

Endovascular Aortic Arch Repair

An update on the devices and techniques available to treat this challenging anatomy.

BY NIKOLAOS TSILIMPARIS, MD, PhD, FEBVS; KRASSI IVANCEV, MD, PhD;
AND TILO KÖLBEL, MD, PhD



Today, open surgery is considered the gold standard in treating the ascending aorta and the aortic arch. However, conventional surgical techniques for managing the aortic arch are invasive and frequently associated with a significant systemic inflammatory response syndrome and related complications. Therefore, patients with multiple comorbidities are often classified as high risk and are denied open repair.



Over the past 10 years, thoracic endovascular aneurysm repair (TEVAR) has prevailed as the treatment of choice for pathologies of the descending aorta and aortic arch up to Ishimaru zone 2. The superiority of TEVAR in comparison to open repair in reducing perioperative and long-term severe morbidity has been demonstrated in a prospective comparative study.¹ In high-volume centers and in patients at low risk, surgical techniques



such as complete open repair of the aortic arch or the hybrid (frozen) elephant trunk have been associated with a mortality rate of up to 9% and a stroke rate of 4% to 12%.²⁻⁴ Minimally invasive treatment of aortic arch pathologies faces a number of technical challenges. First, the supra-aortic branches perfuse the brain, which has a low ischemic tolerance. Furthermore, the aortic arch is wide, angulated, pulsatile, and is further away from the typical access vessels, the femoral arteries. In addition, the presence of plaque and thrombus in the aortic arch (ie, “shaggy aorta”) increases the risk for brain embolism.⁵

ENDOVASCULAR HYBRID TECHNIQUES

The hybrid approach to treating the aortic arch consists of bypasses from the ascending aorta (Figure 1) to the supra-aortic vessels or cervical debranching of the supra-aortic vessels with carotid-carotid bypass and/or carotid-subclavian bypass (or left subclavian artery [LSA] transposition). This technique has shown good results over the last 10 years and has expanded the options for repair of aortic arch pathologies in patients who are considered unfit for open surgery.^{6,7} However, a meta-analysis by Antoniou et al reported that this technique is still associated with a 30-day mortality rate of 13% and a 30-day morbidity rate of 35%.⁷ Patients who



Figure 1. Three-dimensional reconstruction of CT angiography (CTA) of a patient with debranching of the aortic arch with bypasses from the ascending aorta to the innominate and LCCA.

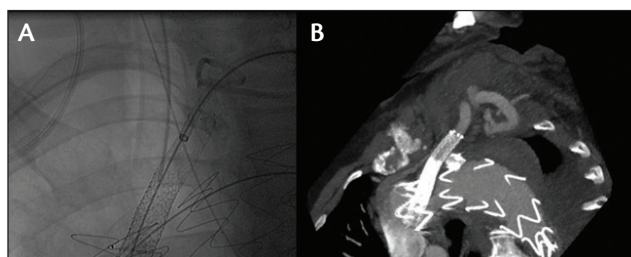


Figure 2. Intraoperative angiography of a patient with implantation of a Zenith Alpha endograft (Cook Medical) and a chimney endograft (Advanta, Maquet) for the LCCA (A). Maximal intensity projection reconstruction of a CTA from the same patient (B).

underwent aortic arch debranching and proximal sealing in Ishimaru zones 0 and 1 had higher morbidity rates compared to those with more distally located landing zones.⁸ Chiesa et al confirmed these results and concluded that most of the deaths occurred due to strokes in patients with stent grafts in Ishimaru zones 0 and 1.⁶

CHIMNEY PROCEDURES

The practice of using parallel or chimney stent grafts has increasingly been reported for the aortic arch in recent

