Chapter 20

Branched and fenestrated stent grafts for endovascular repair of thoracic aortic aneurysms

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Most thoracic aortic aneurysms affect the unbranched segment between the subclavian and celiac arteries, and they can be repaired without ischemic complications by using unbranched stent grafts. However, more complicated forms of repair are required when the aneurysm encroaches on the aortic arch or the visceral aorta. Alternative maneuvers for preservation of the branch artery flow include stenting of the branch artery, fenestration of the stent graft, branching of the stent graft, extra-anatomic bypass, or some combination of these.

Secure attachment and hemostatic sealing are two basic prerequisites for successful endovascular aneurysm repair. Both require stable, coaxial implantation of a stent graft within nondilated segments of the aorta. Unfortunately, the nondilated segment (neck) between the aneurysm and the vital arteries at both ends of the descending thoracic aorta is often short, angulated, irregular, or conical. Some authors advocate lengthening the implantation site by covering the origins of the subclavian or celiac arteries. Although both are well collateralized, catastrophic ischemic complications can occur, especially when the left vertebral artery is dominant, the internal mammary artery is connected to a coronary artery, or collateral arteries to the anterior spine arise from arteries that are aneurysmal or occluded.

Fenestration and branch artery stenting are helpful in the presence of a short angulated neck. Both help to improve the lie of the stent graft by allowing it to be inserted further into nondilated aorta. The effect on the length of the sealing zone is less predictable because, unless the aneurysm emerges from the opposite wall of the aorta, both branch artery stents and fenestrations may serve as routes for type I endoleak into the aneurysm.

Aneurysms that involve the aortic arch or visceral aorta can be repaired by entirely endovascular means only if the stent graft has a branch for each branch of the aneurysmal aorta. The branch bridges the gap between the lumen of the stent graft and the lumen of the branch artery, maintaining perfusion while excluding the aneurysm.

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Competition of interest: Dr Chuter has licensed patents to Cook Inc and receives royalties based on sales of the Zenith stent graft.

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0741-5214/$32.00

doi:10.1016/j.jvs.2005.10.059

BRANCH ARTERY STENTING

Open and covered stents may be used to hold the margin of the stent graft away from the orifice of a branch artery and preserve a channel for branch artery perfusion. In the aortic arch, the additional stent is best inserted through downstream access to the branch artery itself. If the distance is short and the stent rigid, the stent does nothing more than push the margin of the primary stent graft up or down the long axis of the aorta away from the branch artery orifice. If the distance is long and the stent flexible, the stent may actually parallel the primary stent graft and push it away from the aortic wall. Under these circumstances, the potential for leakage depends on the degree to which the primary stent graft wraps around the adjunctive stent. In this regard, the conformability of the Gore Thoracic Aortic Graft device (W. L. Gore & Associates, Flagstaff, Ariz) has distinct advantages.

FENESTRATION OF THE STENT GRAFT

Fenestration refers to the creation of a hole within the stent graft. The challenge is to line up this hole with the orifice of the branch artery, thereby maintaining end-organ perfusion while excluding the aneurysm.

If one has access to the downstream artery, as one does in the aortic arch, it is possible to create the fenestration after stent graft insertion. McWilliams et al[1] have described a technique of subclavian artery fenestration whereby the hole is created by using the back end of a small-gauge guidewire, enlarged by using a series of cutting balloons, and held open by using a balloon-expanded stent. The technique is more difficult to apply to the visceral aorta for lack of downstream branch artery access. Any method of in situ fenestration has to be quick and predictable. One cannot afford much delay in establishing a route for blood flow to organs with a limited tolerance for ischemia.

