Hybrid Thoracic Aneurysm Repair

Combination surgical and EVAR approaches for treating arch and descending thoracic aneurysms.

BY ROY K. GREENBERG, MD, AND LARS SVENSSON, MD, PHD

Aortic aneurysms that affect both the arch and more distal aorta continue to represent extremely challenging cases. The conventional two-staged surgical approach initially requires a median sternotomy with hypothermic circulatory arrest and placement of an elephant trunk graft (ETG). The second stage of the procedure is conducted through a left thoracoabdominal approach whereby the previously placed ETG is extended into the healthy distal aorta. The morbidity and mortality risks associated with the two-stage approach remain substantial and have been previously reported;[1-3] however, the majority of the risks relate to the extensiveness of the second-stage operation.[4]

We, like others,[5] have explored the use of a hybrid approach to such aneurysms in anatomically amenable patients, whereby an ETG is surgically placed, and the aneurysm exclusion is completed using thoracic aortic endovascular repair. Such an approach obviates the need for an open surgical approach to the thoracoabdominal aorta and thus diminishes the potential for complications, yet it is associated with uncharted long-term results. The feasibility of this strategy and intermediate-term follow-up of these patients was the subject of our recent article[6] and remains the subject of continued investigations.

TECHNIQUES

Approximately 400 patients have undergone endovascular repair of thoracic aortic aneurysms at our institution; 31 of these patients were treated with a hybrid

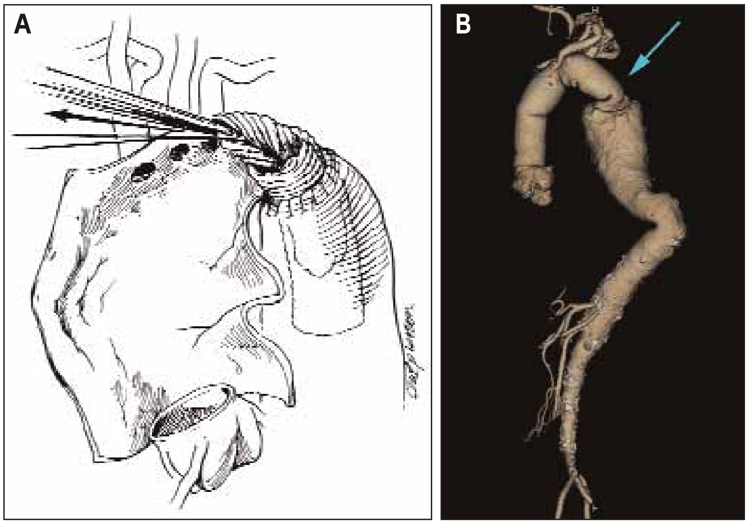

Figure 1. ETGs are constructed through an open arch procedure performed under hypothermic circulatory arrest. An inverted graft is placed in the descending aorta for the distal anastomosis. The inner tube is then withdrawn into the more proximal arch for the attachment of the brachiocephalic vessels and proximal anastomosis (A). Additional procedures are performed during rewarming, such as aortic valve repair and coronary revascularization. The ETG is left dangling within the proximal descending thoracic aorta. After recovery, the ETG is visualized with CT scanning (B) to help with device sizing and procedure planning. Note the appearance of the ETG within the descending thoracic aorta (B, blue arrow).

approach to address aneurysms of the proximal descending thoracic aorta or distal aortic arch using ETG placement followed by endovascular completion procedures. High-resolution CT imaging studies were performed preoperatively to determine acceptable anatomy (adequate distal fixation sites) and periodically during the follow-up period (predischarge and at 1, 6, and 12 months, and yearly thereafter). Imaging studies were analyzed with three-dimensional techniques (Leonardo, Siemens Medical, Erlangen, Germany, or Aquarius Workstation, TeraRecon, San Mateo, CA).