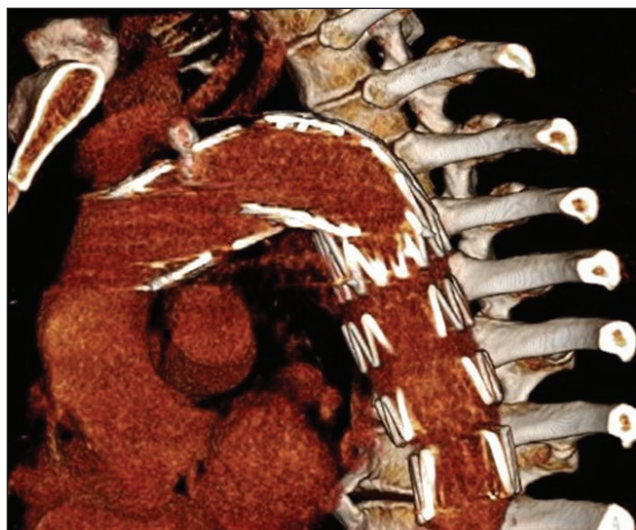


Figure 3. Three-dimensional reconstruction of a CTA in a patient with in situ laser fenestration of the LCCA.

years (Figure 2). Although this technique has typically been used for revascularization of the LSA, the feasibility of the chimney technique for all major supra-aortic branches has been demonstrated.⁹ A recent meta-analysis reported that the incidence rates of type Ia and II endoleaks were 11% and 8%, respectively, thus representing a major drawback of this technique. Although the perioperative mortality rate was reported to be only 5%, the perioperative stroke rate was still 4%.¹⁰

IN SITU FENESTRATED AORTIC ARCH ENDOGRAFTS

The technique of retrograde or antegrade in situ fenestration of stent grafts for the thoracic aorta is well described as a bailout technique for emergent situations.^{11,12} In 2013, Redlinger et al published the largest series to date, in which favorable results were observed in 22 patients who underwent TEVAR with laser fenestration of the left subclavian artery.¹³ In our experience, the laser fenestration procedure was successfully used as a bailout procedure in a case with accidental overstenting of the left common carotid artery (LCCA) (Figure 3).¹⁴

Although laser fenestration can achieve quick perfusion to the target arch vessel, the technique can be demanding and is associated with significant risk, especially when material damage is poorly controlled. Although polytetrafluoroethylene stent grafts are easier to puncture and dilate compared to Dacron stent grafts, they are also more prone to material damage.

CUSTOM-MADE FENESTRATED AND BRANCHED STENT GRAFTS

As far back as 11 years ago, Chuter et al envisioned the endovascular treatment of the aortic arch and introduced branched arch stent grafts.¹⁵⁻¹⁷ Since the initial use of

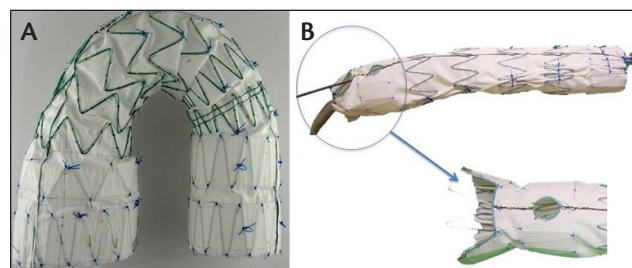


Figure 4. The Zenith arch branched endograft* (A) and the Zenith arch fenestrated endograft (B), both by Cook Medical.

fenestrated and branch stent grafts in the aortic arch, the technique has evolved considerably and has now reached the stage of clinical implementation on a large scale. This is evident by the number of companies that manufacture or develop fenestrated and branch stent grafts for the aortic arch. Although Cook Medical was the first to produce fenestrated and branch stent grafts for the arch, other companies such as Bolton Medical and Medtronic have produced endografts for the aortic arch. Medtronic is conducting a clinical trial on the single-branched stent graft Valiant Mona LSA, which has a funnel-shaped inverted window ("volcano") for the LSA. Similarly, Gore & Associates and MicroPort Endovascular are in the development and clinical trial phase for single-branch endografts for the LSA.

