Endovascular Repair of the Ascending Aorta: When and How to Implement the Current Technology

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Background. The purpose of our study was to examine when and how to implement the current endoluminal stent graft technology to treat ascending aortic disease.

Methods. During a 7-year period (March 2006 through July 2013), 7 consecutive patients (median age, 69 years; range, 61.5 to 80.5 years) with multiple comorbidities underwent endoluminal repair of the ascending aorta. Six had an ascending aortic pseudoaneurysm, and 1 had iatrogenic coarctation. The median number of prior sternotomies was 2 (range, 1 to 4).

Results. Technical success was achieved in all but 1 patient, with 1 death (14.3%) at 30 days. The endoluminal technology used included the Gore TAG (W.L. Gore and Associates, Flagstaff, AZ) thoracic graft (including the new C-TAG) in 6 patients, the Talent stent graft (Medtronic, Santa Rosa, CA) in 1, an Excluder cuff (W.L. Gore) in 2, and an Amplatzer occluder (AGA Medical Corp, Plymouth, MN) in 1. More than 1 stent was placed in 4 patients. Three patients required innominate artery stenting, and 1 required additional left common carotid artery stenting. One patient (14.3%) required intraoperative conversion to open surgical repair. Median follow-up was 14.4 months (interquartile [25th to 75th percentile] range, 5.5 to 22.6 months) with 66.6% overall survival. No aortic-related death was reported during the follow-up period.

Conclusions. Stent grafting of the ascending aorta is feasible but limited and is reserved for high-risk individuals. Technical expertise is essential, and follow-up is mandatory. Technical points, tips, and challenges of the current endovascular technology to effectively treat the ascending aorta are described.

Lesions of the ascending aorta can be challenging to treat because of their complexity and the considerable risk of an open surgical repair, especially if the patient has undergone previous repairs of the aortic root, ascending aorta, or proximal arch. Reoperative aortic operations entail a hospital mortality rate of 4.1% to 15.4% [1–4]. Endovascular surgery is a maturing technology that can facilitate treatment of complex aortic lesions but is used mainly for disease of the descending thoracic aorta. Endografts designed to treat ascending aortic disease are not currently available. Because of anatomic considerations, the lack of specifically designed devices, and off-label use, this technology is infrequently applied to the ascending aorta.

Patients and Methods

Institutional Review Board approval was obtained for this study. From March 2006 to July 2013, 7 consecutive patients, who were a median age of 69 years (interquartile [25th to 75th percentile] range, 61.5 to 80.5 years), were treated with endoluminal technology for their ascending aortic lesions. An ascending pseudoaneurysm was the primary ascending aortic condition in 6 patients. The pseudoaneurysm was located in the midascending aorta in 4 patients and in the distal aorta approximately 2 cm from the innominate artery in 2 patients. Iatrogenic coarctation was present in 1 patient, who had previously been treated for acute type I aortic dissection by wrapping of the ascending aorta 2 months before the endoluminal treatment. All patients had undergone prior sternotomies (median, 2; range, 1 to 4). Patient characteristics are outlined in Table 1. Social Security Death Index and telephone calls were used for follow up.

Preoperative Evaluation

Preoperative computed tomography angiography (CTA) of the chest, abdomen, and pelvis was performed in 6 patients to evaluate the ascending aortic disease and iliac and femoral arterial access. One patient underwent magnetic resonance imaging and magnetic resonance angiography with gadolinium chelate. Preoperative heart catheterization was used in 3 patients to evaluate coronary saphenous vein and left internal mammary grafts.

Dr Coselli discloses financial relationships with Gore, Medtronic, Cook, and Terumo.
Stent Grafts

The Gore Thoracic TAG endoluminal stent graft (10 cm long; W. L. Gore and Associates, Flagstaff, AZ) was used in 5 patients, 1 of whom had the newer C-TAG version of the endograft. Two patients required Gore Excluder (W. L. Gore & Associates) abdominal cuffs: 2 cuffs (28.5 × 3.3 cm) in 1 patient (Fig 1) and 2 cuffs (32 × 4.5 cm) in another patient. One patient required a self-expanding Talent stent graft (Medtronic, Santa Rosa, CA) and then an additional Gore TAG endograft to seal an intraoperative endoleak (Fig 2).

An Amplatzer cribriform septal occluder (AGA Medical Corporation, Plymouth, MN) was used in 1 patient. Continuous endoleak after placement of the occluder necessitated exclusion with an additional Gore TAG endoprosthesis. This patient required placement of a Gore Via-bahn 5 × 11 mm covered stent (W. L. Gore & Associates) in the innominate artery to treat a tracheoinnominate fistula.

