Hybrid Interventions for Complex Aortic Pathology

Expanding endograft therapy to the entire aorta.

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With the approval of the Gore TAG (Gore & Associates, Flagstaff, AZ) thoracic aortic endograft in April 2005, physicians were provided with a new tool for managing patients with thoracic aneurysms (TAAs). Although the FDA approval was specifically for descending aneurysms, endografts have been increasingly used to treat disease extending into and over the arch and into the thoracoabdominal segment, albeit supported by a variety of bypass procedures. Thus, debranching was born, and these hybrid procedures have rapidly increased in popularity. Debranching is fundamentally performed to provide an appropriate landing zone for the stent graft and to preserve perfusion to the aortic branches. We have divided debranching procedures into the aortic arch and visceral aortic segment. In patients with extensive aortic disease, both segments may need to be addressed.[1,2] The considerations and technical challenges involved in these procedures are described in this article.

AORTIC ARCH

Although the definition of a landing zone will be in flux as new devices become available, currently *landing zone* implies segments <38 mm in diameter and 2 cm in length. The landing zone or seal zone is the critical area of the aorta where sealing of the device must occur in order to exclude the aneurysm.

To categorize endovascular repairs of TAAs, Criado and colleagues[3] mapped the thoracic aorta into five landing zones. Briefly, zone 0 involves the origin of the innominate artery, zone 1 involves the orifice of the left common carotid artery (CCA), zone 2 involves the origin of the left subclavian artery, and zones 3 and 4 include the descending thoracic aorta. More importantly, a stent graft landing in zone 1 will compromise the left CCA flow, and a graft landing in zone 0 compromises both the left CCA and innominate artery flows (Figure 1).

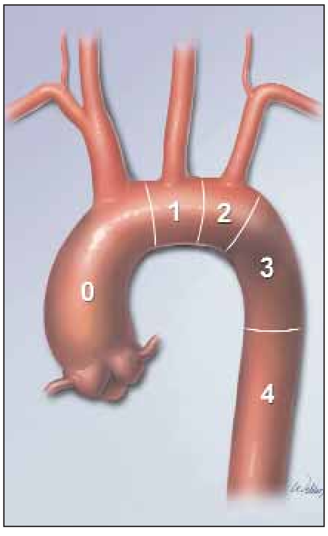

Figure 1. Zones of aortic arch for debranching procedures.

ZONE 0 DEPLOYMENT

When the aneurysm extends to or proximal to the innominate artery, the complexity of the procedure increases dramatically.[2,4-7] Some of these patients have had segmental aortic replacement, and this knowledge is very important in case planning.

The quality of the ascending aorta is an important factor to consider. We have had one death from sutures tearing out of the ascending aorta on postoperative day 1. The aorta cannot be severely calcified or aneurysmal. The surgeon must consciously work to place the graft as far

Figure 2. Radiopaque wire is placed around the base of the bypass graft to mark the proximal limit for deployment.

Figure 3. Grafts to the innominate, left common carotid, and left subclavian arteries originated from the ascending aorta. Side branch for deployment of the endograft passes inferiorly.

proximal as possible. The anastomosis always uses up a significant portion of the ascending aorta, and it is imperative to preserve a landing zone for the stent graft proximal to the aneurysm. The clamp and the anastomosis use approximately 3 cm of the ascending aorta, which is then lost as a seal zone. We place a large clip at the distal margin of the anastomosis as a radiopaque marker delineating the proximal extent of the landing zone (Figure 2). Patients with previously placed ascending grafts, although more difficult to expose, provide secure clamping of the aorta, and we have approached these through a small right thoracotomy using visible sternal wires to "tee-off" the intercostals space selection. The left subclavian artery, in most cases, can be exposed through a median sternotomy. In this case, it can be simply divided and bypassed. We routinely use transcranial Doppler for cerebral monitoring of all thoracic endografting procedures. In most cases, we perform the entire operation, debranching and stent grafting, in one setting. The stent graft is deployed through a 10-mm side limb originating from the proximal end of the bypass grafts. If a two-stage procedure is planned, make sure that the iliac arteries and distal aorta permit stent graft deployment in the standard retrograde fashion. In one case, we used reversed debranching: left subclavian to left carotid to right carotid bypass, to create enough space to land a 10-cm-long X 26-mm-diameter TAG device. There is surprisingly little space from the most distal coronary artery to the left subclavian, in most cases, it is only approximately 10 cm.

