACT

Objective: We evaluated the early- and medium-term outcomes of single- and double-fenestrated physician-modified endovascular grafts (PMEGs) for total endovascular degenerative aortic arch aneurysm repair.

Methods: We performed a single-center, retrospective analysis of prospectively collected data from 52 patients from August 2013 through January 2021 who had undergone homemade fenestrated thoracic endovascular aortic repair for degenerative aortic aneurysms. In all cases, a distal smaller fenestration for the left subclavian artery (LSA) was fashioned and was the only one stented. For a double-fenestrated endograft, a proximal larger fenestration that incorporated both the brachiocephalic trunk and the left common carotid artery was added.

Results: A total of 52 patients with degenerative aortic arch aneurysms were treated. Of the 52 patients, 36 were men, the mean age was 75 ± 8 years, 31% had received a single LSA fenestration, and 69% had undergone double-fenestrated thoracic endovascular aortic repair. Of the 52 procedures, 5 (10%) were emergent procedures. The technical success was 100%. The median time required for stent graft modification was 22 ± 6 minutes. The 30-day mortality was 2% (n = 1). Five patients (10%) had experienced a cerebrovascular event, including two transient ischemic attacks, one minor stroke with full neurologic recovery, and two with sequelae. Two patients (4%) had experienced perioperative retrograde dissection during follow-up. No patient had developed a type I, II, or III endoleak from the LSA. No patient had required reintervention. All supra-aortic trunks were patent. During a mean follow-up of 18 ± 11 months, no patient had required conversion to open surgical repair, aortic rupture, or paraplegia.

Conclusions: Single or double PMEG is a safe and suitable tool for the treatment of high morbidity pathology such as aortic arch degenerative aneurysm repair. In addition, this device can be used in patients requiring elective or emergency repair.

Keywords: Aortic arch aneurysm; Off-the-shelf; Physician-modified stent graft; Surgeon-modified stent graft; TEVAR; Thoracic aorta

At present, both American and European guidelines have recommended thoracic endovascular aortic repair (TEVAR) for asymptomatic low-risk patients with favorable aortic anatomy when the maximal aneurysm diameter is >55 mm. In high-volume centers, technical success has been very high and morbidity and mortality quite low after descending thoracic aortic degenerative aneurysm exclusion.[1] Respecting a proximal landing area >20 mm reduces the risk of type Ia endoleak, retrograde dissection, and migration.[2] For aortic arch pathologies, additional challenges can arise in finding a landing zone for a successful seal and the avoidance of retrograde dissection, neurologic events, reinterventions, and increased economic costs.

The use of single or double homemade fenestrated thoracic physician-modified endograft (PMEG) for the endovascular repair of aortic dissections has been demonstrated to be both feasible and effective for total endovascular aortic arch repair and has been successfully applied in the treatment of dissecting aortic arch aneurysms after surgical treatment of acute type A dissection.[3,4] Furthermore, previous studies have reported interesting results for the same model for endovascular repair of various aortic arch lesions.[5,6] However, to the best of our knowledge, the present series is the first to specifically analyze a large cohort of patients with degenerative aortic arch aneurysms that were characterized by challenges unique to this type of pathology. Thus, in the present study, we reviewed the single-center

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experience of single and double homemade fenestrated stent grafts with one proximal fenestration for both the brachiocephalic trunk (BT) and the left common carotid artery (LCCA) and one distal fenestration for the left subclavian artery (LSA) to treat degenerative aortic arch aneurysms.

- **Type of Research:** A retrospective study of prospectively collected, single-center registry data
- **Key Findings:** Endovascular aortic repair with fenestrated physician-modified endovascular grafts for 52 aortic arch degenerative aneurysms resulted in 100% technical success, 2% early mortality, a moderate neurologic risk with a 4% rate of permanent stroke, and infrequent reinterventions. During 18 ± 11 months of follow-up, no patient had presented with endoleak nor had died of aortic causes, and all supra-aortic vessels remain permeable.
- **Take Home Message:** Single- and double-fenestrated physician-modified endovascular grafts are a valid and reproducible option for aortic arch degenerative aneurysm exclusion in high-risk surgical and emergent patients.

METHODS

Patients. The institutional review boards approved the protocols. All the patients had provided written informed consent, and the local authorities approved the present study. Our monocentric retrospective analysis of prospectively collected data included 52 patients who had undergone homemade fenestrated TEVAR for thoracic aortic degenerative aneurysms.

From August 2013 through January 2021, all patients who had presented with arch or proximal descending aortic aneurysms with suitable anatomy for a fenestrated PMEG, who had been deemed either unfit for open thoracic surgery or had required emergent repair and had been treated at one tertiary referral center were enrolled in the present study. During the same period, 211 open repairs had been performed in our institution.