These days there is nothing novel about the creation and implantation of prefenestrated pararenal stent grafts. The technique has been applied widely and successfully with low rates of branch artery loss or type I endoleak. The key to success has been the use of a bridging catheter (sheath or balloon) between the fenestration and the renal

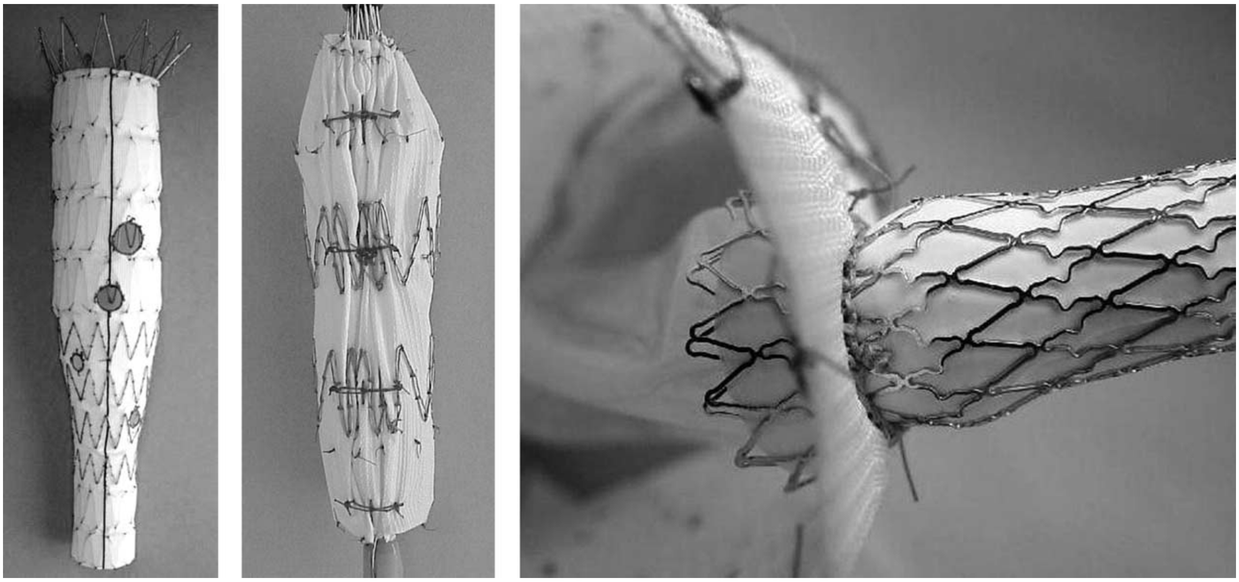

Fig 1. A, A stent graft with multiple fenestrations for endovascular repair of a thoracoabdominal aortic aneurysm. **B,** A fenestrated stent graft during loading, showing the constraining ties that maintain a state of partial expansion during branch catheterization. **C,** A JoMed covered stent flaring both inside and outside of a reinforced fenestration in the primary stent graft.

artery to guide the fenestration into position and the use of a bridging stent to keep it there.[2]

Fenestration is more difficult in the thoracic aorta. There are often many bends in the path from the femoral insertion site that impede rotation of the delivery system. Once the central core of the delivery system bends in one part of the aorta, it tends to rotate, rather than bend again, as it encounters differently oriented segments of aortic angulation further upstream. Furthermore, reorientation of a partially deployed stent graft within the aortic arch risks embolism and stroke. Distal thoracic aortic fenestration faces an additional hurdle because of the presence of the typical Zenith top cap. The top cap constrains the proximal stent and helps maintain the state of partial stent graft deployment, which is critical to the success of the bridging catheter approach. While it remains in place, the top cap impedes access to the stent graft, and once it is deployed, the state of partial stent graft deployment is lost.

One way to overcome these obstacles is to precurve the delivery system so that it orients itself, and the stent graft within it, in a predetermined way. Nevertheless, this technique lacks the precision of the bridging catheter approach. A compensatory increase in the size of the fenestration is accompanied by an increase in the risk of type I endoleak.

BRANCHING OF THE STENT GRAFT

Branched stent grafts are categorized as modular or unibody, depending on whether they are assembled in situ from several components or inserted whole. The modular approach is generally simpler, more predictable, and more versatile, but there is a risk of component separation. The unibody approach is theoretically more stable, but the complexity of implantation increases exponentially with every additional branch.