In most cases, the incision used is a median sternotomy (Figure 3). This is tolerated by even fairly sick patients and provides excellent exposure to the ascending aorta, innominate artery, and left CCA. In most cases, the left subclavian artery can be exposed, although this depends on arch and aneurysm anatomy.

When the aneurysm involves the ascending aorta, arch, and proximal descending aorta, our preference is one-stage open repair with deployment of an endograft through a side branch off the ascending aorta or aorto-innominate bypass graft. We have largely dismissed elephant trunks in favor of this one-stage repair and perform an end-to-end anastomosis in the distal arch followed by endograft deployment in an antegrade fashion (Figure 4).

For bypass to the supra-aortic trunks, we use a bifurcated Hemashield graft (Boston Scientific Corporation, Natick, MA) in an end-to-side fashion, arising from the ascending aorta, end-to-end to the innominate artery and left CCA. A presewn side limb to the left subclavian artery arises from the graft to the CCA. If the subclavian artery is difficult to expose, then a standard cervical

Figure 4. The proximal arch has been replaced under circulatory arrest (A), and an endograft is inserted into the distal aorta (B).

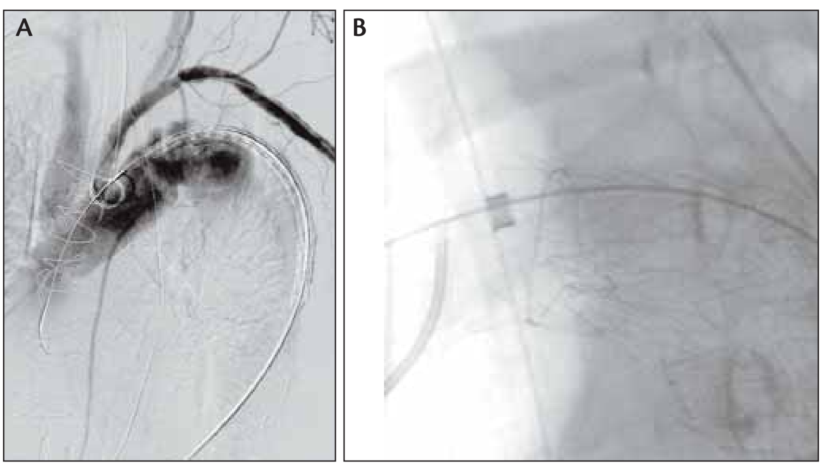

Figure 5. There is difficulty in advancing the endograft into the elephant trunk, likely due to the Dacron intussecepting on itself (A). When the endograft is deployed (B), nonuniform deployment represented by the irregularity of the gold ring results.

carotid subclavian bypass is performed. When carotid subclavian bypass is performed, we embolize the subclavian artery proximal to the origin of the vertebral artery using either coils or an Amplatzer vascular occluder device (AGA Medical Corporation, Plymouth, MN).