The decisions for repair were determined by multidisciplinary teams that included cardiovascular surgeon. Patients with zone 1 aortic arch lesions or zone 0 saccular aneurysms of the lesser curvature of the arch can be considered suitable for this endovascular approach if the lengths of the proximal and distal (length from the distal end of the aneurysm to celiac artery) neck are ≥20 mm and if proximal and distal neck diameters are between 20 and 40 mm. Other zone 0 aortic arch lesions were deemed unsuitable because the size of the proximal fenestration was proximally and laterally larger than that of the BT and LCCA orifice to ensure good permeability for each ostium. An aneurysm encompassing the origin of these target arteries would, therefore, not result in exclusion without an endoleak. No patient had had a left vertebral artery arising directly off the aorta in the present series. If necessary, a vertebral transposition could be performed before endovascular exclusion. The demographic, anatomic, intraoperative, and postoperative data were prospectively recorded and then reported in accordance with the Society for Vascular Surgery reporting standards.

Planning, sizing, and device preparation. The Valiant Captivia endograft (Medtronic, Santa Rosa, CA) was used for every procedure. The description of device modification has previously been reported in detail.[6] The most recent modification consists of the addition of a preloaded guidewire. A vascular imaging workstation (EndoSize Workstation; Therenva, Nanjing, France) was used to precisely measure the anatomy using the computed tomography (CT) angiography images to determine the strategy. Stent grafts were chosen according to their length and diameter to seal a minimum of 20 mm of healthy aorta at each end. Oversizing of 10% to 15% was used for these degenerative aneurysms. The proximal larger fenestration incorporated both the BT and the LCCA and the distal fenestration, the smaller one for the LSA.

Our early experience showed that cannulation of the distal LSA fenestration with the guidewire from the brachial artery was a critical intraprocedural step. From 2018 onward, the device was adapted by incorporating a preloaded guidewire for the LSA fenestration. The endograft must be totally unsheathed, and fenestrations fashioned. A 260-cm, 0.035-in., stiff, angled guidewire (Radifocus Guide Wire M; Terumo Interventional Systems, Tokyo, Japan) was introduced into the needle hole made in the introducer sheath of the stent graft and then inserted through the LSA fenestration with an external exit from the endograft. The device was resheathed as previously described in earlier series (Fig 1).

Technical steps. Each procedure was performed with the patient under general anesthesia, with surgical or percutaneous access of the common femoral arteries and left brachial artery. Systemic heparin therapy, 100 U/kg, was used, and the activated clotting time was monitored (goal range, 60-90 seconds).

An 18F to 24F, 33-cm introducer sheath (DrySeal Flex Introducer Sheath; W. L. Gore & Associates, Flagstaff, AZ) was positioned retrograde through the common femoral access. A 7F, 80-cm sheath was introduced through the left brachial access into the origin of the LSA. A double-curved, 300-cm, extra stiff 0.035-in. wire (Lunderquist, Extra Stiff DC Wire Guide; Cook Medical Inc, Bloomington, IN) was positioned against the aortic valve through the femoral access. The proximal side of the preloaded guidewire was advanced through the femoral access