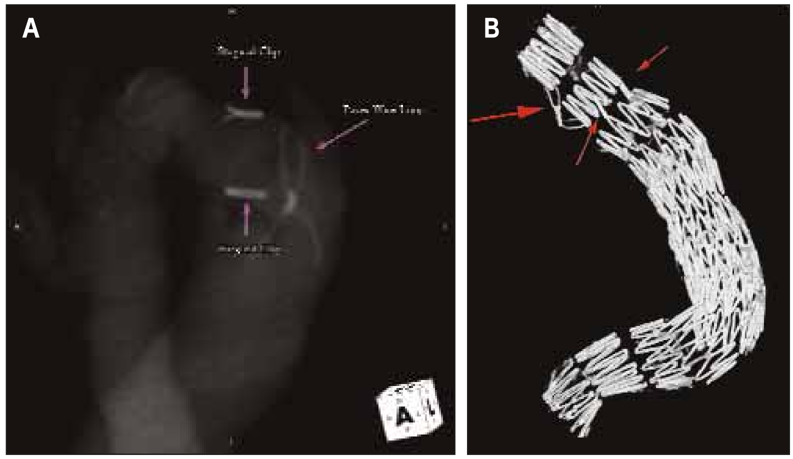

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Figure 2. Markers at the end of the ETG (clips and wire loop) are depicted (A). The completed procedure (B). The degree of overlap of the endovascular graft into the ETG can be calculated by the distance proximal to the two hemaclips (small red arrows). Note the pacer wire loop on the external surface of the ETG (large red arrow).

Description of Surgical Repair Techniques

Elephant trunk and arch repair procedures performed at our institution utilizing the techniques described in our previous publications (Figure 1).[4,7,8] Currently, all first-stage procedures involve the implantation of a modified ETG (Figure 2), which is intended to facilitate endovascular completion of the repair. Two hemaclips, 120º apart, are attached to the distal aspect of the graft material, and a pacer wire is looped and attached approximately 2 cm above the distal end, to the nonluminal component of the ETG (Figure 1). The hemaclips serve as radiographically detectable markers indicating the terminal end of the ETG, while the pacer wire allows downward traction on the implanted graft, should it prove necessary during the insertion of an endovascular delivery system. Downward traction is accomplished, when necessary, by cannulating the pacer wire with a reverse curved catheter and passing a wire through the catheter and back out to a femoral access point. Rarely, a reverse ETG procedure must be performed. This technique involves the placement of a stent graft prior to the surgical arch exposure. Rather than placing a surgical graft into the descending thoracic aorta, the proximal aspect of the stent graft is fashioned to serve as the distal anastomosis for an open arch repair.

Inadequacy of the distal landing site was noted in a small number of patients in whom conventional ETG completion was not deemed feasible and required further surgical measures to be accomplished prior to the placement of an endovascular device. This included either the use of a mesenteric bypass procedure (Figure 3) or wrapping of the distal thoracic aorta. Mesenteric bypass procedures, when necessary, were performed subsequent to the first-stage ETG placement, in an effort to facilitate the second-stage completion with an endovascular graft. Circumferential distal aortic wraps were performed at the time of first-stage ETG placement (via a posterior pericardial approach or upper abdominal minilapararotomy).

Description of Endovascular Repair Techniques

Proximal ETG diameters, distal aortic diameters, and length measurements were then obtained using cross-sectional imaging studies with appropriate reconstructions. Diameter discrepancies between the proximal and distal landing zones were commonly noted, given the fixed size of the elephant trunk or arch repair (generally, a 24-mm to 26-mm graft dilated to 26-28 mm) in contrast to the distal aortic diameters (range, 20-40 mm). These observations resulted in the frequent use of tapered devices.

After anticoagulation, devices were delivered through a femoral access site or, when necessary, introduced through an iliac conduit. Right brachial access was obtained early on in the procedure, providing a means to direct guidewires and catheters directly through the proximal anastomosis of the ETG into the desired iliofemoral vessels. Through-and-through access, when established in this manner, helped to direct delivery systems through the tortuosity of the arch, ETG, and more distal aorta. Endovascular devices were inserted over this through-and-through wire to achieve a minimum of 5 cm to 7 cm of overlap with the ETG. Selective use of induced hypotension or asystole was employed when homemade, TAG (Gore & Associates, Flagstaff, AZ), or

Talent (Medtronic, Santa Rosa, CA) devices were deployed, but not with the Zenith (Cook Incorporated, Bloomington, IN) device. In cases in which the entire aorta was involved, the distal aspect of the tubular thoracic repair was either combined with a bifurcated component, allowing extension into each of the iliac arteries, or a tapered device was used and brought into one of the iliac arteries followed by a femoral-femoral graft with occlusion of the contralateral iliac vessel using an endovascular plug.