Cook Medical has two main stent graft designs that address the specific characteristics of the aortic arch: a fenestrated endograft and an arch branch endograft (Figure 4). Both endografts are custom-made according to a patient's specific anatomy. Fenestrated or branched arch endografts typically come in longer delivery systems compared with standard thoracic endografts and are precurved to facilitate self-alignment of the endograft in the aortic arch during introduction and deployment. The principle of self-alignment is essential, given that the possibility of rotational manipulation in the arch is minimal.

Fenestrated endografts in the arch typically address one to two vessels with either two fenestrations or, more commonly, one fenestration and one scallop depending on the intended landing zone. Fenestrated endografts can be manufactured with a fenestration for the LCCA and a large scallop for the innominate artery, or similarly a fenestration for the LSA and a scallop for the LCCA or the bicarotid trunk. A preloaded catheter and guidewire runs through the graft and the fenestration and is used to achieve femoroaxillary through-and-through wire access. Thus, alignment of the fenestration to the target vessel can be securely achieved. Special notice must be taken during this maneuver not to entangle the through-and-through wire in the uncovered struts of the scallop (Figure 4B), as it may complicate the procedure and require multiple manipulations in the arch.

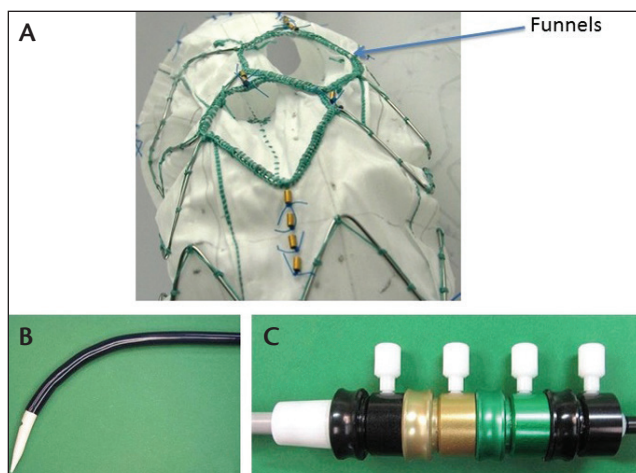


Figure 5. Funnels of the Zenith arch branch endograft at the outer curvature (A), the precurved formation of the endograft facilitating self-alignment in the aortic arch (B), and the multiple trigger wires allowing staged and controlled deployment of the arch endograft (C).

However, just as in the visceral aorta, large aneurysms or post-type A dissection aneurysms involving the entire arch cannot be effectively treated by fenestrated endografts alone. The distance between the fenestration and the target vessel in combination with the strong pulsation of the arch would expose the bridging stents to extreme mechanical stress and compromise seal at the fenestrations. Therefore, branched arch devices are more suitable for these cases. Cook Medical has developed an arch branch device, which is composed of a stent graft with two internal branches.* In contrast to previous branched devices, retrograde catheterization of the internal branches is performed through large funnel-shaped orifices that are oriented at the outer curve of the aortic arch (Figure 5A). The two inner branches typically address the innominate and the LCCA.

Given that endograft rotation and deployment at the intended rotational position in the arch are more complicated than in the visceral aorta, the introduction of inner branches connected to the funnels represents an ingenious characteristic that makes branch catheterization and the entire procedure easier to perform. Furthermore, this prosthesis is made of very thin but high-density Dacron and has a self-alignment system, as well as a controlled-release mechanism (Figure 5B and 5C).

After deploying the main stent graft in the arch, bridging stent grafts are inserted over (1) the right common carotid artery, to which access has been achieved through cutdown; and (2) the left carotid artery via a previously established carotid-subclavian bypass.