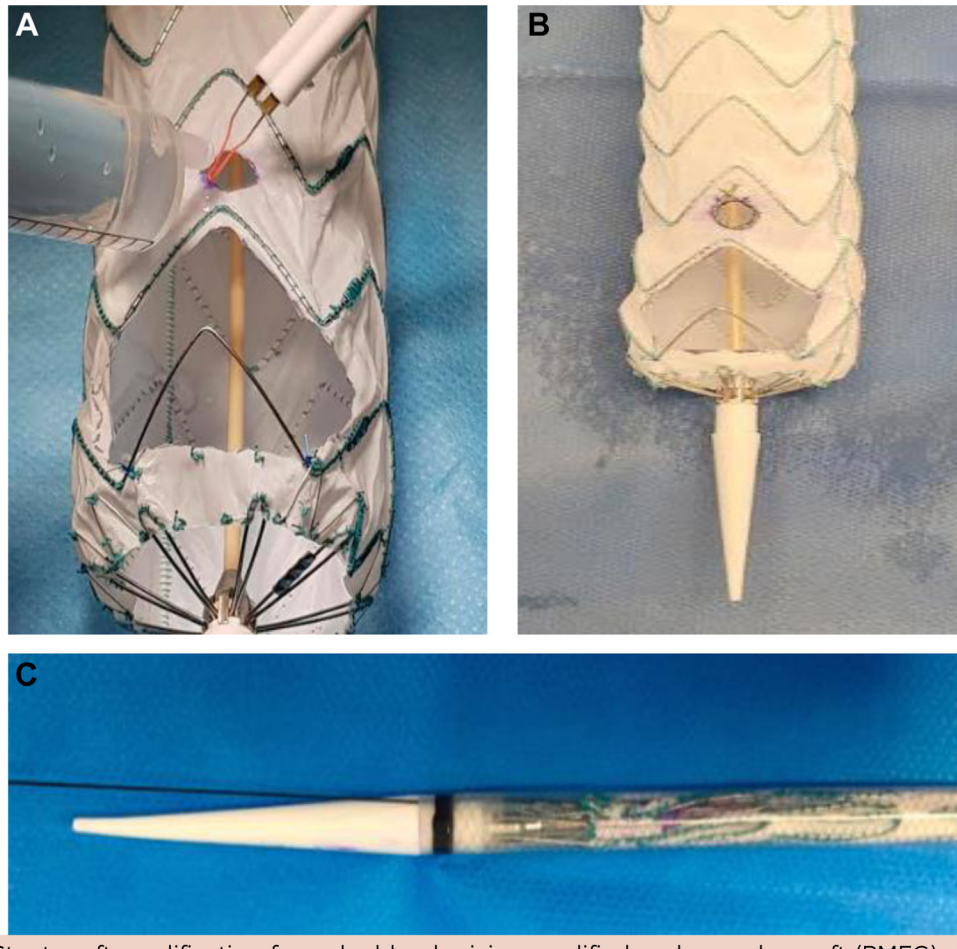

Fig 1. A-C, Stent graft modification for a double physician-modified endovascular graft (PMEG) and preloaded guidewire in the left subclavian artery (LSA) fenestration.

sheath, delivered to the LSA, and exteriorized using a 6F, 25-mm snare loop (Amplatz Goose Neck Snare Kit; Medtronic, Minneapolis, MN; Supplementary Fig 1, online only). The stent graft was inserted on the Lunderquist wire, and the preloaded guidewire was progressively pulled by the second operator from the left brachial access to orient the fenestrations superiorly to face the supra-aortic trunks originating off the superior arch. Angiography was performed perpendicular to the LSA through the left brachial sheath. The mean blood pressure was lowered to 80 mm Hg pharmacologically, and deployment was started with radiologic guidance. The brachial sheath was advanced through the LSA fenestration over the preloaded guidewire, and an 8- to 12-mm-diameter, 38- to 59-mm-long, balloon-expandable covered stent (Lifestream; Bard, Tempe, AZ) was deployed, with 5 mm of protrusion into the aortic stent graft lumen (Supplementary Fig 2, online only). The subclavian stent was flared with a standard 14-mm balloon, concomitantly with aortic stent graft inflation (Coda LP balloon catheter; Cook Medical Inc). Completion angiography was used to check the position of the PMEG and patency of all supra-aortic vessel trunks (Supplementary Fig 3, online only). During the procedure, the BT blood flow was closely monitored using a right radial artery pressure arterial catheter. Cerebral perfusion was systematically assessed using near-infrared spectroscopy.

Follow-up. Follow-up was performed with CT at 1 week, 3, 6, and 12 months, and annually thereafter (Fig 2).

Statistical analysis. Categorical data are presented as frequencies and continuous variables as the mean ± standard deviation or range. Statistical analyses were performed using IBM SPSS Statistics, version 24, software (IBM Corp, Armonk, NY).

RESULTS

From August 2013 through January 2021, 16 patients had received an aortic arch stent graft with a single homemade fenestration for the LSA, and 36 patients had received a double homemade fenestration stent graft for endovascular degenerative aortic arch aneurysm repair.

Demographic data and operative characteristics. Of the 52 patients treated with a modified stent graft, 36

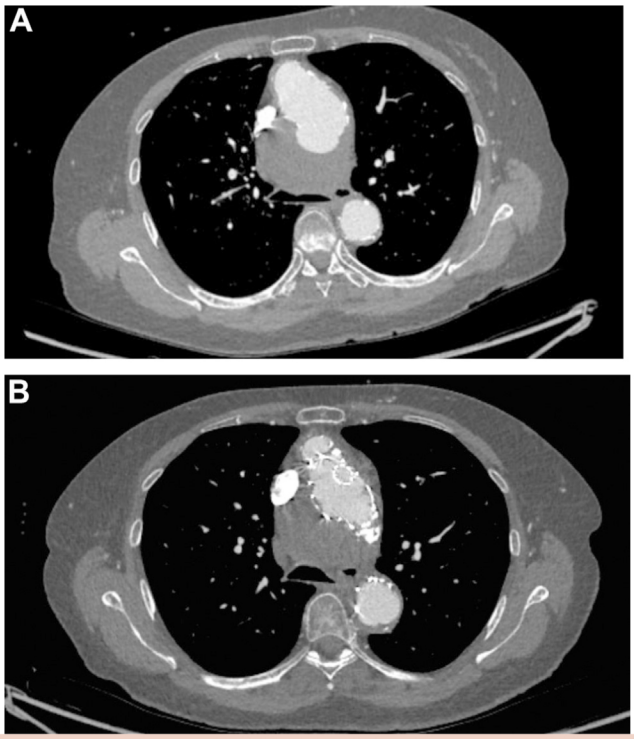

Fig 2. Follow-up surveillance with computed tomography angiography. Preoperative **(A)** and postoperative **(B)** imaging studies of an arch aortic degenerative aneurysm after endovascular exclusion.