ELEPHANT TRUNK ISSUES

The first step involves arch replacement. At the distal anastomosis, a portion of the Dacron graft is inserted down inside the descending thoracic aorta. This "elephant trunk" is then used for sewing the second-stage Dacron graft or increasingly as a landing zone for a stent graft. There are several options for endograft placement during arch and descending aortic repair, including standard arch replacement and elephant trunk with delayed retrograde endograft placement.[8] Our technical suggestions are to shorten the elephant trunk so that it does not move inside the aneurysm when we are inserting the endograft in a retrograde fashion (Figure 5). Mark the end of the elephant trunk either with large ligaclips or by sewing on the radiopaque wren from a laparotomy pad around the circumference of the graft. The concept of a frozen elephant trunk, stabilized with a balloon-expandable stent, has been used as an option outside the US. Bypassing the supra-aortic vessels (rather than sewing them on as a patch) while moving the anastomosis proximally on the ascending aorta will provide a much longer landing zone and may minimize the risk of stroke. Hypothermic circulatory arrest is necessary for arch replacement. Nitinol-based endografts deploy minimally in a patient who has been cooled, although, when ballooned into place, these endografts will adapt to the aortic dimension and stay *in situ* during rewarming. Our preference, however, is to rewarm the patient first before endograft placement to avoid these issues.

ZONE 1 DEPLOYMENT

When deploying across the left subclavian artery using all of zone 2, it becomes necessary to deploy over the left CCA. Zone 1, which includes the origin of the left CCA, is usually shorter than depicted in Figure 6, consequently, simple bypass of the left carotid artery usually adds little additional landing zone. However, it is helpful in some patients, so the technique is well worth understanding (Figure 6). Another factor that affect the decision to perform a zone-1 deployment is anatomy of the CCA origin (a wide funneled origin may lead to displacement of the endograft up into the CCA origin). The presence of a vertebral artery arising from the arch between the left CCA and left subclavian artery must be carefully evaluated. There are, however, a few patients in whom this is appropriate; consequently, CCA-to-CCA bypass is performed for any patient in whom the left CCA origin is to be covered. We routinely add carotid-to-left subclavian bypass as part of the procedure (Figure 7).

Figure 6. In this case, the aneurysm extends to the left subclavian artery. There is a sufficient landing zone if carotid-to-carotid and carotid-to-subclavian bypass is performed.

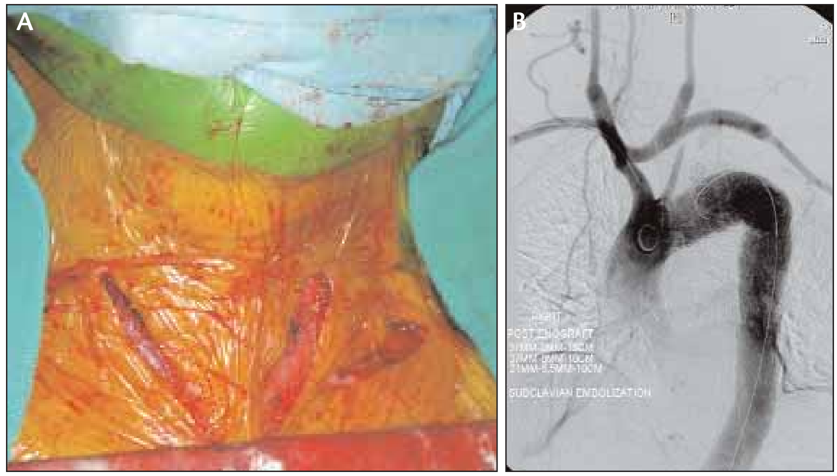

Figure 7. Cervical incisions used to create a carotid-to-carotid bypass and left carotid-to-subcalavian bypass graft (A). Angiogram showing typical configuration of carotid-to-carotid and carotid left subclavian bypass (B).

The carotid-to-carotid bypass can be performed using either a looped subcutaneous graft or a retropharyngeal tunnel. Our preference is the subcutaneous route, but either is appropriate. When the interventionist misjudges the adequacy of the zone for endograft deployment, either partial coverage of the innominate origin occurs, or a persistent type-1 endoleak necessitates innominate bypass as described here, to permit endograft extension.