Haulon et al published the initial international experience, which describes 38 patients deemed medically unfit for surgical repair who underwent placement of this

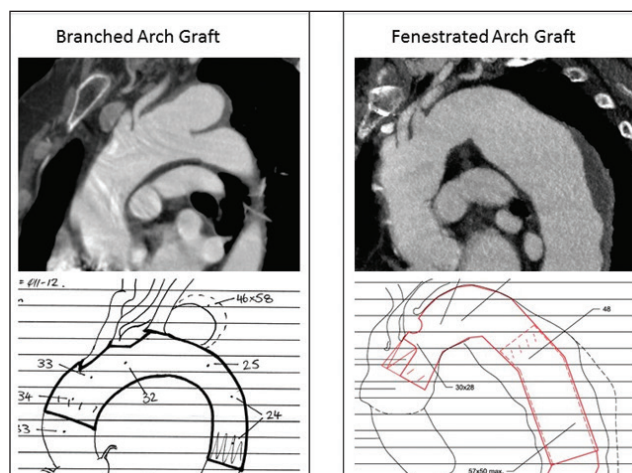


Figure 6. Sagittal reconstructions of CTA and preoperative planning sketches of patients with arch aneurysms planned to undergo fenestrated or branched TEVAR.

arch branch stent graft. The authors concluded that these results support the feasibility of treating patients with arch pathologies using this device, and the early results after overcoming the learning curve appear favorable (30-day mortality: 30% in the first 10 patients vs 7% in the last 28; $P = .066$). A diameter of > 38 mm in the landing zone was associated with increased risks for early morbidity and stroke.¹⁸

In our own experience from 2012 through the end of 2014, 29 patients underwent fenestrated or branched TEVAR (66 ± 9 years, 9 women). No differences in comorbidities were reported between fenestrated TEVAR patients ($n = 15$) and branched TEVAR patients ($n = 14$) (Figures 6 and 7).¹⁹ Previous cervical debranching was performed in only six (40%) fenestrated TEVAR patients compared to all patients who underwent branched TEVAR. In all patients who underwent branched TEVAR, two arch vessels were targeted (innominate artery = 13, LCCA = 14, LSA = 1), whereas in patients who underwent fenestrated TEVAR, 1.6 ± 0.5 arch vessels were targeted (bovine trunk = 4, LCA = 11, LSA = 8). Fenestrated endografts landed proximally in zone 0 in 33% of the cases, while all branched endografts landed in the ascending aorta.

Technical success was achieved in all but one case of a fenestrated endograft that was displaced, resulting in major stroke and death. Strokes occurred in two fenestrated TEVAR patients and one branched TEVAR patient ($P =$ nonsignificant), thus still representing a serious clinical consequence of aortic arch interventions. The 30-day mortality rate in this high-risk cohort was 20% in those who underwent fenestrated TEVAR ($n = 3$) versus 0% in patients who underwent branched TEVAR ($P =$ nonsignificant). The causes of early mortality were major stroke ($n = 1$), access complication ($n = 1$), and myocardial infarction ($n = 1$). Mean follow-up was 8 (range, 1–35)

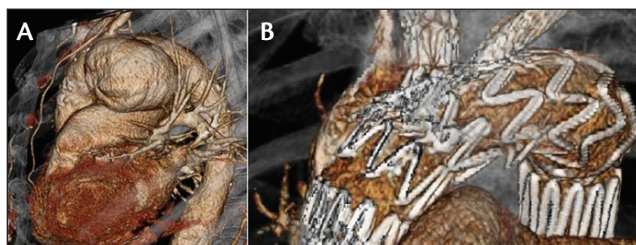


Figure 7. Preoperative (A) and postoperative (B) CTA imaging of a patient with an aortic arch aneurysm who underwent implantation of the Zenith arch device with branches for the innominate artery and LCCA.

and 10 (range, 2–22) months for fenestrated or branched TEVAR, respectively. No branch occlusions occurred, and two patients underwent coil embolization for endoleaks ($P = \text{nonsignificant}$). One patient was readmitted with an infected branched endograft 4 months after intervention and has so far been successfully treated with aneurysm sac drainage and antibiotics. There was one late, nonaneurysm-related death in each group.

DISCUSSION

The special hemodynamic and anatomic characteristics of the aortic arch make manipulation in this region challenging. Inaccuracy of stent graft placement can have fatal consequences for the patient and increase the risk of endoleaks and stroke. Precise preoperative planning to achieve optimal stent graft dimensions and implantation tactics are essential to avoid complications (Figure 6). Further, careful patient selection for aortic arch stent grafts is essential. An interdisciplinary conference with cardiologists and heart surgeons is crucial to match the right patient with the right therapy.