(69%) were men, and the mean age was 75 ± 8 years (range, 56-88 years; Table I). The 47 elective patients (90%) were unfit for open surgical repair with thoracic aortic cross-clamping because of a high surgical risk and the associated probability of major complications and mortality. Most of these patients had had a saccular aneurysm of the proximal descending thoracic aorta. An average of 1.5 stent grafts (range, 1-3) were deployed. The associated procedures included femoral endarterectomy in one patient, iliofemoral thrombectomy in one patient, femoral–femoral bypass in two patients, and an iliac conduit (unplanned) was necessary to introduce the stent graft delivery system and hematoma at the puncture site in two patients.

Early and midterm outcomes. The mean time required for stent graft modification was 12 ± 2 minutes for the single and 26 ± 6 minutes for the double PMEG (Table II). Technical success was defined as a successful deployment of the device in the intended position without open conversion, early death, or the development of endoleak or thrombosis. Technical success was 100%, with no type I endoleak, and all the arteries were patent.

Only one patient (2%) had died within 30 days. The patient died of an intrapericardial ruptured aorta secondary to retrograde dissection the day of surgery after single-fenestrated TEVAR. Postoperative neurologic events occurred in five patients (10%), three of which were in a vertebra–basilar distribution and had largely occurred in patients with a high aortic atheroma burden found on CT in the proximal landing zone (Table III), as defined in the series reported by Gutsche et al.[7] None of these patients had had vertebral occlusion or a high degree of vertebral stenosis on the preoperative CT angiogram. Each LSA covered stent had had a suitable length to not cover the left vertebral artery, which was checked on the postoperative follow-up CT angiogram.

Every patient with a clinical cerebrovascular event had undergone brain magnetic resonance imaging and assessment by a neurologist. Two patients (4%) had presented with a transient ischemic attack in the early postoperative period, which had resolved spontaneously and were not associated with parenchymal infarction on follow-up imaging studies. Three patients (6%) had had concordant radiologic signs defining a stroke, of whom one had had a full neurologic recovery. Thus, the permanent stroke rate was 4% overall (2 of 52 patients). Systematic screening using imaging for silent strokes was not performed. Four patients had developed a retroperitoneal hematoma secondary to sheath introduction during stent graft placement, and no patient had experienced groin wound dehiscence requiring surgery.

Each additional perioperative procedure was unplanned and was required to treat iliofemoral access complications. One retrograde dissection was recorded in each group (4%) during the perioperative period. The second retrograde dissection was diagnosed at 1 month postoperatively. The patient was treated by the cardiac surgery team without explantion of the endoprosthesis. The endoprosthesis was still permeable without kinking or significant thrombus and no endoleak. No type I endoleak was seen on completion angiography or postoperative follow-up CT scans. No open surgical conversion was needed, and no paraplegia or perioperative myocardial infarction occurred.

Follow-up. During a mean follow-up of 18 months (range, 1-45 months), no graft migration, graft collapse, or conversion to open surgical repair had occurred. Two additional patients had died (total overall mortality, 5.7%). Neither late death was related to the aorta (2% total overall aorta-related mortality). No patient had required embolization for a type II endoleak, and none had developed occlusion of the LSA or LCCA revascularization. No additional case of retrograde dissection or paraplegia was recorded during follow-up.

DISCUSSION

The results from the present study have demonstrated that the use of both single- and double-fenestrated PMEGs is a feasible and reproducible strategy for aortic arch aneurysms with excellent technical success and low mortality. Avoiding neurologic complications is one

Table I. Demographic data and operative characteristics

Characteristic	Whole cohort (n = 52)	Single-fenestrated TEVAR (n = 16)	Double-fenestrated TEVAR (n = 36)
Mean age, years	75.1	73.6	75.8
Male gender	36 (69)	10 (63)	26 (72)
Comorbidity			
Smoking history[a]	24 (46)	8 (50)	16 (45)
Hypertension[b]	38 (73)	11 (69)	27 (75)
Dyslipidemia[c]	16 (31)	6 (38)	10 (28)
Diabetes mellitus[d]	8 (15)	2 (13)	6 (17)
COPD	15 (29)	3 (19)	12 (33)
Coronary heart disease[e]	17 (33)	7 (44)	10 (28)
Chronic renal insufficiency[f]	16 (31)	5 (32)	11 (31)
Mean ASA score	3.1	3.0	3.1
ASA class, %			
I	0	0	0
II	14	12	14
III	63	69	61
IV	23	19	25
Aortic aneurysm characteristics			
Maximal aortic diameter, mm	61.7	62.5	59.6
Proximal aortic diameter, mm	33.9	32.3	34.9
Distal aortic diameter, mm	29.7	29.5	29.8
Operative details			
Elective	47 (90)	14 (87)	33 (92)
Emergent	5 (10)	2 (13)	3 (8)
Symptomatic	14 (27)	3 (19)	11 (31)
Mean operative time, minutes	80	69	86

