New Technique

Single-Stage, Off-Pump Hybrid Repair of Extensive Aneurysms of the Aortic Arch and the Descending Thoracic Aorta

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Surgical treatment of aortic arch aneurysms has been challenging. These aneurysms are usually treated with open surgical repair that requires cardiopulmonary bypass (CPB) and hypothermic circulatory arrest (HCA). Furthermore, in cases of aneurysms involving both the aortic arch and the descending thoracic aorta (DTA) extensive surgical incisions or staged procedures are often necessary, increasing the perioperative risk.

The purpose of this report is to describe the use of an innovative, hybrid technique that avoids the use of CPB and HCA in a single-stage surgical treatment for high-risk patients with extensive aortic arch and DTA aneurysms and a non-aneurysmal ascending aorta (Figure 1). This technique employs surgical debranching and revascularization of the aortic arch, and placement of endovascular stent-grafts within the ascending aorta, the aortic arch and the DTA.

Technique

The procedure is performed under general anesthesia and involves a median sternotomy and, occasionally, small cervical incisions. The operating room is equipped with a portable C-arm image intensifier, capable of digital subtraction angiography. The CPB team is on standby. Central venous lines, a pulmonary artery catheter and transesophageal echocardiography are routinely used. Cerebral perfusion is monitored by continuous transcranial recording of cerebral regional oxygen saturation (Invos 5100 system, Somanetics, Troy, Michigan, USA). Arterial blood pressure is monitored in both radial arteries and the left femoral artery.

Following pericardiotomy, the ascending aorta and the branches of the aortic arch are prepared anatomically and encircled with umbilical tapes. Depending on the individual patient's anatomy, small cervical incisions can be made for access to the carotid and the subclavian arteries, when not accessible through the chest.

Following intravenous heparinization (5000 IU), a partial occlusion clamp is applied to the ascending aorta, as close to the aortic root as possible, leaving an adequate distance for the subsequent landing of the endovascular prosthesis. During this maneuver, arterial blood pressure is lowered pharmacologically. The proximal end of a bifurcated woven polyester vascular graft (Polythese IC, Perouse Medical, Ivry le Temple, France) is trimmed to just a short length from its bifurcation and is slightly beveled. An end-to-side anastomosis is performed (Figure 2) as close
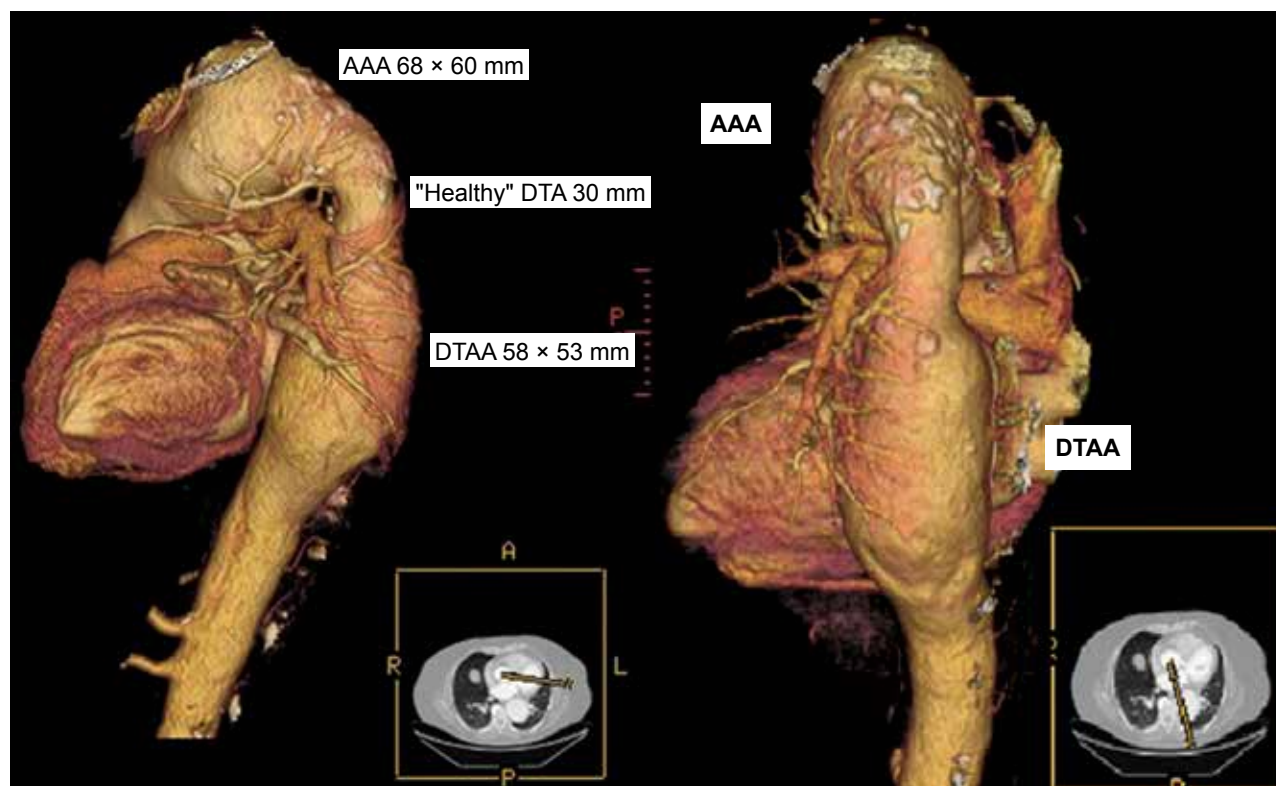
Figure 1. Preoperative computed tomography scan with three-dimensional reconstruction showing coexisting aortic arch aneurysm (AAA) and descending thoracic aortic aneurysm (DTAA). A 35 mm long and 30 mm wide normal-sized segment of descending thoracic aorta separates the two aneurysms.