Table 1. Patient Characteristics^a

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Sex</th>
<th>Prior Operations</th>
<th>Prior Sternotomies</th>
<th>Comorbidities</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>M</td>
<td>Pulmonary banding arterial switch procedure Closure of a ventriculoseptal defect Aortic valve-sparing root replacement Aortic valve replacement with a 21-mm St. Jude Medical mechanical prosthesis (St Paul, MN)</td>
<td>4</td>
<td>Multiple previous sternotomies</td>
</tr>
<tr>
<td>59</td>
<td>M</td>
<td>Type I aortic dissection repair CABG × 3 with LIMA Pericardial stripping</td>
<td>3</td>
<td>CHF In hospital intracranial bleed before the endovascular intervention Sepsis on current admission due to retained foreign body, which was removed by left thoracotomy Tracheoinnominate fistula</td>
</tr>
<tr>
<td>84</td>
<td>M</td>
<td>Aortic valve replacement Sternal wound dehiscence, muscular flaps</td>
<td>2</td>
<td>CHF Prior PE Hemorrhagic CVA Sick sinus syndrome Pacemaker placement Severe PVD History of sternal wound dehiscence with methicillin-resistant Staphylococcus aureus infection</td>
</tr>
<tr>
<td>69</td>
<td>F</td>
<td>Ascending aortic and proximal arch replacement Aortic valve commissuroplasty</td>
<td>1</td>
<td>CVA Atrial fibrillation Recent right upper lobectomy for lung adenocarcinoma History of renal failure after prior cardiac operation</td>
</tr>
<tr>
<td>79</td>
<td>M</td>
<td>CABG (patent LIMA)</td>
<td>1</td>
<td>Very frail on presentation CHF DM type 2 Hypertension Prostate CA treated with radiation therapy Radiation proctitis History of lower gastrointestinal bleed after CABG History of right cerebellar infarct after CABG</td>
</tr>
<tr>
<td>82</td>
<td>F</td>
<td>Repair of acute type II aortic dissection CABG × 1 LIMA to LAD</td>
<td>2</td>
<td>CHF Hypertension Angina Moderate aortic insufficiency Moderate mitral regurgitation AICD placement</td>
</tr>
<tr>
<td>64</td>
<td>M</td>
<td>Repair of acute type I aortic dissection with primary end-to-end reanastomosis with circumferential sandwich reinforcement of both ends of the aorta with Teflon (DuPont, Wilmington, DE) strips Pericardial tamponade Sternal wound dehiscence</td>
<td>3</td>
<td>PVD Hemolytic anemia requiring multiple transfusions Hypertension</td>
</tr>
</tbody>
</table>

^a All patients had an ascending pseudoaneurysm unless otherwise indicated. ^b Patient had ascending iatrogenic coarctation. ^c Patient presented to our institution 4 months after the initial sternotomy. ^d Patient wanted the endovascular procedure despite the absence of severe comorbid factors.

AICD = automatic internal cardiac defibrillator; CA = carcinoma; CHF = congestive heart failure; DM = diabetes mellitus; internal mammary artery; M = male; PE = pulmonary embolism; LIMA = left internal mammary artery; LAD = left anterior descending artery; LIMA = left internal mammary artery; PVD = peripheral vascular disease.

**Stent Grafts**

The Gore Thoracic TAG endoluminal stent graft (10 cm long; W. L. Gore and Associates, Flagstaff, AZ) was used in 5 patients, 1 of whom had the newer C-TAG version of the endograft. Two patients required Gore Excluder (W. L. Gore & Associates) abdominal cuffs: 2 cuffs (28.5 × 3.3 cm) in 1 patient (Fig 1) and 2 cuffs (32 × 4.5 cm) in another patient. One patient required a self-expanding Talent stent graft (Medtronic, Santa Rosa, CA) and then an additional Gore TAG endograft to seal an intraoperative endoleak (Fig 2).
In 2 patients, a 10- × 25-mm bare-metal, balloon-expandable Express Stent (Boston Scientific, Quincy, MA) and a Genesis 10- × 59-mm balloon-expandable stent (Cordis Corporation, Bridgewater, NJ) were used, respectively, for the innominate artery; 1 of these patients also required a Genesis 10- × 59-mm balloon-expandable stent across the origin of the left common carotid artery (Table 2). The innominate and left common carotid artery stents for this patient were used as “snorkels” because the ascending aorta was shorter than the available 10-cm-long endovascular graft. In the second patient, the innominate stent was used because the initially placed endograft partially covered the origin of the innominate artery as the result of “windsock effect.”

