Unmet Needs of Current TEVAR Devices

An overview of technological improvements that may be expected in the next generation of thoracic endovascular devices.

BY W. ANTHONY LEE, MD, FACS

Four years have passed since I wrote the initial article addressing this very question,[1] a time when there was only one commercially available device in the United States that was approved by the US Food and Drug Administration (FDA). Since then, we have come a long way, but there are still "miles to go before [we] sleep…"[2]

Today, there are three FDA-approved devices that are commercially available in the United States: the Zenith TX2 endovascular graft with Pro-Form (Cook Medical, Bloomington, IN), the Conformable Gore TAG thoracic endoprosthesis (Gore & Associates, Flagstaff, AZ), and the Talent thoracic stent graft with the Captivia delivery system (Medtronic, Inc., Minneapolis, MN). The Valiant thoracic stent graft with the Captivia delivery system (Medtronic, Inc.), which represents the next iteration of the Talent platform, was recently FDA approved but has not been commercially released as of the time this article was published.

All four devices have undergone incremental iterations since the original market release to address certain problems that their predecessors did not. Both the Zenith TX2 with Pro-Form and Conformable Gore TAG devices have made improvements in arch conformability using a combination of endograft and delivery system modifications. The Talent and Valiant devices corrected the issue of misaligned or retroflexed deployment in the arch by introducing a tip-capture mechanism (Captivia) to its delivery system.

This article outlines some of the unmet technological challenges that still remain for this therapy. This select list is neither meant to be complete nor is it listed in any particular order of priority; however, it does reflect the maturation of our collective understanding of the therapy, our increased respect for the anatomy and biology of the thoracic aorta, and the recognition of limitations associated with the current array of devices.

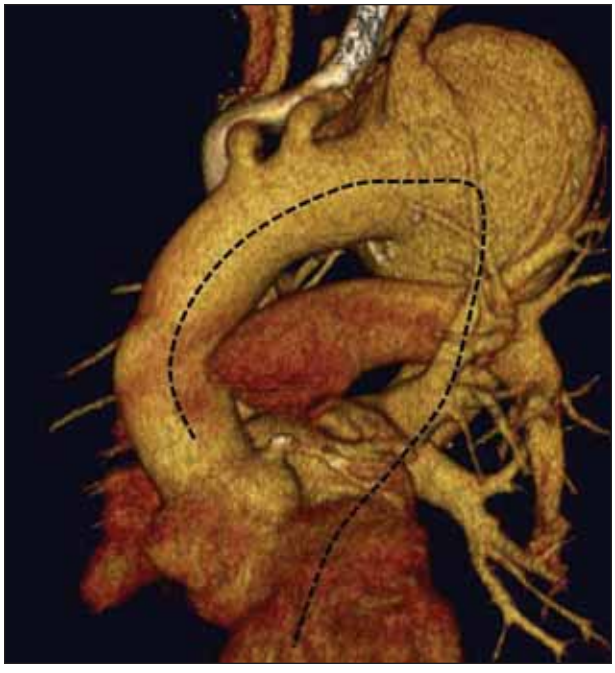

Figure 1. The helical curvature of the aortic arch.

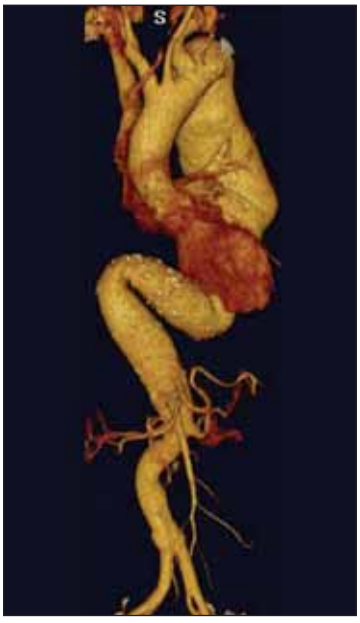

Figure 2. A thoracic aortic aneurysm with severe compound tortuosity.