ASA, American Society of Anesthesiologists; *COPD*, chronic obstructive pulmonary disease; *TEVAR*, thoracic endovascular aortic repair.
Data presented as number (%), unless noted otherwise.
[a]Consumption of >100 cigarettes in patient's lifetime.
[b]Blood pressure ≥140/90 mm Hg at rest.
[c]Total cholesterol ≥2 g/L and/or low-density lipoprotein cholesterol ≥1.6 g/L and/or triglycerides ≥1.5 g/L.
[d]Fasting blood glucose ≥1.26 g/L or 7 mmol/L for two successive determinations.
[e]Diagnosed and treated medically or by cardiologic intervention.
[f]Alterationin glomerular filtration rate or urinary sediment for >3 months.

of the major challenges in treating degenerative arch aneurysms; thus, it is notable that the stroke rate in our study was at least as low as that reported for other treatment strategies.

Open surgery remains the reference standard for aortic arch repair of aneurysms. Even for elective procedures, the mortality and stroke rates have remained significant, especially for elderly patients and those with major preexisting comorbidities.[8] Because many patients will be deemed unsuitable for open repair, alternatives have emerged. Less invasive than open surgical arch replacement, debranching TEVAR has been shown to be effective in the long term for distal aortic arch aneurysm exclusion, especially in high-risk patients.[9] Nevertheless, Soares et al[10] identified older age and zone 0 or 1 as significant predictors for overall mortality. Konstantinou et al[11] reported that debranching TEVAR resulted in more perioperative complications and required a longer operative time compared with fenestrated TEVAR. Moreover, debranching TEVAR has a substantial risk of lost of view and mortality in the period between the two surgical stages, when patients do not show up at the second operation.[12]

The effectiveness of physician-modified fenestrated stent graft repair can be limited by the different issues encountered depending on the aortic disease being treated. In aortic arch dissection,[3] it has been proven that the stroke rate is very low but the development of endoleaks is a substantial concern because of the requirement for reentry. In contrast, in aortic arch degenerative aneurysms, the possibility of cerebral events should be considered the dominant issue because of the typical effectiveness of exclusion without endoleak development. Thus, for patients with degenerative aneurysms, the perioperative risk of morbidity is higher but the risk will be lower in the medium and long term.

The shaggy score has been described as a tool to prevent overt neurologic events (ie, stroke, paraplegia) by improving patient selection.[13] Greater aortic shagginess is a significant predictor of periprocedural ischemic strokes.[14] In the present series, the transient ischemic attack/stroke rate was associated with the presence of thrombus in the proximal landing zone, and 50% of the patients had had atheroma protruding into the aortic lumen (grade III and IV[7]). Although most of the patients with a cerebrovascular event had had a full recovery with no neurologic sequelae, for patients with high-grade proximal thrombus, we would recommend consideration of alternative strategies or even conservative management (ie, surgical turn down).

Both the American and European guidelines have recommended consideration of LSA revascularization in elective zone 0, 1, or 2 TEVAR to reduce the risk of neurologic complications such as stroke and spinal cord ischemia.[15,16] The risk of paraplegia is highest with LSA coverage combined with extensive coverage of the thoracic aorta. LSA transposition is often not suitable in emergent cases simply because of the time factor. Moreover, patients undergoing TEVAR with cervical debranching, carotid subclavian bypass, or transposition have had significantly greater morbidity and longer hospital stays compared with patients undergoing TEVAR alone. The morbidity and stroke rate were increased with an increasing number of bypasses,[17] justifying consideration