Mode of Delivery and Intraoperative Technique
All procedures were performed in a hybrid operating room. To deliver the stent grafts, the femoral artery was exposed and used as the access vessel in 5 patients; 1 patient required retroperitoneal exposure of the iliac artery, and the left axillary artery was accessed through an intraclavicular incision in 1 patient. Injection of 5,000 units of heparin was administered after insertion of the appropriate sheath (5F or 9F) in the exposed vessel.

In all 7 patients, intraprocedural angiography was used before stent deployment to evaluate the proximal aortic pathology and the length of the ascending aorta and to identify the ascending aorta condition and its anatomic relationship to the head vessels. Intravascular ultrasonography was also used in 3 patients to further clarify the ascending disease (ie, the size of opening of the ascending aortic pseudoaneurysm) and for precise measurements of the distance of the treated area from the coronary ostia and the head vessels. When it appeared that the stent graft might partially obstruct the head vessels, a soft 0.35-inch Glidewire (Terumo Medical Corporation, Tokyo, Japan) was used to cannulate the innominate or the carotid artery, or both, before endograft delivery.

Systolic blood pressure was kept at 80 to 90 mm Hg before endograft deployment, and adenosine was administered to 2 patients to briefly arrest the heart for more precise placement. Balloon dilatation of the ascending endograft was performed only in 2 cases in which the “snorkeling technique” was used.

Results
The 30-day mortality rate was 14.3% (1 of 7). In the patient who died, exclusion of the ascending pseudoaneurysm was successful, but postoperative repair of a right brachial pseudoaneurysm was required. During recovery, respiratory distress and ventricular fibrillation developed, requiring intubation and cardiopulmonary resuscitation, which was unsuccessful. The patient died on postoperative...
day 14. The survival rate during the follow-up period (median, 14.4 months; interquartile [25th to 75th percentile] range, 5.5 to 22.6 months) was 66.6%. No aorta-related death was reported.

Technical success with endovascular exclusion of the ascending pseudoaneurysm was achieved in 6 of the 7 patients. Open conversion was required in 1 patient (14.3%) who had undergone a prior open repair of a type I aortic dissection with primary end-to-end reanastomosis by circumferential sandwich reinforcement of either end with Teflon strips (DuPont, Wilmington, DE), thus creating iatrogenic coarctation with a 34 mm Hg gradient and severe hemolytic anemia. The latter had necessitated multiple transfusions (Fig 3). In this patient, 2 abdominal Gore Excluder cuffs (32 × 4.5 cm) were used. The aorta was 31 × 7 cm, and the length of the coarctation that needed to be covered was 1.5 to 2 cm. A windsock effect made the first cuff jump backwards upon deployment, necessitating a second cuff insertion. Even though we accurately deployed the second cuff, which significantly relieved the coarctation, we proceeded with open conversion because of the misplacement of the first cuff into the proximal arch. Removal of the stent grafts, hypothermic arrest with antegrade cerebral perfusion, and ascending and proximal arch replacement were performed. Only after the aorta was completely excised did we confirm that the approach would fail because of the circumferential felt strip. During the initial attempt, we were uncertain of the full extent of the prior operation because the preoperative report was unclear. The patient recovered uneventfully, and the hemolytic anemia resolved.

One patient (14.3%) required an additional endovascular procedure during the same hospital stay for continuous endoleak after an 18-mm Amplatzer cribriform septal occluder was used off label to exclude the pseudoaneurysm. The opening of the pseudoaneurysm was 3 mm, and we anticipated that the 18-mm disk would provide adequate closure within a few days, once the polyurethane within the disk underwent thrombosis.

Table 2. Technical Points

<table>
<thead>
<tr>
<th>Stent Graft and Other Endoprosthesis</th>
<th>Innominate Stent</th>
<th>Left Common Carotid Artery Stent</th>
<th>Access</th>
<th>Endovascular Exclusion of Aortic Pathology</th>
</tr>
</thead>
<tbody>
<tr>
<td>28- × 3.3-cm Gore® Excluder, abdominal cuff (×2)</td>
<td>Yes</td>
<td>No</td>
<td>Femoral</td>
<td>Yes</td>
</tr>
<tr>
<td>18-mm Amplatzer® cribriform septal occluder, 34 × 10-cm Gore TAG®</td>
<td>Yes</td>
<td>No</td>
<td>Femoral</td>
<td>Yes</td>
</tr>
<tr>
<td>36- × 7.5-cm Talent thoracic stent graft®, 37- × 10-cm Gore TAG®</td>
<td>No</td>
<td>No</td>
<td>Femoral</td>
<td>Yes</td>
</tr>
<tr>
<td>28- × 10-cm Gore TAG®</td>
<td>No</td>
<td>No</td>
<td>Femoral</td>
<td>Yes</td>
</tr>
<tr>
<td>40- × 10-cm Gore C-TAG® (×2)</td>
<td>Yes</td>
<td>Yes</td>
<td>Femoral</td>
<td>Yes</td>
</tr>
<tr>
<td>40- × 10-cm Gore TAG®</td>
<td>No</td>
<td>No</td>
<td>Iliac</td>
<td>Yes</td>
</tr>
<tr>
<td>32- × 4.5-cm Gore Excluder®, abdominal cuff (×2)</td>
<td>No</td>
<td>No</td>
<td>Left axillary</td>
<td>No; open conversion</td>
</tr>
</tbody>
</table>