Required Adjunctive Procedures

A number of strategies were employed to address the subclavian artery, which included placement of the proximal anastomosis of the ETG between the left carotid and left subclavian arteries, followed by subclavian artery ligation (surgical or endovascular) or carotid-subclavian bypass. The choice of technique was influenced by the degree of aneurysmal involvement of the subclavian artery, the presence of coronary flow derived from internal mammary grafts, or the status of the verterbral arteries with regard to cerebral posterior circulation. Subclavian artery coverage was required in approximately 40% of patients. In each of those cases, the ETG was placed proximal to the left subclavian artery using a technique previously described.[7] Extra-anatomic reconstruction (carotid subclavian bypass) was performed in half of the patients after subclavian coverage prior to endovascular completion procedures. A single patient underwent a carotid subclavian bypass after endograft implantation as a result of a retrograde leakage through the subclavian artery and arm claudication. Three patients required mesenteric bypass procedures prior to the second-stage ETG. Iliac conduits were necessary in four patients (18%, all female) to assist with the introduction of endovascular devices.

RESULTS

No intraprocedural mortalities occurred. The overall Kaplan-Meier 1-month and 12-month mortality rates were 4.5% and 15.8%, whereas aneurysm-related mortality was 4.5%, 11.3%, and 11.3% at 1, 12, and 24 months, respectively.[6] Technical success was ultimately achieved in all patients. However, complex anatomy that required modification of the initial endovascular plan was necessary in two cases. In each of these cases, an inability to advance the intended endovascular graft (one homemade device and one Zenith device) into the ETG was unsuccessful. These challenges were resolved by inserting a TAG device to accommodate the proximal tortuosity, which, in one case, was coupled with a Zenith device to address the required proximal-to-distal aortic diameter disparity. Endoleaks were initially noted in approximately 30% of the patients.

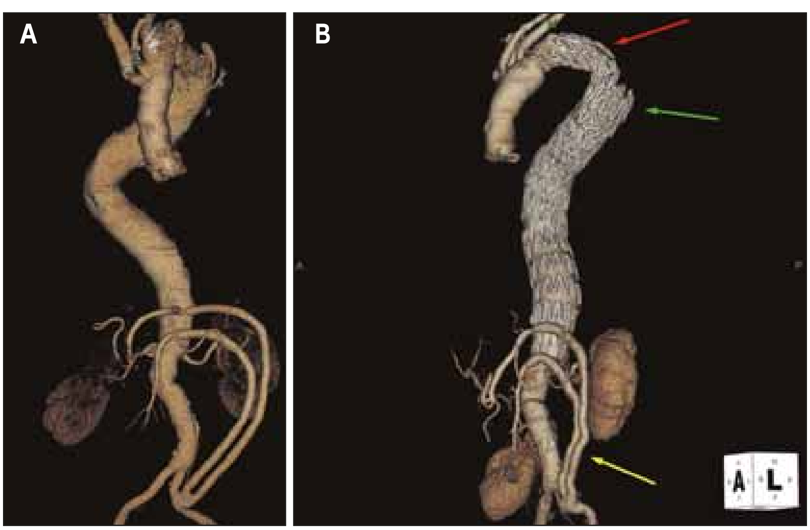

Figure 3. Figure 3A demonstrates a complex, tortuous type II thoracoabdominal aneurysm with arch involvement in a patient with Ehlers-Danlos syndrome. The distal arch was repaired with an open surgical approach, with placement of an ETG. Subsequently, a mesenteric bypass to the celiac and superior mesenteric arteries was constructed (B, yellow arrow). After this, the aortic repair was completed with the placement of a series of stent grafts within the ETG (TAG, [B, red arrow]) with extension into the suprarenal aorta with additional prostheses (Zenith TX2, [B, green arrow]).

Type II endoleaks (from retrograde subclavian flow, patent inferior mesenteric arteries after mesenteric extra-anatomic revascularization, and intercostal arteries) were the most common, but one type III leak (from a modular joint) and a single leak of unknown etiology were identified. Secondary interventions were performed (extension grafts) to treat the type III leak and retrograde flow from all but the intercostal arteries. Distal migration of the proximal fixation system (23 mm) was noted in one patient implanted with a TAG device, whereas cranial migration (7 mm) of the distal fixation system was detected immediately after a reverse elephant trunk procedure and was attributed to traction during the procedure.