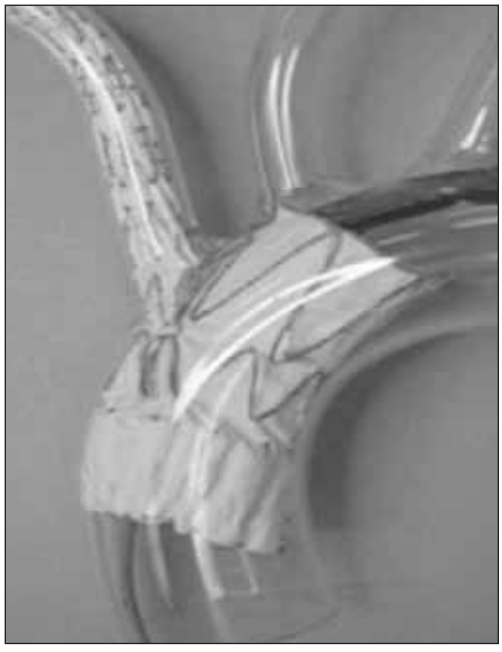

Figure 3. Bench-top prototype of a single-branch arch device.

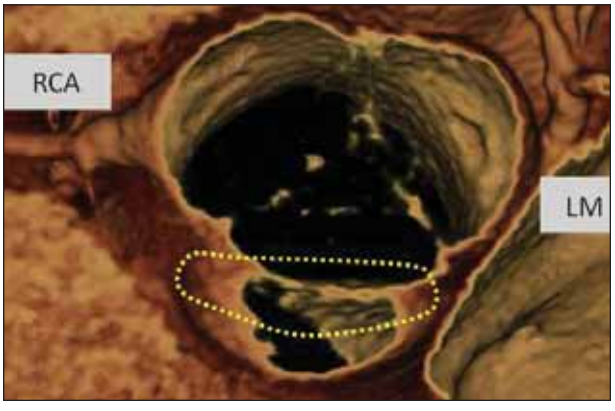

Figure 4. Three-dimensional rendering of an acute type A dissection (looking down toward the aortic valve).

CHALLENGES

Technical challenges during thoracic endovascular aortic repair (TEVAR) include anatomic and physiologic factors that are unique to this aortic segment. A significant number of thoracic pathologies occur in close proximity to either the arch and/or the mesenteric vessels. Indeed, the often-depicted mid-descending thoracic aortic aneurysm is most commonly seen in the marketing pages of industry publications but is a relative "unicorn" in actual practice. One of the challenges that gives rise to current unmet needs is the aortic arch itself, which poses a combination of unique anatomic features that are not found anywhere else in the thoracoabdominal aorta. These include a helical curvature that varies widely with age and pathology (Figure 1), high impulse forces that create beat-to-beat movement of the aorta, and numerous anatomic variations of the origins of the arch vessels, all of which may adversely impact device deployment and the associated risk of complications.

Inadvertent coverage of or catheter guidewire manipulations near the critical aortic branches can result in devastating neurologic complications or mesenteric ischemia. Unlike in the iliac arteries, aortic tortuosity is not readily corrected, even with super-stiff guidewires, and navigation sometimes requires a transbrachiofemoral guidewire (Figure 2). The area of treatment is more remote from the point of entry of the endovascular devices compared to the abdominal aorta, and degenerative diseases of the thoracic aortic segment are frequently associated with concomitant aneurysmal and/or occlusive disease of the abdominal aorta, resulting in tandem segments of tortuosity and ectasia.

Finally, although aortic diseases primarily affect men, the relative proportion of women is greater in regard to disease in the thoracic aorta than in the abdominal aorta. Women also tend to have smaller access vessels, which are generally more afflicted with calcific occlusive disease, and the larger profiles of thoracic devices compared to abdominal endografts result in a higher incidence of access-related complications and the need for iliac conduits.

UNMET NEEDS AND NEXT-GENERATION DEVELOPMENTS

Management of Branch Vessels

One of the main obstacles that has limited endovascular aortic therapy to two discrete and separate segments—the descending thoracic aorta and the infrarenal aorta—are the branch vessels, specifically the arch vessels proximally and the visceral-renal vessels in the middle. The ability to revascularize two of the three arch vessels extra-anatomically potentially allows a simpler single-branch design for the arch compared to the abdominal segment (Figure 3).