to the aortic root as possible. Subsequently, with the help of a small partial occlusion clamp, an end-to-side anastomosis is performed between one of the two limbs of the graft and the innominate artery, which is then ligated proximally with umbilical tape and heavy silk ties. Alternatively, a vascular stapler can be used. The innominate artery is not transected, to avoid the risk of bleeding. During these maneuvers, flow to the right carotid artery is not interrupted for any period of time. Subsequently, the left carotid artery is test-clamped for a period of three minutes while the cerebral oxygen saturation is monitored for signs of ischemia. (Occlusion of this artery for the period required to complete the anastomosis was well tolerated in all patients.) The left carotid artery is then ligated, and then transected at its origin from the aortic arch. An end-to-end anastomosis is performed between the remaining limb of the bifurcated graft and the left common carotid artery (Figure 2). Occasionally, when the origins of the aortic arch branches lie high within the chest, the two limbs of the bifurcated graft can be tunneled behind the clavicles and the anastomoses can be performed to the cervical segment of the com-

mon carotid arteries. In the case of cerebral ischemia, as demonstrated by diminishing left cerebral oxygen saturation to less than 60% of baseline, an intraluminal shunt with an end-to-side anastomosis can be constructed in the neck.

Subsequently, a left carotid artery to left subclavian artery bypass is constructed through a small supraclavicular incision, using an 8 mm polytetrafluoroethylene graft (Figure 3) that is interposed in an end-to-side fashion between both arteries. Proximal ligation of the origin of the subclavian artery from within the chest is the final step of the aortic arch debranching procedure (Figure 3).This can be a risky maneuver when the origin of the left subclavian artery is not easily accessible. Alternatively, a vascular occluder device can be delivered via the brachial artery or directly through the bypass graft prior to deployment of the endografts.