Aneurysm growth was noted in two patients (9%) at 12 months. One patient had sac growth that was attributed to the porosity of an ePTFE graft (TAG prosthesis) also in the set-

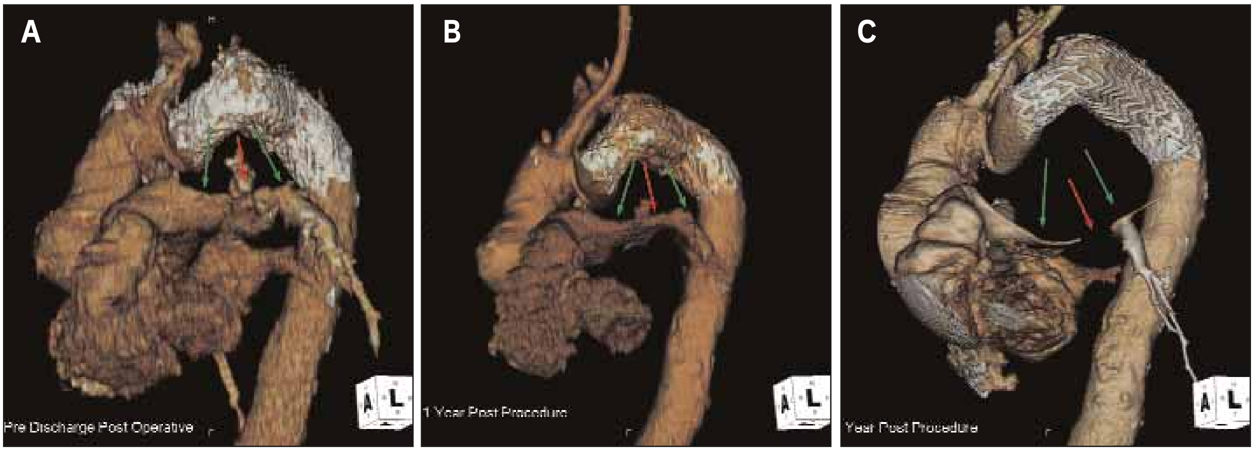

Figure 4. Complications after endovascular completion of ETGs may differ from those seen after conventional ETG completion. The single case of aneurysm sac enlargement is depicted here. The aorta and ETG were quite tortuous as evidenced by the unsubtracted image of the deployed TAG device (A). The predischarge film with mild compression of the left pulmonary artery (green arrows) by the thrombus-filled aneurysm. This defect becomes progressively more severe at 1 year (B), and by 3 years (C), the pulmonary artery is essentially occluded (red arrows).

ting of observed proximal migration (Figure 4). The patient had refused additional treatment despite the near occlusion of his left pulmonary artery. A second patient had growth noted on follow-up CT studies and was diagnosed with a type III (modular joint) leak and treated with an extension graft, which resolved the leak and arrested the growth. Three patients experienced transient postoperative neurologic events attributed to spinal cord perfusion. All but one of these patients recovered and were ambulatory before hospital discharge. The single patient with a more significant deficit ultimately recovered, but required prolonged rehabilitation prior to returning home. Interestingly, each of the patients who exhibited transient neurologic defects had adjunctive mesenteric bypass procedures (two patients) or previous abdominal aortic aneurysm repair (one patient). There were no strokes in this series.

DISCUSSION

Despite consistent improvement in perioperative strategies used for open two-stage procedures to address arch and proximal descending thoracic aortic aneurysms, there is still substantial morbidity and mortality associated with this approach.[1,3,4,8] A mortality of 5.1% for the first stage, 3.6% during the interval period (of which 75% were due to rupture), and 6.2% for the second-stage operation was reported by Safi et al,[3] and was recently updated[1] and confirmed by others.[9] In our own series of 142 ETGs, the first-stage operative mortality was 2%, and of those patients who underwent the distal repair, a 4% mortality rate was noted.[4] Endovascular completion of ETGs avoids a left lateral thoracotomy and associated complications, particularly the risk of respiratory issues in patients with pulmonary disease. Mortality surrounding the endovascular or open procedures was low and, coupled with a similarly low risk of stroke, makes this strategy more palatable than previously employed staged open repairs in anatomically suitable patients. However, the risk of spinal cord ischemia, particularly in the setting of extensive aortic disease, must be recognized given the inability to reimplant intercostal and lumbar vessels.