Besides the aortic devices themselves, advances in mating branch stent (graft) technology and ancillary devices,

such as sheaths, guidewires, and catheters, must keep in step with the rest of the therapy. Changes in delivery systems, such as total working lengths and nosecone design, must adapt to the differences in distances from previously unconventional access sites, such as carotid, axillary, or brachial arteries, to their targets. The upper limits of aortic device sizes may need to be increased to accommodate the larger native diameters of the ascending aorta. The risk of stroke is obviously increased when treating the arch. Embolic protection devices or mechanisms specifically designed to work in concert with the aortic endograft as a unified system may be required to avoid this complication.

Ascending Aorta

Although working prototypes and a number of first-generation devices with arch branch designs have been successfully implanted in human subjects, endovascular treatment of the ascending aorta may represent the true final step toward an endovascular solution to treating the entire aorta. Presently, the ascending aorta is principally used as the proximal landing zone for treating arch lesions. Despite a very small number of anecdotal experiences with endovascular stent graft repair of focal lesions, such as iatrogenic pseudoaneurysms and rare cases of type A dissections, primary degenerative aneurysms of the ascending aorta and most type A dissections cannot be treated with current technologies (Figure 4).

The main obstacles to treating this segment of the thoracic aorta involve its relatively large native size and the short length delimited by the aortic valve and coronary arteries proximally and the arch vessels distally. Devices to treat ascending aortic pathologies must, by necessity, be mated with constructs that combine branch vessel and percutaneous valve technologies, bringing to bear a multispecialty collaboration of cardiac surgeons, vascular surgeons, and interventional cardiologists.

Profile

Current thoracic endografts are large, with outer diameters ranging from 23 F (3.14 F = 1-mm diameter) to 28 F. Nearly 50% of women who undergo TEVAR require an iliac conduit. Hydrophilic coatings represent a significant improvement, but they still cannot overcome intrinsically small and diseased iliac arteries that do not significantly dilate. Although the need for alternative access techniques can never be completely eliminated, the next generation of thoracic endografts should aim for a 30% reduction in the current profile, with a maximum outer diameter of 20 F for the largest endograft sizes. This may reduce the need for iliac access to < 10% for women and to almost zero for men.

Trackability

The delivery catheter carrying a thoracic endograft must potentially traverse at least three tandem segments of significant tortuosity—the abdominal aorta, the distal thoracic aorta, and the arch. Current catheter designs have an intrinsic flexion point between the proximal shaft where the endograft is loaded and the distal shaft near the handle. Pushability is lost after passage of each successive segment due to the serial frictional resistance and the noncoaxial vector forces transmitted along the delivery catheter. This is exacerbated when the delivery catheter becomes bent at the flexion point as it curves around a tight angle.

In these situations, continued pushing can paradoxically retract the proximal end of the delivery catheter from its forward position as the shaft distal to the flexion point advances away from the axis of the aorta. More significantly, even if the delivery catheter were able to eventually reach the target, it may be damaged to the point that deployment of the endograft may not be possible. Although a stiffer guidewire may remediate this situation, even the stiffest wires available are inadequate in certain cases, and the only option is to use a transbrachiofemoral wire (Figure 2). The next-generation delivery catheter should have a balanced combination of added flexibility and stiffness to overcome these compound tortuosities.

Deployment

Although the importance of accuracy and controlled deployment cannot be overstated when it comes to endovascular aortic repair in general, it is even more important in the thoracic aorta, as the consequences of misdeployment are significantly greater. To date, most of the attention in the design and development of endograft delivery systems has focused on proximal accuracy. It is now time to focus on distal accuracy.

Nearly all designs employ a conventional tip-to-hub unsheathing mechanism that is similar to all self-expanding stent platforms. This method allows controlled and accurate deployment of the proximal end of the endograft, but unfortunately, it affords little of the same for the distal end. The only device that does not deploy in this manner is the Conformable Gore TAG device, which deploys starting from the middle of the device and then outward in both directions in a single step. If we accept the fact that thoracic pathologies involve the distal thoracic aorta as often as the proximal segment, the next-generation thoracic delivery system should allow the same level of deployment control and accuracy it currently provides the proximal end of the endograft to its distal attachment site.