Modular branched stent grafts. All of the modular branched stent grafts inserted to date have been variants of the basic Zenith prosthesis, in which a Z-stent–based aortic component has attachment points for multiple branches, each composed of a covered stent. The steps in this procedure resemble the steps in fenestrated stent graft insertion, involving the insertion of a bridging catheter followed by a bridging stent. However, the connection point need not necessarily be just a simple fenestration. The connections may be enhanced by the addition of internal, external, upgoing, downgoing, transaxial, and partial cuffs. The distinctions between these may seem trivial, but they have important consequences for the procedure of stent-graft insertion, the likelihood of endoleak, and the long-term stability of intercomponent connections.

When the connection point is a simple fenestration, the rules of fenestrated stent graft insertion apply.[3] Stent-graft design has to mirror aortic anatomy precisely, and each fenestration has to line up exactly with each branch artery orifice (Fig 1). Otherwise, the branches become difficult to catheterize and stent. No self-expanding covered stent is capable of attaching itself securely to the unaugmented margin of a fenestration; balloon-expanded stents are required. Both sealing and attachment depend on flaring of the covered stent on either side of the fenestration. The two most widely used balloon-expanded covered stents are the i-cast (Atrium Medical Corp, Hudson, NH) and the JoStent (a subsidiary of Abbott Vascular Devices, Redwood City, Calif). The i-cast has more rebound and flares less well than the JoStent. However, the i-cast comes premounted on a balloon, which facilitates delivery. Neither can be delivered bare. They require 7F or 8F sheaths to be placed within the target arteries.

A common variant of the fenestrated approach involves the use of a hinged fenestration, in which a small inner fenestration is connected to a larger outer fenestration by a short, curved polyester cap. The inner fenestration, which opens distally to the lumen of the stent graft, is the real site of intercomponent connection. The outer fenestration opens laterally to the aneurysm outside the stent graft; in theory, its greater diameter affords a small degree of latitude in the relative positions of the fenestration and the target artery. The curve imposed by the cap may also have a role in directing a catheter laterally toward the target artery. This is particularly important when the target artery takes off in a caudal direction, thus creating a bend in the path of catheter (and stent) insertion.

A transversely oriented cuff on the outer surface of a fenestration may have a limited role in improving the intercomponent seal. However, there is a risk that the presence of such a cuff may complicate target artery catheterization, especially when the position is not quite right and the wall of the stent graft is close to the wall of the aorta.

Longitudinal cuffs (Fig 2) orient the line of insertion with the long axis of the stent graft and the aorta.[4] In most cases the cuff is accessible only through its proximal end, and this necessitates prior release of the top cap and transbrachial insertion of the covered stent. The former eliminates any possibility of repositioning the stent graft to facilitate target artery catheterization. However, precise position is less important when the line of insertion follows the long axis of the aorta; the catheter can be directed to the target artery, even when the outer orifice of the cuff is not quite at the intended location. The additional overlap afforded by the longitudinally oriented cuff enhances intercomponent sealing and attachment, even with self-expanding covered stents. This is a particular advantage for visceral arteries, such as the celiac, in which a balloon-expanded stent might be crushed by diaphragmatic excursion (Fig 3). The low pull-out resistance and low kink resistance of the Fluency (Bard Peripheral Vascular, Tempe, Ariz) covered stent are both addressed by the insertion of an additional stent, such as a Wallstent. This does little to increase the frictional forces between components, but it stabilizes the connection by stiffening the covered stent and restricting the range of possible movements. The resulting conduit is so stiff that there is little possibility of disconnection, unless the graft is being used to bridge a very long gap between the primary stent graft and the target artery.

Unibody branched stent grafts. These devices resemble complex versions of the Ancure and Trivascular bifurcated abdominal aortic aneurysm devices. In this approach, preattached limbs are towed or pushed into position by using catheters, depending on the availability of downstream branch artery access. Versions of this device have been used to treat aneurysms of the aortic arch[5] and visceral aorta.[6] The largest experience is in the distal aortic arch using a graft with one branch to the subclavian artery.[7]