Table II. Early and midterm outcomes

Variable	Whole cohort (n = 52)	Single-fenestrated TEVAR (n = 16)	Double-fenestrated TEVAR (n = 36)
30-Day mortality	1 (2)	1 (6)	0 (0)
Endoleak			
Type I	0 (0)	0 (0)	0 (0)
Type II	0 (0)	0 (0)	0 (0)
Type III	0 (0)	0 (0)	0 (0)
Access-related complication	9 (17)	4 (25)	5 (14)
Aortic rupture	0 (0)	0 (0)	0 (0)
Retrograde dissection	2 (4)	1 (6)	1 (3)
Early secondary procedures	0 (0)	0 (0)	0 (0)
Conversion to open surgical repair	0 (0)	0 (0)	0 (0)
Cerebrovascular events	5 (10)	1 (6)	4 (11)
Transient ischemic attack	2 (4)	0 (0)	2 (6)
Stroke with full recovery	1 (2)	0 (0)	1 (3)
Stroke with sequelae	2 (4)	1 (6)	1 (3)
Spinal cord injury	0 (0)	0 (0)	0 (0)
Perioperative myocardial infarction	0 (0)	0 (0)	0 (0)
Supra-aortic trunk permeability	52 (100)	16 (100)	36 (100)
Late aortic secondary procedure	0 (0)	0 (0)	0 (0)
Median hospital stay, days	4.9	5.2	4.5
Follow-up, months	18	21	17
Aorta-related death	0	0 (0)	0 (0)
Aorta-unrelated death	2 (4)	1 (6)	1 (3)

TEVAR, Thoracic endovascular aortic repair.
Data presented as number (%).

Table III. Assessment of thrombus in proximal neck

Variable	Whole cohort (n = 52)	Cerebral event	
		Symptomatic (n = 5)	None (n = 47)
Thrombus in aortic neck, No. (%)	13 (25)	4 (80)	9 (19)
Healthy aortic neck, No. (%)	39 (75)	1 (20)	38 (81)
CT grade for aortic atheroma,[a] %			
I	75	20	81
II	15	20	15
III	6	40	2
IV	4	20	2
Mean score	2	3.5	1.5
Median score	2	3.5	1.5

CT, Computed tomography.
[a]Grading scale according to the classification of Gutsche et al.[7]

of alternatives. Some have preserved antegrade flow by deliberate partial coverage of the LSA,[1] and others have promoted in situ laser fenestration. The significant disadvantages of the latter include the stroke risk, technical difficulties associated with angulation of the target artery relative to the stent graft, and endoleaks around the LSA.[18,19] Even in reference centers, the use of in situ fenestration techniques have been associated with a 12% rate of perioperative strokes, and 56% of cases have required additional supra-aortic bypass procedures. The technique is not particularly convenient for emergent cases.[20]

In the treatment of thoracic aortic disease, better short- and midterm outcomes for endoleaks and branch vessel patency have been demonstrated with PMEGs than with the chimney technique.[21] The latter seems to result in imperfect exclusion because of the high rate of gutter leaks.[22] For high-risk patients, Voskresensky et al[23] reported reasonable technical success and a low mortality rate. The disadvantages included the large number of major secondary procedures required, including subclavian–carotid bypass and aortic reintervention for type Ia endoleaks from gutters or proximal stent compression.

Precannulation of the fenestration with a preloaded guidewire reduces the operating time and intra-aortic manipulation and, therefore, the neurologic risk and maximizes the technical success rate and reproducibility.[24,25] In addition, since its introduction, the investigators have observed 100% technical success, regardless of the pathology treated.

In the present series no patient had required open revascularization of the supra-aortic trunks. Although Tsilimparis et al[26] also reported high technical success using the Cook custom-made endograft (Cook Medical, Inc), >30% had required transposition or bypass of the cervical arteries. With most of the elective exclusions in zone 1 for various pathologies, they reported a 7% perioperative major stroke rate.[26]

For urgent and emergency cases, the availability of off-the-shelf devices is key. The double inner branched arch device by Cook Medical was used in this context.[27] However, a large number of early reinterventions was described because the prosthesis used had often been custom made for a different patient, in addition to the complexity of the procedures and emergency setting. Although the follow-up period was short, the thoracic branch endoprosthesis (W.L. Gore & Associates) can be considered as an alternative single side branch device.[28] The technical success rate was satisfying; however, the procedural times averaged 211 minutes, and 18% early type I endoleaks were reported. The use of a precurved fenestrated endograft, targeting, in particular, a zone

0 landing, reduce the incidence of retrograde dissection and stroke with fewer maneuvers in the aortic arch but a 12% type Ia endoleak rate.[29]

A recent systematic review of PMEGs for a variety of aortic arch pathologies reported 30-day mortality of 2.9% and a stroke rate of 2.1%.[30] In the study of 50 patients reported by Chassin-Trubert et al,[6] alignment of the graft relied solely on the LSA fenestration. This is a great intraoperative advantage with this approach, because it reduces the manipulation in the supra-aortic trunks, which is key to reducing the perioperative neurologic risk.[6] At present, no off-the-shelf endografts are available that will be suitable for most aortic arch anatomies and offer an option for acute endovascular treatment of aortic arch disease.[31] Chassin-Trubert et al[32] previously analyzed the structural variations of the aortic arch and supra-aortic arteries and determined the average spatial configuration. It seems likely that a universal double fenestration design, with a proximal landing in zone 0, for PMEGs and off-the-shelf stent grafts could be used to treat most (97%) aortic arch lesions. It has been shown in aortic dissection that the main limitation to the use of an off-the-shelf stent graft is the proximity between the LSA and LCCA.[33] However, the standardized fenestration technique can overcome this limitation in most cases.