The second phase of the hybrid procedure constitutes the insertion, under fluoroscopic guidance, of the stented endovascular grafts. Most commonly, the right common femoral artery is exposed and encircled with tapes, while the left femoral artery is used for diagnostic angiography catheter insertion. Using standard
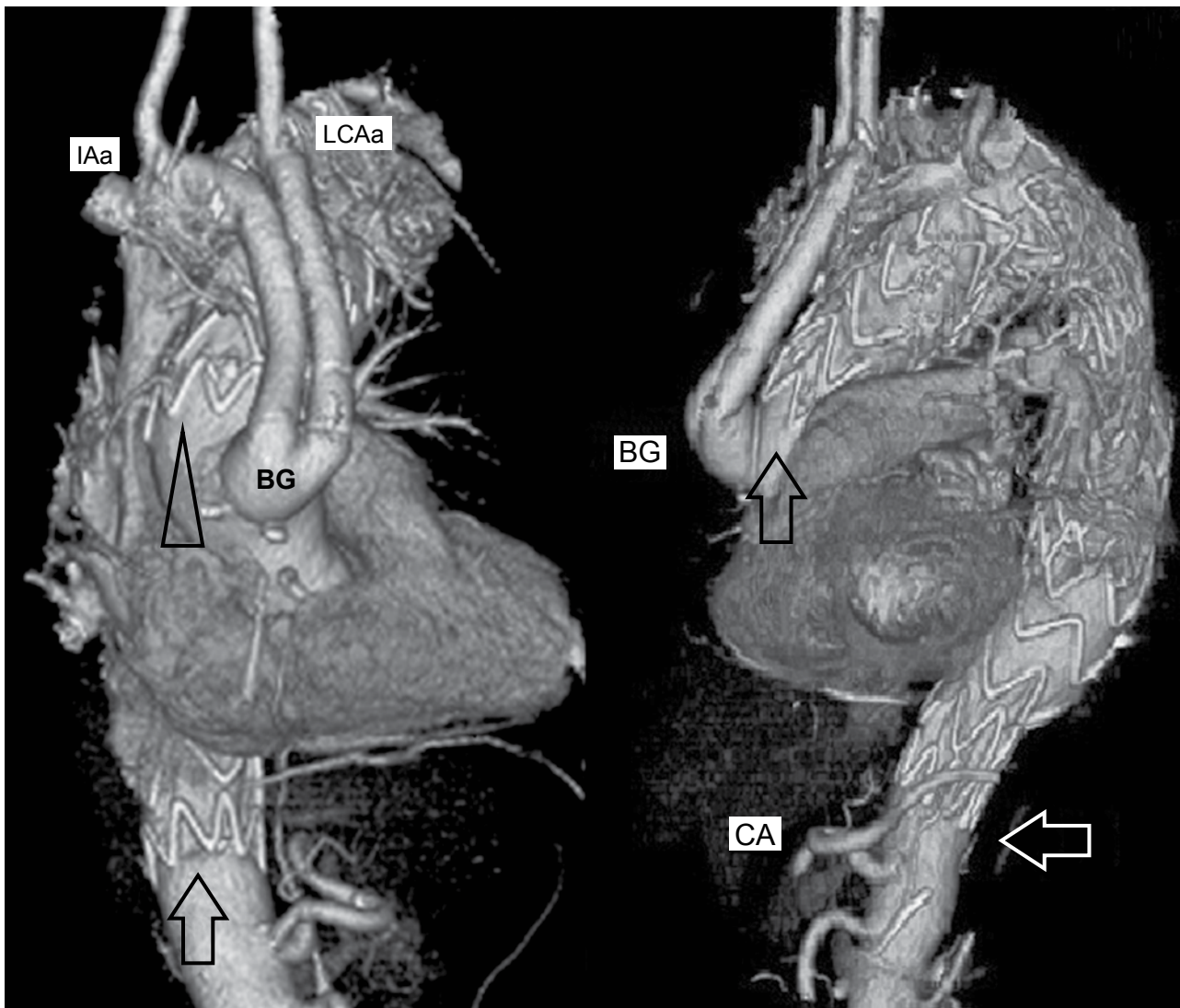
Figure 2. A: Postoperative scan showing the bifurcated graft (BG) anastomosis to the ascending aorta as well as the anastomoses of the innominate artery (IAa) and the left carotid artery (LCAa) to the two limbs of the graft. The proximal extent of a stented vascular graft is also shown (arrowhead) just distal to the BG anastomosis. B: The three overlapping stented endografts are shown. The first endograft (42 × 42 × 150 mm) extends from the ascending aorta (distally to the bifurcated graft anastomosis, black arrow) to the subclavian artery. The second, tapered graft (46 × 42 × 150 mm) extends from the left subclavian artery to the descending thoracic aorta, and the third graft (46 × 46 × 200 mm) reaches to the origin of the celiac artery (CA, white arrow).

endovascular techniques, depending on the extension of the aortic arch and DTA aneurysms, pre-selected stented endografts are then deployed to cover the ascending aorta, the aortic arch and the DTA, as needed, to exclude all of the aneurysmal aorta (Figure 2). Transesophageal echocardiography and aortography are performed to confirm a satisfactory final result.