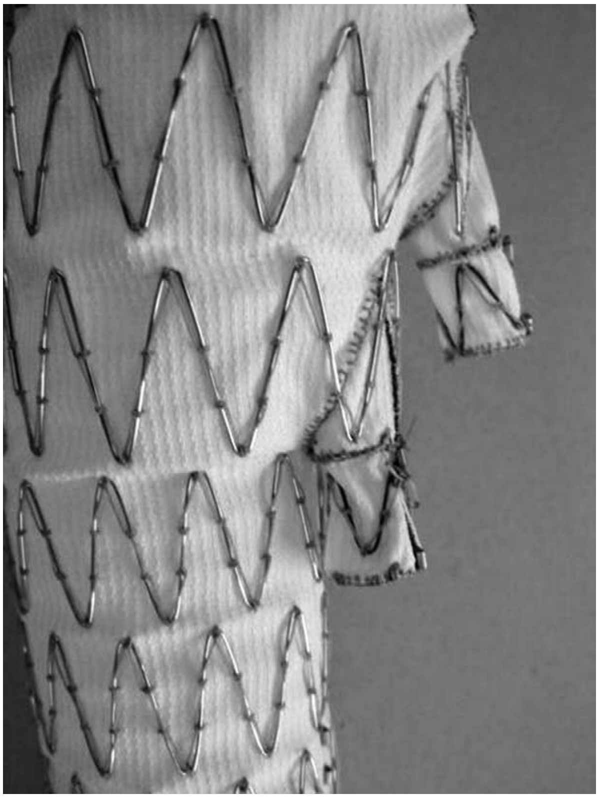

Fig 2. A stent graft with two longitudinally oriented cuffs: one for the celiac artery and one for the superior mesenteric artery.

This ingenious stent graft has two critical features: a ringlike attachment stent and catheter-based control of position and opening. At diameters close to full expansion, the attachment stents are capable of creating a seal with a very short segment of aorta, even in the presence of acute angulation. Catheter-based control of stent graft expansion allows the entire graft to be released from its sheath for catheter retrieval and limb deployment while still in a collapsed state. Although the single-branch version seems to be successful in a high proportion of cases, more complex multibranch versions have been plagued by high rates of stroke, endoleak, and mortality.

COMBINED APPROACHES

The combination of extra-anatomic bypass and single-lumen endovascular aneurysm exclusion is the focus of other chapters. However, the combination of extra-anatomic bypass and branched endovascular repair deserves mention here. In the absence of an endovascular source of inflow changes, full exclusion of the entire aortic arch requires inflow to the reconstructed brachiocephalic circulation from either the ascending aorta or the femoral artery. Ascending aortic origination requires median sternotomy, whereas femoral origination makes the perfusion of the brain dependent on the patency of a femoral-axillary bypass.