A wide aortic angle (>50°) in the deployment zone is an independent risk factor for bird beaking.[34] Proximal fixation in zone 0 will result in significantly fewer, shorter, and less angulated bird-beak configurations than a landing in zone 1 or 2, thereby reducing the risk of type Ia endoleaks and graft migration.[35] This is one of the potential advantages of greater use of a double fenestrated approach.

The factors predisposing patients to retrograde type A aortic dissection after endovascular aortic arch repair include female gender, oversizing of >10%, a diameter of the stent graft >42 mm, an indexed aortic diameter >20 mm/m^2, aortic root morphology (specifically, loss of the sinotubular junction), and the presence of an aortic arch malformation.[36] A rate of retrograde type A aortic dissection of only 4% was described in the present series. The possible explanations include preoperative systematic sizing, the reasonable selection of eligible patients, special care taken to avoid traumatic manipulation, and the lessons learned from standard TEVAR and transcatheter aortic valve implantation at our institution.

Until an off-the-shelf device is available, patients unfit for open surgical repair with symptomatic, ruptured, or rapidly expanding arch aneurysms have limited options other than immediate physician modification of the stent grafts. In the long term, strict surveillance of these stent grafts and modifications will be necessary to monitor and ensure the durability of the repair owing to the potential for stent collapse and breakage.

CONCLUSIONS

The use of single- and double-fenestrated PMEGs is a safe, suitable, and reproducible technique for the treatment of high morbidity pathology such as aortic arch degenerative aneurysms. The strategy was associated with a low perioperative neurologic complication rate. The device can accommodate most aortic arch conformations and is particularly useful for emergent cases. Rigorous follow-up is still essential, and long-term outcomes are needed to allow for wider use of this approach.

AUTHOR CONTRIBUTIONS

Conception and design: RC, AB, PA, TG, LC
Analysis and interpretation: RC, AB, BO, TG, LC
Data collection: RC, AB, TG, LC
Writing the article: RC
Critical revision of the article: AB, BO, PA, TG, LC
Final approval of the article: RC, AB, BO, PA, TG, LC
Statistical analysis: RC, BO, LC
Obtained funding: Not applicable
Overall responsibility: LC