Bovine configurations of the left CCA are common and usually associated with a wide innominate artery origin. However, these origins vary in their anatomical configuration, which must be taken into consideration. When the configuration is broad, with a left CCA arising from within the innominate artery, away from the aortic wall, it is reasonable to “cheat a little” and project the TAG flanges into the innominate orifice so that the stent graft ring lands at the distal innominate margin, thereby providing a maximal landing zone length.

ZONE 2 DEPLOYMENTS

Any patient in whom an adequate landing zone is not available distal to the left subclavian artery is considered for subclavian coverage. This technique has been widely practiced and is even permitted in the many investigational device exemption trials that have been completed and are currently underway. Sacrifice of the left subclavian artery was not even considered as part of the debranching concept until interventionists began to consider extending endograft deployment to cover the CCA. Similarly, as other aortic pathologies are treated and much longer aortic segments are covered than were permitted with the investigational device exemption trials, the potential role of the left subclavian artery (particularly in the blood supply of the spinal cord) becomes increasingly important. Furthermore, the important role of the left vertebral artery has been increasingly recognized. Revascularization of the left subclavian artery, by either carotid subclavian bypass or subclavian-to-carotid translocation, has consequently undergone evaluation and reevaluation as our experience has evolved.[9-13] Initially, our practice was to bypass all subclavian arteries in patients in whom planned coverage was anticipated, which was an overuse of the procedure. This practice was followed by a period in which very few carotid-to-subclavian bypass procedures were performed. Contemporary practice involves selective subclavian revascularization (Table 1).

TABLE 1. INDICATIONS FOR SUBCLAVIAN REVASCULARIZATION
• Previous left internal mammary artery use for coronary artery bypass grafting
• Critical left vertebral artery[14]
• Atretic right vertebral artery -Absent right vertebral artery -Known left posterior inferior cerebellar artery syndrome
• Extensive aortic coverage
• Aortic dissections
• Any patient in whom carotid-to-carotid bypass being performed for left CCA revascularization

Figure 8. The proposed single-branched thoracic aortic endograft under development from Gore & Associates.

Although many interventionists prefer using the subclavian transposition over bypass, this method has never been our practice for several reasons. When a left internal mammary artery to the left anterior descending artery transposition is contraindicated, bypass is preferable to maintain antegrade flow. Second, all of these patients have a large arch aneurysm, which can project up into the apex of the left chest and distort the mediastinum, complicating proximal exposure and ligation of the subclavian artery. In the future, single-branched endografts or endovascular techniques that preserve side branches may be available for perfusion of the subclavian artery (Figure 8).[15]

There must be an adequate area between the distal margin of the left CCA origin and the proximal margin of the left subclavian orifice. Occasionally, the origin of the left subclavian is so wide and funnel-shaped that the endograft tends to displace up into the subclavian artery. This must be judged in advance with a low threshold for anticipatory left CCA bypass.

ANEURYSMS INVOLVING THE VISCERAL SEGMENT

Aneurysms that extend to involve the visceral segment of the aorta (zone 4) must also be carefully evaluated to determine the extent and configuration of abdominal debranching required. In most cases, a decision must be made whether to cover the origins of the celiac and superior mesenteric artery (SMA) or both of these vessels in conjunction with the renal arteries.[16,17] This location, like the ascending aorta, is one of the few situations in vascular surgery in which a previous operation, namely replacement of the infrarenal aorta, is technically beneficial once it has been exposed, again providing a secure clamp and anastomotic site for the debranching bypasses, as well as a secure landing zone for the stent graft.