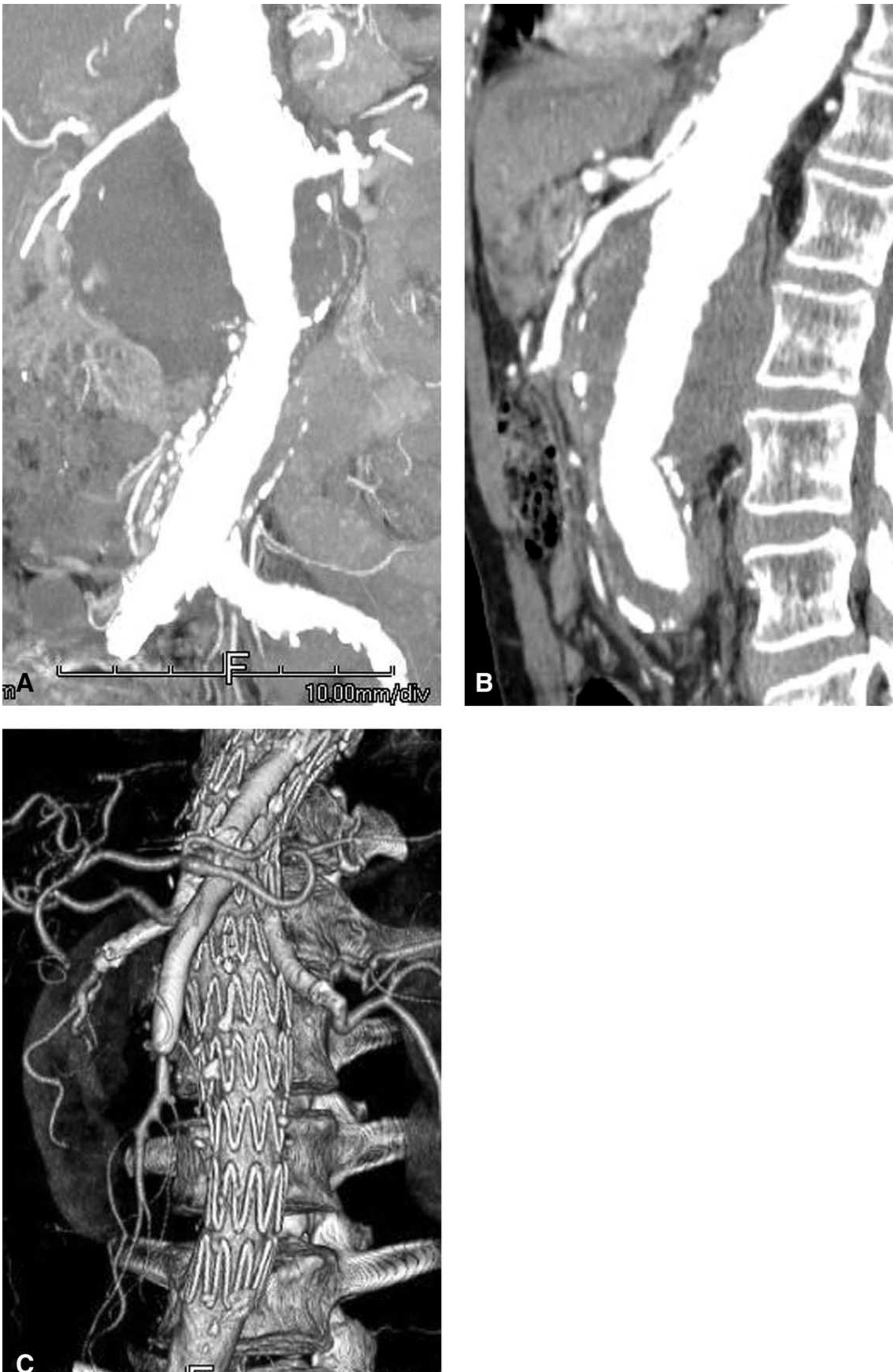

Fig 3. A, Coronal section from a preoperative CT, showing a large type IV thoracoabdominal aortic aneurysm. **B,** Sagital section from the preoperative CT of the same patient, showing compression of the celiac artery by the diaphragm. **C,** Shaded surface rendering from the postoperative CT of the same patient.

Our approach to complete arch aneurysm was developed after a series of experiments with a rubber model of the aortic arch.[8] We concluded that multibranched repair was too slow and unpredictable for clinical use in a location where the end organ (the brain) has such a poor tolerance for ischemia. Instead, we insert a simple bifurcated stent graft with one long, narrow branch to the innominate artery and one short, wide branch to the aorta.[9] Open insertion through the right common carotid artery provides a short, straight route to the ascending thoracic aorta and ensures that the trailing branch ends up in the innominate artery. Preliminary subclavian-carotid reimplantation and carotid-carotid bypass permit left-to-right flow during stent-graft insertion and right-to-left flow afterward. A large-diameter aortic extension completes the conduit, which then has one inflow in the ascending thoracic aorta, one outflow to the innominate artery, and one outflow to the descending thoracic aorta.

CONCLUSION

Although multibranched stent grafts were first described many years ago, their widespread application has been slow for three reasons. First, the original branched stent grafts were made by for their own use by surgeons, the only people with access to the devices. Second, regulatory hurdles limited the number of patients studied in the United States. Third, approved covered stents, such as the Hemobahn (W. L. Gore and Associates) and the Wallgraft (Boston Scientific, Natick, Mass), were ill suited to this application. The recent expansion in the endovascular treatment of pararenal, thoracoabdominal, and arch aneurysms followed the approval of better covered stents and the commercial manufacture of branched stent grafts (Cook, Brisbane, West Australia). Although these techniques will always be confined to centers with a focused expertise, they will become the standard of care as soon as there are data showing long-term success, given the morbidity, debilitation, and expense associated with the open-surgical alternatives.

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Submitted Oct 27, 2005; accepted Oct 27, 2005.