Significant procedural evolution occurred during this series. Modifications to the proximal implant included the use of hemaclips, and a pacer wire loop also proved useful during the endovascular procedure, as well as for visualization of the terminal end of the ETG on follow-up imaging studies (Figure 1).[4] Initiating the procedure from the right brachial artery eliminated the potentially challenging retrograde elephant trunk cannulation and provided a means to achieve wire access into the desired femoral or iliac vessel, if necessary. The delivery system was then advanced over the through-and-through wire until the tip abutted the innominate artery, where a 5-F sheath had been placed via the right brachial artery. At this point, rather than advancing a large stiff delivery system into the innominate artery, the through-and-through wire was advanced from both the femoral and brachial positions, forcing it to form a loop within the ascending aorta. The delivery system was then advanced into the ascending aorta to allow for the desired overlap of within the ETG. The importance of flexibility, fixation, and sealing are magnified when dealing with such complex anatomy. The TAG device was the most deliverable and resulted in successful deployments where other grafts failed. However, the absence of an active fixation system (TAG) may be associated with a higher incidence of migration (the only case of distal migration in this series). After this observation, the use of barbs to affix the stent graft within the ETG was used preferentially. An additional factor specific to endovascular device design included the construct of significant tapers to accommodate patients with disparate proximal and distal diameters (Figure 5). Modifications of current devices are underway that should ameliorate the challenges faced during the development of this approach. However, complex anatomy, particularly chronic dissections, remain challenging to treat with endovascular grafts.

New complications associated with this hybrid approach were noted in a few patients and included thrombus formation (6 months after the second-stage completion procedure) within the proximal ETG anastomosis in the setting of marked hypotension. This ultimately resulted in the patient's death. An endoleak was noted to arise from the suture line of another proximal ETG anastomosis that spontaneously resolved without treatment. Of note, persistent growth of the aneurysm sac in close proximity to the lower-pressure pulmonary vasculature and esophagus is undesirable and underscores the close-knit architecture of the thoracic vascular structures. This emphasizes the need for careful radiographic follow-up after such procedures.

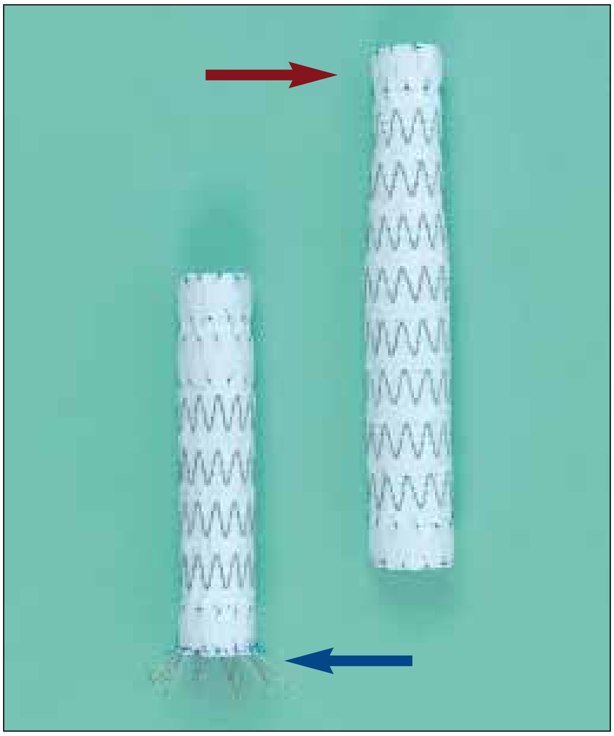

Figure 5. A two-piece modular design was most commonly used to complete the ETG in this series. A reverse taper was typically necessary with a narrow proximal component (red arrow), such that the device was not extensively oversized to the ETG, while a more dilated distal component (blue arrow) was used to mate this to the larger diameter distal aorta.

CONCLUSION

Significant improvements have been made to the hybrid approach for complex proximal aortic aneurysm repair. The elimination of a thoracotomy, aortic cross-clamp, and extensive exposure will likely render better results and allow a therapeutic option to patients who have historically been relegated to medical management. Adequate endovascular device fixation, prosthesis, and delivery system flexibility and durable aneurysm exclusion remain the hallmarks of an acceptable repair, and will require additional longer-term study. Our early experiences have demonstrated the safety and intermediate-term effectiveness of a hybrid endovascular-open surgical approach. Newer devices with improved delivery systems will further facilitate repair of these complex aneurysms. ■

Roy K. Greenberg, MD, is Director of Endovascular Research, The Center for Aortic Surgery, Departments of Vascular and Cardiothoracic Surgery, The Cleveland Clinic Foundation, Cleveland, Ohio. He has disclosed that he is a paid consultant to and receives royalties from Cook Incorporated. He receives research funding from Sulzer-Vascutek, Gore & Associates, and Cook. Dr. Greenberg may be reached at (216) 445-5306; greenbr@ccf.org.

Lars Svensson, MD, PhD, is from the Department of Cardiothoracic Surgery, at The Cleveland Clinic Foundation, Cleveland, Ohio. He has disclosed that he is a paid consultant to Cook Incorporated. Dr. Svensson may be reached at (216) 445-4813; svenssl@ccf.org.

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