Case presentations

We have performed the above hybrid repair for ath-erosclerotic aortic arch and DTA aneurysms in 4 patients during the last 2 years. Patients with an aneurysmal ascending aorta, or chronic dissecting aneurysms within the aortic arch or the DTA were excluded. The median age was 73.75 years and all patients were assessed to be at high risk for conventional open repair, with preoperative median predicted mortality by Euroscore I and II 36.66% and 9.62% respectively (Table 1). In all cases the aneurysm involved the aortic arch and the DTA, whereas the ascending aorta was normal or mildly dilated (Table 2). None of
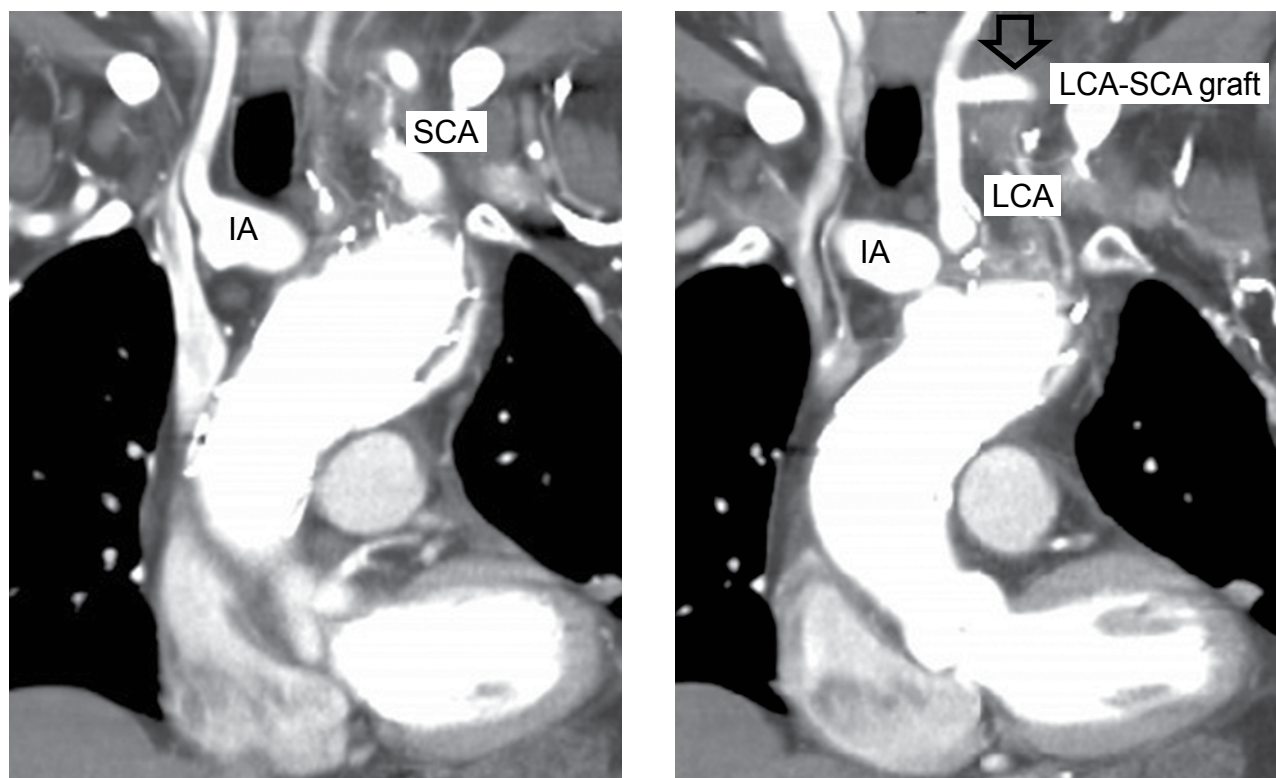
Figure 3. Coronal images showing the "de-branched" aortic arch. Left: proximally ligated innominate artery (IA) and subclavian artery (SCA). Right: transected left carotid artery (LCA) and LCA-SCA bypass graft (arrow).