The future of fenestrated and branched TEVAR in the aortic arch is promising, and as technology evolves and experience grows, more and more patients will be considered for this technique (Figures 7 and 8). There are some problems that still need to be addressed, specifically arch repair, which is mostly restricted by the absence of an adequate landing zone in the ascending aorta due to its large diameter.

Currently, endovascular repair of the arch is reserved for patients with a landing zone distal to the coronary arteries or in the presence of at least an open repair with a graft long enough to provide a landing zone that can facilitate further endovascular repair. The next challenge for both academic and industry innovators is the combination of an aortic valve and an ascending graft with preservation of the coronary arteries, which would make a complete endovascular repair, starting from the heart, possible.

CONCLUSION

Hybrid interventions can be a good alternative to open surgery in high-risk patients. Endoleaks are a relevant

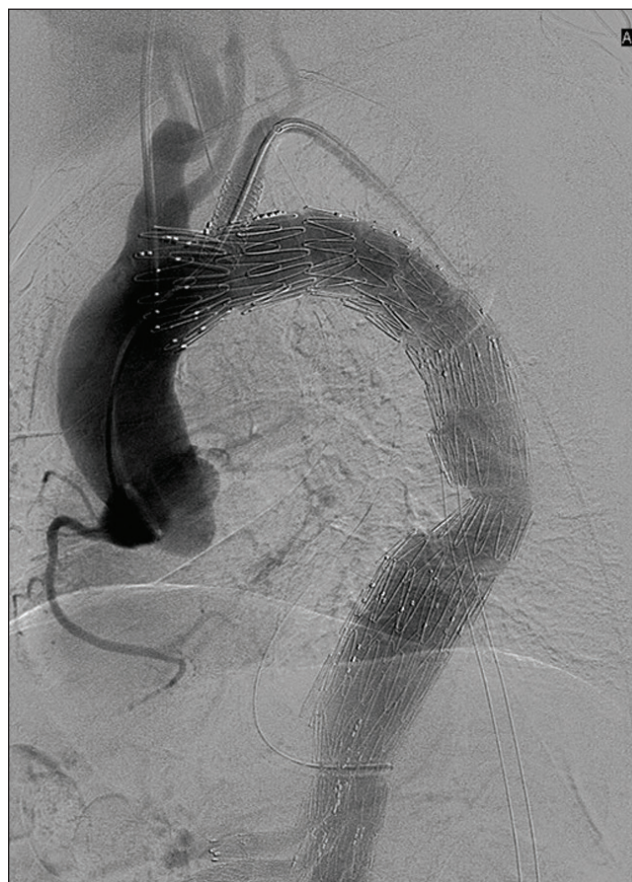


Figure 8. Intraoperative final angiography of a patient with a thoracoabdominal aortic aneurysm after implantation of a fenestrated Zenith arch device with a fenestration for the left subclavian artery and a scallop for the bicarotid trunk.

problem during chimney procedures in the aortic arch due to the high hemodynamic forces involved. Custom-made fenestrated and branched stent grafts provide an excellent option for high-risk patients and represent a potential future option for more patients with aortic arch disease. ■

**The Zenith arch branched device is an investigational device in the United States and Europe. It is not FDA or CE Mark approved at this time.*

Nikolaos Tsilimparis, MD, PhD, FEBVS, is Assistant Professor, University Heart Center Hamburg in Hamburg, Germany. He has disclosed that he has received travel support from Cook Medical. Dr. Tsilimparis may be reached at n.tsilimparis@uke.de.

Krassi Ivancev, MD, PhD, is with University Heart Center Hamburg in Hamburg, Germany. He has disclosed that he has intellectual properties with Cook Medical.

Tilo Kölbel, MD, PhD, is with University Heart Center Hamburg in Hamburg, Germany. He has disclosed that he has intellectual properties with Cook Medical.