* W.L. Gore and Associates, Flagstaff, AZ.  b AGA Medical Corp, Plymouth, MN.  c For the tracheoinnominate fistula.  d Medtronic, Santa Rosa, CA.

Fig 3. (A) Computed tomography angiography (CTA) of the thoracic aorta in the oblique sagittal projection shows an iatrogenic focal narrowing of the ascending aortic graft (arrowhead). (B) Gradient echo cine magnetic resonance (MR) imaging in the same orientation as panel A shows turbulence distal to the site of narrowing. (C) Phase-contrast MR angiography at the same orientation as panel A shows dephasing, with peak velocity quantified to be 3.8 m/s, suggesting significant stenosis. (D) Postoperative CTA shows a new Dacron (DuPont, Wilmington, DE) aortic graft placed in the ascending aorta and proximal transverse arch. (* = residual dissection in the descending aorta.)
In the early postoperative period after Amplatzer insertion, the pseudoaneurysm enlarged, and we proceeded to cover it with a thoracic Gore TAG endograft.

A non-ST elevation myocardial infarction developed in 1 patient postoperatively. The patient recovered, but acute-on-chronic ischemia of the right lower extremity required embolectomy of the right profunda femoris and superficial femoral arteries and patch angioplasty of the external iliac and common femoral artery.

Comment

Although various referral centers have reported acceptable results with reoperative aortic operations [5], open surgical repair of an ascending aortic pseudoaneurysm entails considerable risks, including hemorrhage and coagulopathy, as well as other risks associated with sternal reentry, cardiopulmonary bypass, and circulatory arrest. Our study suggests that the endovascular approach may be a reasonable option in selected patients. The proximal aorta presents a significant endovascular challenge because it is close to vital anatomic structures, such as the aortic valve, the coronary ostia, and aortic arch vessels, as well as patent coronary bypass grafts. Currently, no commercially available endovascular stent grafts are specifically designed to treat proximal aortic lesions or are approved by the United States Food and Drug Administration for such indications. Options for the endovascular repair of ascending pseudoaneurysms include off-label use of the current thoracic and abdominal endovascular stents.

In all our patients, an initial open surgical approach was precluded by the nature of the aortic lesion, the comorbidities, and the prior sternotomies. The investigational nature of the procedure was clearly explained to all the patients. In our study, one perioperative death (in-hospital and 30-day) occurred, and there were no new neurologic events. Kolvenbach and coauthors [6] observed a combined mortality and morbidity of 18% in 11 patients with ascending aortic lesions that were treated with endovascular stent grafts; in 5 of those patients, the thoracic endograft had to be shortened intraoperatively, which underscores the limitations of current devices. Altering the endografts was not necessary in our study; however, 1 patient required snorkeling technique stenting of both the innominate and left common carotid arteries, and another patient required stenting of the innominate artery because of partial coverage of the ostium of the artery. The preoperative images were carefully evaluated in each case, and the use of intravascular ultrasound was an important intraoperative diagnostic adjunct.

In the endovascular treatment of ascending thoracic disease, the length of current thoracic endovascular stents is a potential issue because the ascending aorta is close to the coronary ostia and the brachiocephalic vessels. Although abdominal endovascular devices have a more desirable length for this purpose than do thoracic ones, the delivery system for abdominal devices is often inadequate, especially in tall patients, whose proximal aorta may not be reachable through the standard femoral approach. Alternative access sites, such as the axillary or subclavian artery, may be used when there is an inadequate length through the femoral approach.