Table 1. Demographic data and preoperative risk stratification.

Patient	Age, sex	HTN	DM	DLPD	Smoking	Comorbidities	Euroscore I/II (%)
1	74, F	yes	yes	yes	yes	COPD, PVD, obesity	36.7/8.3
2	70, F	yes	no	yes	no	COPD, PVD,CRF	29.41/7
3	72, M	yes	no	yes	yes	COPD, PVD	35.7/8.5
4	79, F	yes	no	yes	no	COPD, VHD, poor mobility	44.8/14.6

F – female; M – male; HTN – hypertension; DM – diabetes mellitus; DLPD – dyslipidemia; COPD – chronic obstructive pulmonary disease; PVD – peripheral vascular disease; CRF – chronic renal failure; VHD – valvular heart disease

the patients had a prior sternotomy. One patient had undergone abdominal aortic aneurysm repair 3 years previously. Coronary angiography, performed preoperatively in all patients, confirmed the absence of coronary artery disease. Echocardiography showed normal tricuspid aortic valves without regurgitation in all patients, and moderate mitral and tricuspid valve regurgitation in one case (Table 1).

During the operation, small supraclavicular incisions were made prior to sternotomy for precautionary exposure of the common carotid arteries only in the first two patients. Tunneling of the limbs of the bifurcated graft behind the clavicles in order to perform the anastomoses in the cervical portion of the

carotid arteries was never required, since the origins of the aortic arch branches were handily accessible from within the chest. Nor was an intraluminal left carotid artery shunt ever required, because cerebral oxygen saturation never fell below 20% of baseline during the anastomosis of the transected left carotid artery to the limb of the bifurcated graft. The left subclavian artery was revascularized by means of a left carotid-subclavian bypass through a separate left supraclavicular incision in 3 patients.

Ligation of the aortic arch branches at their origin was achieved by applying heavy silk ties, small umbilical tapes and large vascular clips, depending on the size of the vessel. In one patient with difficult

Table 2. Aneurysm extension to ascending aorta, aortic arch and descending thoracic aorta (maximum aortic diameter in mm).

Patient	Aortic root	Ascending aorta	Aortic arch	Descending aorta
1	30	37	62	67
2	32	40	68	58
3	38	41	60	72
4	40	42	82	110

exposure of the left subclavian artery origin, a vascular occluder device (Amplatzer vascular plug, St. Jude Medical, St. Paul, MN, USA) was delivered directly through the bypass graft.

Deployment of the endografts was performed via the right or left common femoral artery. Depending on aortic anatomy and availability, different types of pre-selected grafts were used (Valiant Captivia Stent Graft System, Medtronic, Minneapolis, MN; Zenith TAA Endovascular Graft, Cook Medical, Bloomington, IN and Gore Tag Thoracic Endoprosthesis, W.L. Gore & Associates, Flagstaff, AZ). Three endografts per patient were implanted in three cases, whereas the fourth patient required four endografts to effectively exclude the aneurysmal aortic segments.

The described hybrid method, consisting of arch debranching and endovascular repair of the aortic arch and DTA, was technically applied successfully in a single-stage, off-pump manner in all patients. However, a 79-year-old female patient (patient 4; Tables 1 and 2) expired on the second postoperative day from right heart failure and subsequent low cardiac output syndrome. Transesophageal echo and surgical exploration revealed a severely hypokinetic right ventricle, unresponsive to pharmacological measures. Preoperatively, she was assessed to be at prohibitively high risk for open repair (Euroscore I predicted mortality 44.79%) due to advanced age, severe pulmonary disease, pulmonary hypertension, and valvular heart disease (moderate mitral and tricuspid valve regurgitation), probably underestimated. The postoperative mean length of stay for the survivors was 10.25 days. CT aortography was performed prior to discharge and every 6 months thereafter. Over a mean follow-up period of 23.7 months, only an early, small, type I endoleak was detected in one patient, which gradually improved without any further intervention. There was no late mortality or any neurological complication, such as stroke, paraparesis or paraplegia.

