Endovascular Aortic Arch Repair After Aortic Arch De-branching

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Purpose. **Conventional surgical therapy of aortic arch aneurysms consists of aortic arch replacement requiring cardiopulmonary bypass and deep hypothermic circulatory arrest. This method is associated with significant morbidity and mortality, mainly due to neurologic complications and the sequelae of deep hypothermic circulatory arrest. Thus, it makes sense to work on developing less invasive surgical techniques.**

Description. **Surgical aortic arch de-branching is required before the supra-aortic vessels can be safely covered by an endovascular stent graft. We describe how the supra-aortic vessels can best be revascularized, followed by complete coverage of the aortic arch with endovascular stent grafts.**

Evaluation. **We hereby present our case selection criteria, preoperative work-up, and surgical approach for aortic arch de-branching with supra-aortic revascularization, followed by complete coverage of the aortic arch by endovascular stent grafting. This technique's safeguards and pitfalls are described for a cohort of 26 patients.**

Conclusions. **Endovascular aortic arch repair after aortic arch de-branching has the potential to lower the morbidity and mortality rates in patients with aortic arch diseases.**

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NEW TECHNOLOGY

Technology

Endovascular aortic arch repair (EVAAR) is less invasive compared with open surgical aortic arch repair in treating aortic arch disease; this correlates with low morbidity and mortality rates, even in high-risk patients [1]. Aortic arch pathologies, such as aneurysms or dissections, often involve the origin of the supra-aortic branches. In that case, it may be necessary to cover the origin of the supra-aortic vessels using endovascular stent grafts (ESGs) to extend the proximal landing zone. Without revascularization of the supra-aortic branches, a range of neurologic and vascular complications may ensue [2, 3]. Surgical aortic arch de-branching is therefore indicated before covering the brachiocephalic trunk (BT) and left common carotid artery (LCCA) by ESGs. As we demonstrated in a previous investigation, the left subclavian artery (LSA) does not need to be revascularized in the absence of supra-aortic pathology [4].

We now describe how the BT and LCCA can best be revascularized, followed by complete coverage of the aortic arch with ESGs.

Technique

Patients

We performed EVAAR after aortic arch de-branching in 26 patients. We chose the endovascular approach over conventional aortic arch replacement with cardiopulmonary bypass (CPB) and deep hypothermic circulatory arrest in selected patients considered at high-risk due to multiple comorbidities and advanced age (Fig 1). Aortic arch pathology consisted of an aneurysm in 15 cases, and 6 patients presented a previous aortic dissection with development of an aortic arch aneurysm. A penetrating ulcer in the aortic arch was the underlying pathology in five cases. The ethics committees approved the study and waived the need for patient consent.

Arch Vessel Revascularization

Surgery was initiated with an upper right, L-shaped, hemi-sternotomy to the third or fourth intercostal space. After exposing the ascending aorta, the supra-aortic vessels were dissected and the innominate vein was encircled. Then the ascending aorta was tangen-

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Fig 1. Preoperative computed tomographic angiography of a patient with aortic arch aneurysm.

tially clamped after systemic heparinization, and a longitudinal arteriotomy was performed. An end-to-side anastomosis between the proximal portion of a bifurcated polyester prosthesis (14 × 7 mm or 16 × 8 mm, Gelweave; Vascutek, Renfrewshire, Scotland) and the ascending aorta was done with a 4-0 Prolene running suture (Ethicon Inc, Somerville, NJ). The cross clamp was then released and the air was removed from the graft (Fig 2). If there was a shortage of room in which to sew the main body of the bifurcated graft to the ascending aorta, a 10-mm polyester graft could be fashioned to the ascending aorta, reducing the space required for the anastomosis. Subsequently, an end-to-side 8-mm polyester graft was sewn onto the 10-mm polyester graft for anastomosis to the LCCA (Fig 3). The supra-aortic vessels were then exposed. First the BT was clamped tangentially, followed by longitudinal arteriotomy, and one branch of the bifurcated graft (or T-graft) was anastomosed end-to-side to the BT. Then the LCCA was clamped tangentially, followed by longitudinal arteriotomy, and an end-to-side anastomosis was done to the LCCA with the other branch of the bifurcated graft (or T-graft) (Figs 2 and 3). Each anastomosis was followed by proximal ligature of the vessel to prevent a type II endoleak. If the exposure of the BT was adequate, we preferred an end-to-end anastomosis, but there was often too little space to permit one on the LCCA because of the arch aneurysm. In patients with large aneurysms, the exposure of the LCCA may have been so compromised that it was inadequate for expedient anastomoses. In such cases, we made an additional small incision in the left neck for the bypass to the LCCA.