Alternative delivery techniques have been used to resolve these issues [7, 8]. The transapical approach has been used extensively in percutaneous aortic valves and mitral valves [9]. Although a transapical approach is not an applicable approach for patients with an aortic mechanical valve, it can be used if other access sites are anatomically unavailable or crossing the arch is challenging [8]. The left axillary artery was used as an access site in 1 of our patients. Moreover, in patients with mechanical valves, the length of the nose cone of the delivery system of certain devices, which varies from 4.5 to 6 cm, prohibits placing the device as proximal as may be necessary when a femoral approach is used. Excessive length of the tip of the delivery system may result in incompetency or obstruction of the mechanical aortic valve. Furthermore, if the curvature of the aortic arch is narrow, conformity of the graft may be tenuous, increasing the risk of bird’s beak and malformation and possibly precluding effective deployment of the endograft into the ascending aorta.

The Amplatzer septal occluder has been used to close atrial septal and ventricular septal defects. Hussain and associates [10] reported 6 cases performed at a single center in which Amplatzer devices were used to treat aortic pseudoaneurysms. They successfully used an Amplatzer septal occluder in a high-risk patient to exclude a recurrent pseudoaneurysm that had previously been treated with another Amplatzer device and documented subsequent shrinkage of the aneurysmal sac [11]. In our series, the Amplatzer device was used in 1 patient without success, and additional exclusion with an endograft was required.

In conclusion, ascending aortic pseudoaneurysms can present a difficult clinical problem, and endovascular technology can facilitate their treatment, especially in high-risk individuals. Once a favorable short-term result has been obtained, ongoing surveillance is necessary to assess the durability of treatment. Appropriate clinical trials and devices specifically designed to address the ascending aorta are required.

The technical and engineering challenges of solving this problem are much more complicated than simply making shorter grafts or longer cuffs or altering the nose cones of currently available devices. The anatomic and physiologic complexity of the ascending aorta is different from that of the descending thoracic or abdominal aorta. The curvature of the ascending aorta, the distance from the sinotubular junction to the innominate artery, the proximity of the coronary arteries, the need to maintain competency of the aortic valve, and the 3-dimensional motion characteristics unique to the ascending aorta make engineering ascending aortic devices challenging.

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INVITED COMMENTARY

The ascending aorta is the last frontier for endovascular technologies because of the particular relationship of the ascending aorta with the aortic valve and the coronary artery ostia. In addition, several diseases of the ascending aorta are not limited to this segment but affect the aortic root and the arch too. Finally, neither endovascular material nor delivery systems are adequate so far, owing to the large difference in needs when compared with stent grafts for the descending or abdominal aorta.

Several institutions have reported on isolated cases or small series of patients. The results are difficult to compare because of huge differences in the anatomic presentation. Coselli’s group has to be congratulated for the pioneering work to treat complex diseases of the ascending aorta [1]. In this series, endovascular repair was performed to treat complications (eg, pseudoaneurysm or coarctation) observed after primary repair of acute aortic dissection type A (AADA). Different endovascular systems and components were used, which clearly demonstrates that there is no standardized material for endovascular treatment of the ascending aorta. In the literature, only one case using a specially customized endovascular stent graft has been reported [2].

In the present paper, one patient experienced iatrogenic coarctation after the ascending aorta was wrapped in presence of AADA. This is a curious procedure, and another intriguing point is that a narrowed anastomosis performed with a Teflon felt support was dilated, although such reinforced anastomoses are hard like stone. Most interestingly, this patient survived although he was considered to be high risk or inoperable for conventional surgery. This is the best proof that in experienced aortic centers, even patients at highest risk may survive.

This paper deals with endovascular repair of complications after repair of the ascending aorta. Others show that a substantial proportion of patients with AADA may be treated initially by endovascular stent graft.

In a series of 37 patients with AADA, Ronchey and coauthors [3] considered 9 patients to be at high risk for surgery. Four patients received endovascular stenting when the following criteria were met: entry tear in the ascending aorta, proximal landing zone of at least 2 cm, enough distance between the tear and the innominate artery, and absence of cardiac tamponade and severe aortic regurgitation. All patients survived a median follow-up of 15 months.

Sobocinski and colleagues [4] demonstrated that approximately 50% of patients undergoing open repair of AADA could potentially benefit from an endovascular repair. In a computed tomography–based feasibility study of 102 patients presenting with AADA, numerous anatomic variables of the dissection were analyzed. Endovascular repair with a tubular stent graft was deemed feasible in 37 patients. An additional 8 patients were considered as candidates but would have required a carotid-to-carotid crossover bypass. Finally, an arch-branched stent graft could have been used in 13 patients to exclude an entry tear located in the arch.

I fully agree with the authors that either studies or registries are absolutely necessary to collect a maximal number of cases to define the exact needs for endovascular treatment of acute and chronic diseases of the ascending aorta. As soon as low-profile stent grafts are available together with better delivery systems for transfemoral and transapical approaches, this tempting aortic segment will be reachable.

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References