1. Matsumura JS, Melissano G, Cambria RP, et al; Zenith TX2 Clinical Trial Investigators. Five-year results of thoracic endovascular aortic repair with the Zenith TX2. *J Vasc Surg*. 2014;60:1-10.
2. Sundt TM 3rd, Orszulak TA, Cook DJ, Schaff HV. Improving results of open arch replacement. *Ann Thorac Surg*. 2008;86:787-796; discussion 787-796.
3. Tian DH, Wan B, Di Eusario M, Yan TD. A systematic review and meta-analysis on the safety and efficacy of the frozen elephant trunk technique in aortic arch surgery. *Ann Cardiothorac Surg*. 2013;2:581-591.
4. Minakawa M, Fukuda I, Yamauchi S, et al. Early and long-term outcome of total arch replacement using selective cerebral perfusion. *Ann Thorac Surg*. 2010;90:72-77.
5. Okada T, Shimamoto M, Yamazaki F, et al. Insights of stroke in aortic arch surgery: identification of significant risk factors and surgical implication. *Gen Thorac Cardiovasc Surg*. 2012;60:268-274.
6. Chiesa R, Melissano G, Tshomba Y, et al. Ten years of endovascular aortic arch repair. *J Endovasc Ther*. 2010;17:1-11.
7. Antoniou GA, Mireskandari M, Bicknell CD, et al. Hybrid repair of the aortic arch in patients with extensive aortic disease. *Eur J Vasc Endovasc Surg*. 2010;40:715-721.
8. Kotellis D, Geisbusch P, Attigah N, et al. Total vs hemi-aortic arch transposition for hybrid aortic arch repair. *J Vasc Surg*. 2011;54:1182-1186 e2.
9. Mangialardi N, Serrao E, Kasemi H, et al. Chimney technique for aortic arch pathologies: an 11-year single-center experience. *J Endovasc Ther*. 2014;21:312-323.
10. Moulakakis KG, Mylonas SN, Markatis F, et al. A systematic review and meta-analysis of hybrid aortic arch replacement. *Ann Cardiothorac Surg*. 2013;2:247-260.
11. Ahanchi SS, Almaroof B, Stout CL, Panneton JM. In situ laser fenestration for revascularization of the left subclavian artery during emergent thoracic endovascular aortic repair. *J Endovasc Ther*. 2012;19:226-230.
12. Murphy EH, Dimaio JM, Dean W, et al. Endovascular repair of acute traumatic thoracic aortic transection with laser-assisted in-situ fenestration of a stent-graft covering the left subclavian artery. *J Endovasc Ther*. 2009;16:457-463.
13. Redlinger RE Jr, Ahanchi SS, Panneton JM. In situ laser fenestration during emergent thoracic endovascular aortic repair is an effective method for left subclavian artery revascularization. *J Vasc Surg*. 2013;58:1171-1177.
14. Tsilimparis N, Debus ES, Wipper S, et al. Proximal thoracic endograft displacement rescued by balloon-assisted pull-back, external shunting, and in situ fenestration of the left carotid artery [published online ahead of print July 28, 2014]. *J Vasc Surg*.
15. Chuter TA, Buck DG, Schneider DB, et al. Development of a branched stent-graft for endovascular repair of aortic arch aneurysms. *J Endovasc Ther*. 2003;10:940-945.
16. Chuter TA, Schneider DB, Reilly LM, et al. Modular branched stent graft for endovascular repair of aortic arch aneurysm and dissection. *J Vasc Surg*. 2003;38:859-863.
17. Chuter TA, Schneider DB. Endovascular repair of the aortic arch. *Perspect Vasc Surg Endovasc Ther*. 2007;19:188-192.
18. Haulon S, Greenberg RK, Spear R, et al. Global experience with an inner branched arch endograft. *J Thorac Cardiovasc Surg*. 2014;148:1709-1716.
19. Tsilimparis N, Debus ES, Boehme T, et al. Performance of branched vs fenestrated endografts for endovascular repair of aortic arch lesions. *J Vasc Surg*. 2015;61:65.