Endovascular Aortic Arch Repair

We selected commercial ESG devices according to length, required diameter, and anatomical findings. The ESG diameter was calculated from the largest proximal or distal neck diameter and an over-sizing factor of 10% to 15%. The ESG devices were implanted in the operating room under general anesthesia. Intraoperative angiography was performed using a breath-hold technique and a mobile C-arm intensifier. The ESGs were advanced under fluoroscopic guidance and deployed during systemic hypotension (blood pressure, 20 to 40 mm Hg) and rapid cardiac pacing (frequency, 180-220/min). We used latex balloons in patients with aortic aneurysms (Reliant balloon; Medtronic, Minneapolis, MN) to improve expansion for modeling the ESGs to the aortic wall.

We preferred a one-stage approach, especially in cases with tight aortic arches, as it was often impossible to

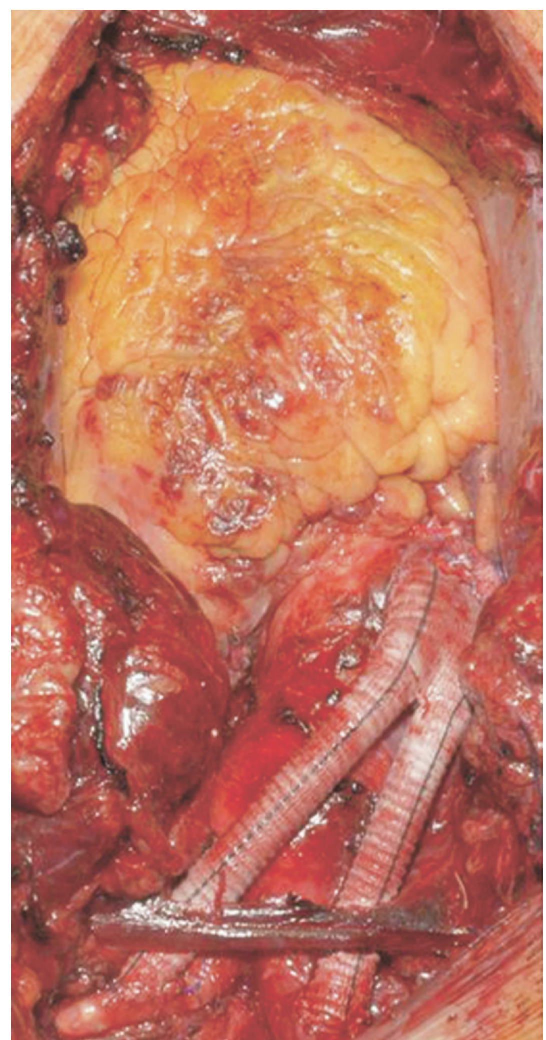

Fig 2. Aortic arch de-branching (bifurcated graft).

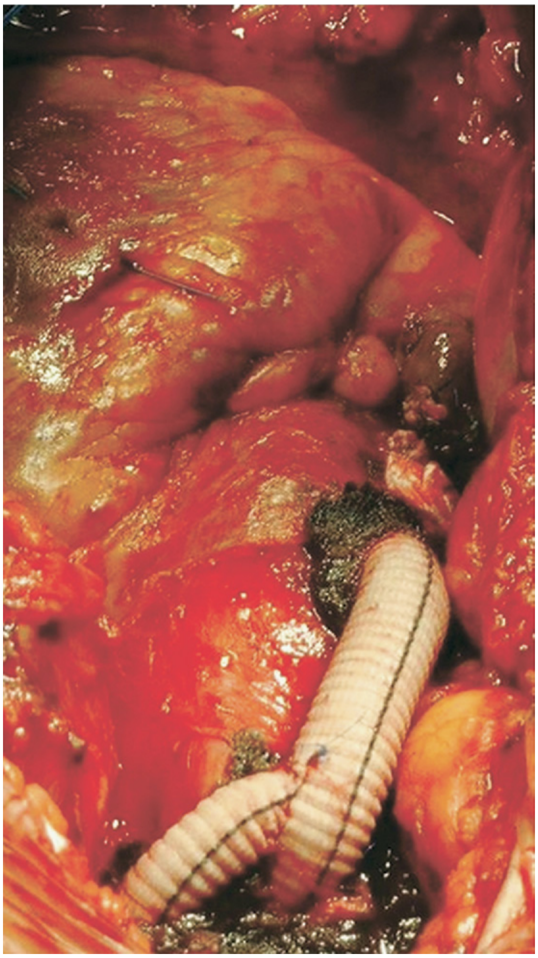

Fig 3. Aortic arch de-branching (T-graft).