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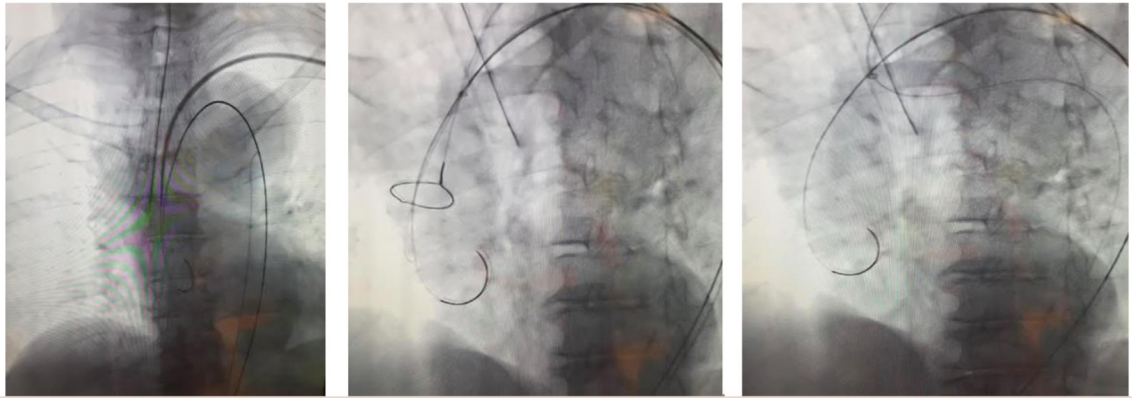
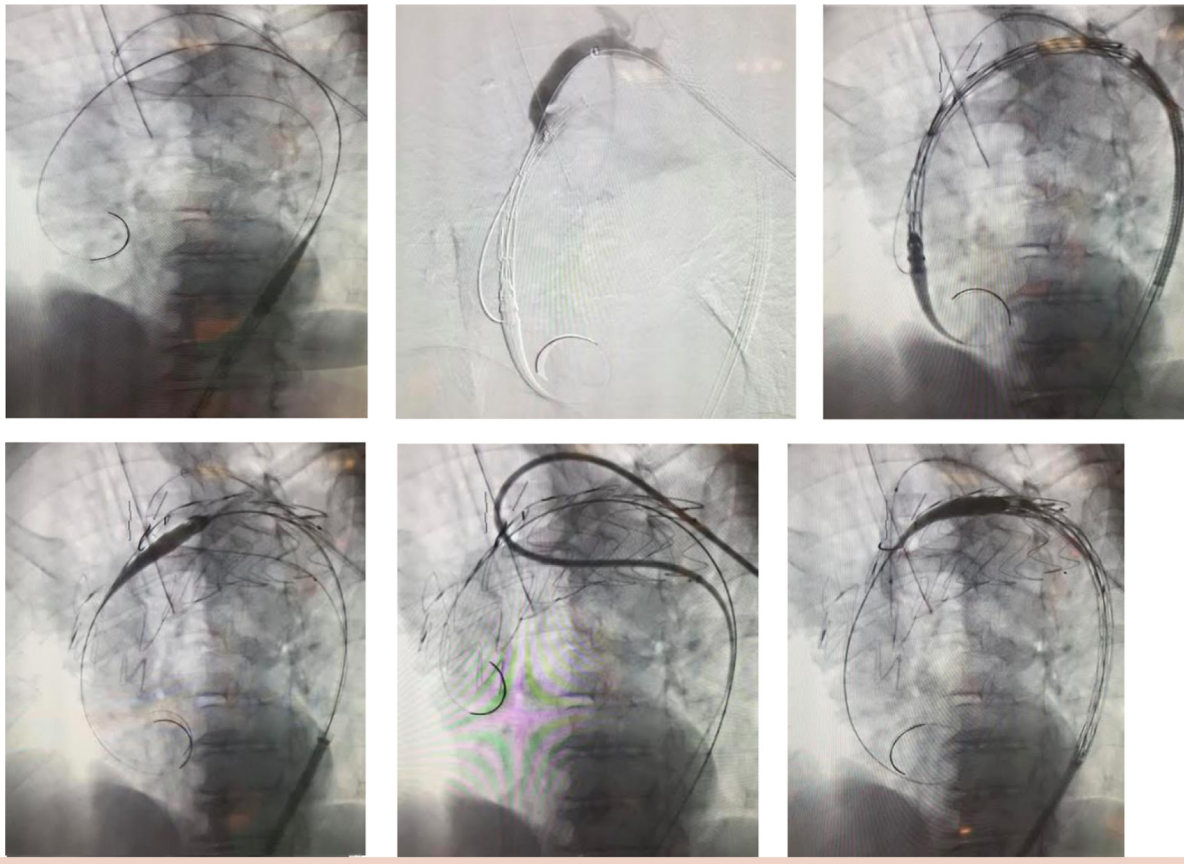
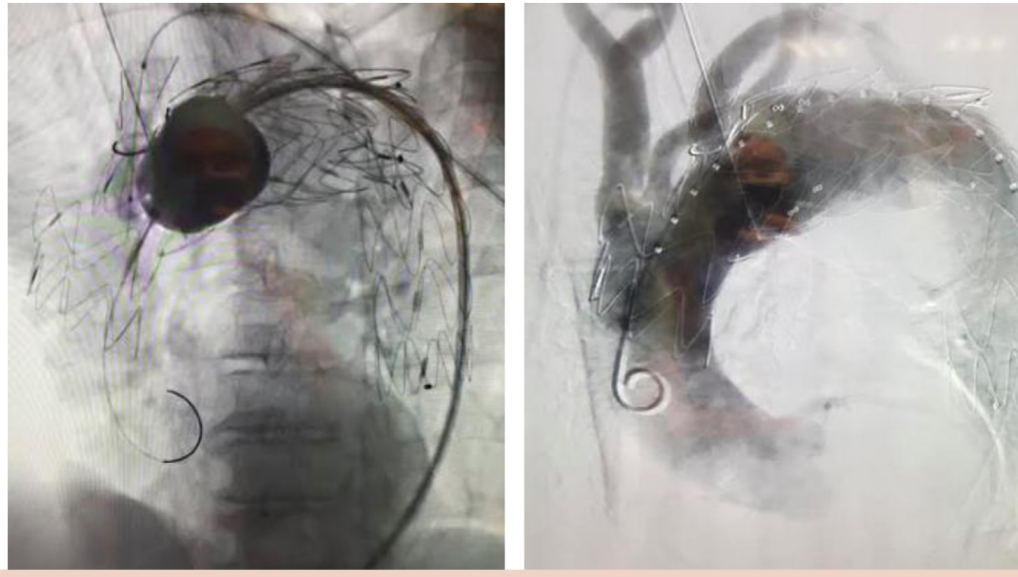


Supplementary Fig 1 (online only). A-C, Through-and-through left subclavian artery (LSA) catheterization via the preloaded guidewire and brachial snare.



Supplementary Fig 2 (online only). A-F, Angiography performed through the left brachial sheath and covered stent expansion in the proximal left subclavian artery (LSA).



Supplementary Fig 3 (online only). A,B, Concomitantly aortic stent graft and left subclavian artery (LSA) covered stent inflation and completion angiography.