Discussion

Extensive aneurysms of the aortic arch and the proximal DTA are usually treated with open surgical repair utilizing CPB and HCA. A two-stage approach utilizing the "elephant trunk" procedure has been applied successfully, while a "clamshell incision" (bilateral anterior thoracotomy with transverse sternotomy) has been used for single-stage open repair.[1,2] Despite recent advances in cerebral protection perfusion strategies, these methods can be associated with considerable morbidity and mortality in high-risk patients.[3,4] Recently, new hybrid surgical techniques have been proposed to improve the outcome of the surgical treatment of these lesions. The "frozen elephant trunk" procedure is a technique that combines the conventional open aortic arch repair with open endovascular treatment of the descending aorta during a single-stage operation, using newly developed hybrid grafts.[5]

Nevertheless, these hybrid methods require the use of CPB with deep HCA, leading to increased perioperative complications and considerable mortality in high-risk patients. The application of purely endovascular procedures is hindered by limitations related to the origin of the cervical arterial branches of the aortic arch. The development of combined endovascular and open surgical treatment is a new hybrid alternative to open surgical repair.[6,7] Debranching of the aortic arch followed by revascularization of the aortic arch branches, preferably off-pump, enables the placement of vascular stented grafts in these segments of the aorta, thereby avoiding HCA. This new hybrid technique for the treatment of high-risk patients with aortic arch and DTA aneurysms is technically feasible as a single-stage procedure without the use of CPB.

In our modest initial experience, there were no strokes or spinal cord ischemic injuries, even in the cases with extensive DTA stent-grafting. It appears that a short, temporary interruption of blood flow into the left carotid artery is well tolerated.[9] Furthermore, most patients tolerate occlusion of the left subclavian artery without neurological complications or ischemia to the arm. Nevertheless, a left carotid-subclavian bypass can be easily performed without adding significant surgical risk, due to the off-pump nature of the procedure.

This hybrid technique can only be applied to patients with a non-aneurysmal ascending aorta that can serve as a landing zone for the endograft. Potentially,

it can also be used in patients who have undergone prior replacement of the ascending aorta. A limitation of the procedure is the presence of chronic dissecting aneurysms within the aortic arch or the DTA that may preclude the safe deployment of stent-grafts because of the presence of intraluminal thrombus and fenestrations. In cases of severe peripheral vascular disease that precludes intra-aortic access through the femoral arteries, the endograft can be deployed antegradely through the ascending aorta by using specially designed side-branched grafts.

The early and midterm results of this hybrid procedure are encouraging, with low operative morbidity and mortality, including a low risk of stroke and spinal cord ischemic injury.[6,7] A recent extensive review of the literature, including 26 studies and 956 type I aortic arch debranching procedures published up to December 2012, revealed an 11.9% 30-day mortality, 7.6% cerebrovascular events, 3.6% irreversible spinal cord injury and 6% cardiac complications.[8] The long-term results and durability of stent-grafting, however, are still unknown. Stent-grafting requires frequent postoperative surveillance scans to promptly identify aneurysm expansion and late stent-related complications, such as endoleaks, graft migration or stent fractures.[9]

A comparison between open aortic arch surgery and hybrid repair is difficult to make, as the latter method is so far reserved for selected, high risk patients who are unsuitable for major open surgical intervention. Hybrid, preferably off-pump repair of complex aortic arch and DTA aneurysms may potentially extend the treatment indications to patients who are not candidates for conventional arch surgery. The risk involved in conventional open repair of the aortic arch and DTA can be prohibitive in frail, elderly patients with significant comorbidities. Milewski et al reported that patients aged over 75 years who underwent open arch repair had a significantly higher in-hospital mortality, up to 36%, when they were compared to younger patients (9%) or hybrid arch procedures (11%).[10] Although very good results have been published,[11] open aortic arch repair can still be challenging in many inexperienced centers.

In conclusion, hybrid one-stage endovascular and off-pump aortic arch debranching is an appealing evolving new technique for the treatment of high-risk patients with extensive aneurysms of the aortic arch and the DTA. Its continued use in this highly selected group of patients appears to be promising.

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