bring the ESGs around tight aortic arches using femoral access, due to excessive resistance with the currently available ESGs. In such cases, antegrade ESG deployment (using a side limb sewn to the prosthesis) permitted the ESG navigation, even through very tight arches. If an antegrade approach was chosen to deploy the ESG, it was important that the ESG be advanced from the side arm of the ascending aortic graft into the ascending aorta without excessive mechanical force. If the ESG could not be easily advanced through the sternotomy incision, a small incision could be made in the right anterior chest. This would allow the ESG to be advanced with much less mechanical force.

With patients whose stent-landing zone were clearly distinguishable from external anatomic landmarks, and if the wire position in the correct lumen was transesophageal echocardiographically verifiable, we marked the planned ESG deployment site with radio-opaque thread markers in surgical 4 × 4 sponges. This enabled us to significantly reduce the need for angiographic contrast media use. The ESG could be deployed exactly at the planned site without pre-deployment angiography. Surgical clips are much less visible on fluoroscopy and are less suitable as external markers.

Clinical Experience

We carried out EVAAR after aortic arch de-branching in 26 patients (Fig 4). Four patients died due to perioperative cardiovascular adverse events. No patient suffered from stroke or paraplegia. One patient who presented with a heavily-calcified ascending aorta underwent total arch re-routing due to multiple penetrating atherosclerotic ulcers; he experienced a temporary neurologic event most likely due to embolization during tangential clamping of the ascending aorta, which had resolved by the time he was discharged. We observed two minor adverse events: one patient with a separate aortic arch branch of the left vertebral artery suffered from type II endoleak and the other patient had a sternum infection.

Comment

Experience with surgical bypass grafting in conjunction with EVAAR is limited. Reasons for this are the novelty of the combined endovascular and open surgical approach, and the paucity of patients with aortic arch disease who are potential candidates for this procedure. The endovascular method requires suitable "landing zones" (2 cm of normal aortic wall) for ESG fixation [5]. In aortic pathologies (including the aortic arch), surgical bypass grafting prior to EVAAR is necessary to prevent ischemic events. Such events can lead to neurologic complications, occlu-

Fig 4. Postoperative computed tomographic angiography after aortic arch de-branching and endovascular aortic arch repair.

sive ischemia, or embolisms, and they occur centrally, such as in the brainstem or spinal cord, and peripherally (ie, arm ischemia) [4].

We propose an ascending aortic bi-carotid bypass using an inversed bifurcated prosthesis or an 8-mm and 10-mm T-graft for revascularizing the BT and LCCA in aortic arch pathologies involving the origin of these vessels. This method offers several advantages over conventional procedures (ie, avoidance of CPB and deep hypothermic circulatory arrest), even though its long-term durability remains unproven. We and others have demonstrated that additional transposition of the LSA or LSA to LCCA bypass before coverage of the LSA origin by an ESG is not necessary in all patients with normal supra-aortic vessels [3, 4, 6], nor is it necessary to bypass or transpose the LSA in patients with occlusive LSA disease, as they usually present collateral vessel development due to slow disease progression [7]. However, some patients do require additional transposition or bypass of the LSA to the LCCA (ie, those having undergone coronary artery bypass grafting with patent left internal mammary arteries, and those presenting with carotid or vertebral artery stenoses or anatomical variants of the subclavian, vertebral, or basilar arteries, or the circle of Willis [1, 8]). Another indication for transposing the LSA or for LCCA to LSA bypass surgery with proximal ligation is to prevent type II endoleaks with retrograde perfusion of the aneurysm sac or the false lumen in dissections [2]. In our previous investigation, we covered the LSA with ESGs without ligating the LSA, observing no type II endoleaks from the LSA during follow-up [4].

Byrne and colleagues [9] analyzed 143 extra-anatomical procedures for carotid and subclavian reconstruction. Indications for surgery were primarily occlusive or embolic disease. Most bypass grafts were made from polytetrafluoroethylene, and the 5-year patency rate was 92%. This study suggests that artificial bypass grafts can reveal excellent patency rates [9]. We used polyester prostheses in our series.