TECHNICAL ISSUES

The aortic component of a bifurcated graft used to replace the infrarenal aorta should be cut longer than usual to maximize the seal zone. The aortic graft diameter should be increased to accommodate the distal end of the stent graft, which has a minimal diameter of 26 mm. We typically originate two bifurcated Dacron grafts (12 mm X 6 mm) from each limb of the aortic graft (Figure 9). Those from the left limb go to the left renal artery and SMA. Those from the right limb go to the right renal and common hepatic artery. Both the celiac artery and SMA must be ligated as close to their aortic origins as possible. When staged abdominal debranching followed by endograft placement is performed, it is essential to facilitate endograft placement during the initial procedure. Make sure the iliac limbs are fully stretched out, ideally place a graft down to the groin and upsize the graft so that at least a 10-mm-diameter limb is brought down to the femoral artery.

We have also used the ascending aorta as an inflow source for not only the supra-aortic trunks but also the celiac and SMA. The latter is relatively easy to achieve though a median sternotomy extending down to the umbilicus. The ascending aorta can easily support these bypass grafts (Figure 10).

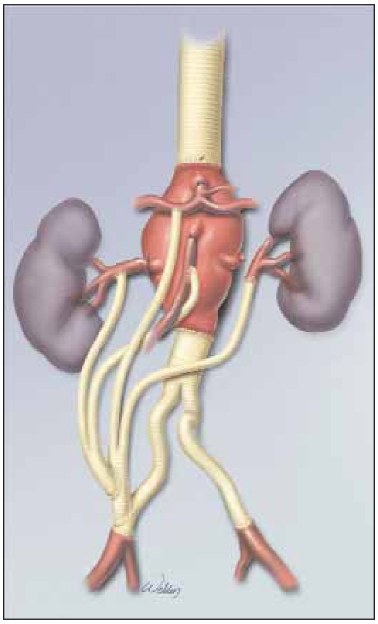

Figure 9. In this configuration, two bifurcated grafts originate from the right iliac limb. Our preferred configuration is to originate two separate 12-mm X 6-mm grafts from each of the iliac limbs.

CONCLUSION

Debranching of the aorta has greatly expanded our therapeutic armamentarium with regard to complex thoracic aortic pathology. Partly as a consequence of debranching, most

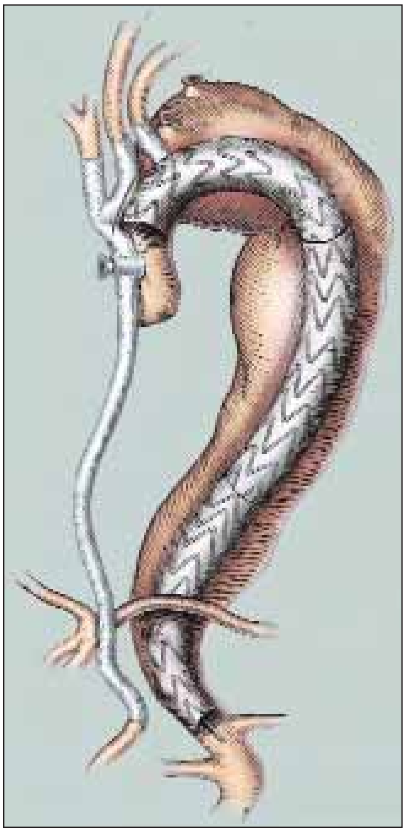

Figure 10. The utility of the ascending aorta to provide inflow to the supra-aortic trunks and the celiac/superior mesenteric artery is shown.

of the devices implanted in the thoracic aorta are off-label from the directions-for-use–defined straightforward descending thoracic aneurysms. In our experience of more than 70 cases, it is of particular benefit in debranching the aortic arch. A close interaction between cardiac and vascular surgeons is the key to preoperative planning and successful outcomes. Debranching of the abdominal aorta remains a challenging procedure and necessitates a full laparotomy and multiple bypass procedures. We usually perform debranching and stent graft placement at the same setting but would have no hesitation in staging the procedure should the patient be hemodynamically unstable. Overall, as branched stent graft placement improves and becomes more user-friendly, we hope ultimately to make debranching redundant. Currently, however, it provides a therapeutic alternative for patients who would be otherwise inoperable. ■

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