Conformability

Nearly all devices have a minimum radius of curvature to which it can conform and below which malapposition of

the endograft to the inner curve can occur. This can lead to type IA endoleak and even complete endograft collapse. The inner curve acts as a fulcrum over which the proximal edge of the endograft hangs over the ascending aorta. The Zenith TX2 Pro-Form and the Conformable Gore TAG devices have been specifically designed to deal with this issue.[3]

Although they represent significant advances in conformability compared to their predecessors, incomplete apposition continues to occur to varying degrees, and design modifications have introduced new technical problems as predicted by the law of unintended consequences. One design that can partially overcome this problem involves a proximal bare stent, which can help coaxially align the first covered or sealing stent. That said, given the relatively greater association of retrograde type A dissections with such devices, the challenge is to achieve mural apposition and conformance with a design that does not necessitate a bare stent.

Pathology-Specific Designs

Although the only FDA-approved on-label indication for TEVAR is for treating degenerative aneurysms and penetrating ulcers, these techniques and devices have been successfully applied to treat a wide variety of pathologies that are not typically encountered in the abdominal aorta. These other entities include dissections, intramural hematomas, penetrating ulcers, traumatic transections, second-stage elephant trunk procedures, postsurgical pseudoaneurysms, and aortoesophageal and aortobronchial fistulas.

Despite the promising early results of these procedures, device-related limitations have also become apparent. Endovascular repair of complicated acute type B aortic dissection has yielded encouraging short-term results in achieving a seal of the primary tear and restoration of true lumen and branch vessel flow. However, in nearly all of these cases, the endograft must extend to the left common carotid artery and accommodate significant differentials in lumen size between the proximal and the compressed distal true lumen.

The role and utility of bare stenting of the true lumen in an acute dissection (PETTICOAT [provisional extension to induce complete attachment] technique) remains undefined in terms of remodeling and thrombosis of the false lumen. Visceral branch vessel management in the setting of a chronic dissection may need to be handled differently than for a thoracoabdominal aneurysm due to the presence of the false lumen.[4] The next-generation thoracic endovascular systems will have pathology-specific device modifications that will allow a more tailored treatment than those with a one-device-fits-all paradigm.

REGULATORY PATHWAY

One of the factors that contributes to and perpetuates the existence of unmet needs in a technology-dependent therapy such as thoracic endografting is not the pace of research and development but the regulatory barriers that make it unduly onerous for the timely dissemination of new technology that already exists and that can address some of these unmet needs. The pathway to commercialization, while intended to protect the patient through rigorous hypothesis-based testing, may not be realistic or feasible in certain circumstances due to the complexity of the therapy and/or prevalence of the disease and denies access to potentially life-saving therapies.

The creative mind will always find ways to circumvent barriers, and the unintended consequence of this in the current regulatory environment is the ever-growing practice of "back-table" modification of complex devices in an uncontrolled manner without any oversight.[5] Therefore, a clear unmet need is the formulation of regulatory processes that are disease therapy specific to allow the optimization of getting new technologies into the hands of operators quickly without compromising the safety of the patient. It would be interesting to imagine a world in which technology, and not regulatory approval, was the bottleneck to therapy.

CONCLUSION

Since the earliest report of thoracic endografting using homemade devices by Dake et al,[6] the entire space has made significant advances in terms of technology, operator technique, and a deeper appreciation of the unique pathophysiology that is involved in the endovascular treatment of the thoracic aorta. Despite some of their shortcomings, current thoracic devices work very well for their designed purpose in a large proportion and variety of cases, and many patients (young and old, low or high risk) have all benefited from the technology. ■

W. Anthony Lee, MD, FACS, is Director of the Endovascular Program at Christine E. Lynn Heart and Vascular Institute in Boca Raton, Florida. Dr. Lee has disclosed that he is a paid consultant to Medtronic, Inc. He further disclosed that he is a paid consultant to, receives grant/research funding from, and has a royalty agreement with Cook Medical. Dr. Lee may be reached at (561) 395-2626; walee66@hotmail.com.

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