Technical Pitfalls and Safeguards

One of the main dangers associated with this procedure is the construction of the end-to-side ascending aortic anastomosis. In our method, we clamp the ascending aorta tangentially without using CPB, thus avoiding aortic cross clamping. Some authors see the need for CPB before they tangentially clamp the ascending aorta (ie, in patients with proximal ascending aortic aneurysms whose landing zone extends almost to the level of the sinotubular junction) [10].

It is extremely important that a large, atraumatic side-biting clamp be used for the ascending aorta, and that the blood pressure be lowered significantly so as to minimize the significant risk of ascending aortic dissection. After aortotomy, we prefer to sew the proximal side-to-end anastomosis on the ascending aorta first, before sewing the distal anastomosis on the supra-aortic vessels.

Undue forces on the ascending aortic anastomosis during antegrade ESG advancement constitute a real danger and can lead to disruption of the ascending anastomosis. If there is any doubt, a small incision in the right chest should be made to prevent the build-up of undue forces. Should significant bleeding from this anastomosis occur after ESG deployment, one must keep in mind that it has to be fixed without re-clamping the ascending aorta, since the ESG can not be clamped safely with a tangential clamp.

A single-stage approach allows for better arch access, and unorthodox solutions, such as control of the wire on both sides (ie, tooth-floss technique), which should advance the ESG across the aortic arch. A radio-opaque marker (such as the marker threads in surgical 4×4 sponges) can reduce the amount of contrast media used for such cases, potentially preventing potential renal complications.

For proper ESG placement, we recommend the use of rapid cardiac pacing and systemic hypotension. Under such optimum conditions, the expansion and placement of the ESGs can be controlled and precise. Adenosine before ESG placement has not yielded reproducible results in our hands, as there is great variation in the required dose and the interval to heart block.

In conclusion, we have presented a method for surgical de-branching of the aortic arch before completely covering it with ESGs, which is a procedure that can be carried out safely while avoiding significant pitfalls. This method makes both CPB and deep hypothermic circulatory arrest unnecessary, thereby having the potential to lower morbidity and mortality rates.

Disclosures and Freedom of Investigation

The authors have no commercial association or sources of support that may pose a conflict of interest. In addition, the authors had full control of the study, methods used, outcome measurements, data analysis, and production of the written report.

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Disclaimer

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INVITED COMMENTARY

One of the last surgical domains yet to be addressed in a less invasive fashion is repair of the aortic arch. This is significant because surgical repair of aortic arch disease involves cardiopulmonary bypass and hypothermic circulatory arrest. Although surgical outcomes for aortic arch replacement have improved consistently, many patients are not surgical candidates secondary to multiple medical comorbidities that frequently accompany aortic arch disease. Therefore newer surgical alternatives that incorporate emerging endovascular techniques have the potential to transform the way we address the aortic arch.

In this study, Weigang and colleagues [1] describe their innovative approach to hybrid arch repair using surgical debranching of the great vessels, followed by endovascular repair. This is not the first report of this technique; however, their report contains important technical details that better elucidate critical aspects of their procedure, such as placing a radiopaque marker at the proximal anastomosis in the ascending aorta, which can better ensure success and should be widely adopted. Because the current generation of aortic stent grafts do not have side branches to accommodate perfusion to the great vessels, surgical bypasses of the great vessels must be performed before endovascular repair of the aortic arch. This technique avoids many of the complications associated with surgical repair, although long-term durability is unknown.

In their series of 26 patients, the authors concluded that the hybrid technique has lower morbidity and mortality rates compared with standard surgical repair of aortic arch disease. Of note, their patient cohort consisted of 15 patients with arch aneurysms and 6 patients with a history of a chronic dissection and subsequent aneurysm formation of the false lumen. This is an important point, because these patients generally have a higher atherosclerotic disease burden that can translate into a higher stroke rate using surgical repair. The hybrid technique minimizes this because the great vessels are directly bypassed and ligated at their origin, which would essentially eliminate the chance for embolic stroke during endovascular repair of the arch.

The hybrid technique certainly has a role in patients with anatomy that is favorable to endovascular repair; however, little is known about its long-term success. Of concern would be progressive dilation of the proximal or distal seal zones of the stent graft and whether progressive expansion of the aorta might lead to lack of apposition and subsequent perfusion of the excluded aneurysm sac. This is purely speculation, but additional studies are needed. Nevertheless, this article helps bring to the forefront a new and innovative approach to the aortic arch that offers the potential of treating arch disease in a safer manner and possibly allowing "nonsurgical" candidates to undergo aortic arch repair in a less invasive fashion.

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NEW TECHNOLOGY

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