Endovascular repair of the ascending aorta: the last frontier

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Different pathologies of the ascending aorta (AA), including aneurysms, acute and chronic dissections, and pseudoaneurysms, have been treated with open surgical repair with very good results, especially at aortic centers of excellence. There is, however, a subset of patients for whom open surgery is considered to pose high or prohibitive risk. These patients can benefit from a less invasive approach with catheters and wires, percutaneous techniques and stent grafts. However, the existing technology was developed to treat descending thoracic aortic pathologies; it is not approved for use in the AA by the US Food and Drug Administration (FDA). The devices used for the descending thoracic aorta (DTA) have certain size and design limitations that make their application to the AA cumbersome at times. As a result, custom-made endografts have been used to treat pathologies in the AA, although their use is feasible only in elective procedures. In addition, the AA has specific anatomic and physiologic characteristics that raise concerns about the long-term durability of the current technology. In this review, we outline the limitations, challenges and current status of endovascular technology to treat pathologies of the AA.

Keywords: Endovascular; aorta; surgery; minimally invasive; ascending

Introduction

The use of thoracic endovascular aortic repair (TEVAR) to treat aneurysm and dissection of the descending thoracic aorta (DTA) is well established (1). The success of TEVAR in the management of descending thoracic aneurysm has led to considerable interest in the application of this technology in the ascending aorta (AA).

Traditionally, pathologies of the AA, including aneurysms, dissections, intramural hematomas (IMHs) and pseudoaneurysms, were treated surgically. At experienced centers, operative intervention for these conditions yields acceptable results (2-5). Unfortunately, an important subset of patients present with preoperative characteristics that render surgery prohibitively risky (6). In these patients, the use of TEVAR for the AA and the aortic arch can be considered, presenting an invaluable treatment option.

In the absence of devices approved by the US Food and Drug Administration (FDA) for use in the AA and the aortic arch, the literature on the use of TEVAR in these segments deals primarily with custom-made and modified stent grafts. In the AA, complex branched grafts may not be necessary; instead, a single-branched device may be enough to treat most of the pathologies of the AA. Therefore, many of the principles used to treat the AA are extrapolated from studies focused on the DTA. However, even with limited experience, it is evident that TEVAR for the AA presents particular challenges. The AA has different anatomical and physiological characteristics than the DTA. Consequently, stent grafts specifically designed for the AA are needed to treat this area successfully. The ARISE trial—a multicenter, early feasibility study of the use of the FDA-approved Gore Ascending Stent Graft to treat type A aortic dissection—could offer promising new options for treating the AA (7,8).

Anatomic considerations

The ideal landing zone in the AA has the following

characteristics: a lengthy segment of healthy aorta, homogenous diameter and no sharp angles or calcification. This is to ensure adequate apposition of the stent graft to prevent endoleak, device migration, retrograde dissection and creation of a bird-beak.

The use of TEVAR in the AA, defined as landing zone 0, requires consideration of anatomic attributes distinct from those of the DTA (9). Although these are off-the-shelf devices and their use is off-label, they are designed for the DTA. For the AA, the most important factor is the distance from the entry tear to the sinotubular junction (STJ) proximally and to the brachiocephalic artery distally. For sealing, commercially available endografts require landing zones approximately 20 mm proximal and distal to the aortic pathology being treated. The shortest available stent graft for treating pathology in the DTA is 100 mm long, while the average length of the AA is around 70–80 mm. As a result, off-the-shelf grafts are often too long and thus unsuitable for many patients. Solutions suggested for this problem are: (I) custom-made grafts such as Medtronic Valiant PS-IDE Physician Sponsored-Investigational Device Exemption and the Relay NBS (non-bare stent) Plus (Terumo Aortic, Sunrise, FL, USA); and (II) off-label use of stent cuffs designed for the abdominal aorta (10-12). Neither of these options is optimal. Investigational devices are used by a small subset of surgeons. In addition, custom-ordered grafts are impractical in acute situations. The use of expanders or cuffs originally intended for use in the abdominal aorta is unsatisfactory as they are often too small for the AA. In addition, usually more than one expander cuff is required and the delivery system for cuffs is much shorter, often failing to reach the AA though a transfemoral approach. However, other access routes are available (13).

In addition, specific traits of the ascending aortic anatomy, such as angulation and differences in length between the inner and outer curvature of the AA, can cause difficulties when the existing devices are used. Consequently, devices with greater conformability are better suited for this purpose. Furthermore, the angulation must be taken into consideration when sizing the device. We typically use the outer curvature to determine the appropriate length of the stent graft.

Proximally, obstruction of low-lying coronary arteries is always a concern and can be alleviated by obtaining wire access to the coronary ostia before the device is deployed. If the coronary ostia are obstructed without wire placement into the ostia of the left and right coronary arteries before endograft deployment, conversion to open surgery may

be necessary. In patients with patent grafts from previous coronary artery bypass grafting, TEVAR for AA is usually not feasible because of the proximity to saphenous vein grafts.

Also, in patients with a previously implanted mechanical aortic valve, proximal landing above the coronary ostia can be problematic as the nose cone of the delivery device will interfere with the mechanical prosthesis, causing severe insufficiency. Cannulating the mechanical valve with a custom-made spear-shaped short-tip dilator (35 mm, 18 to 20 F) on the lateral side of the mechanical prosthesis has been described as a way to minimize the aortic insufficiency and permit delivery of the stent graft close to the aortic root (14).

Distally, concerning the length of the distal landing zone, this segment can be extended with aortic arch debranching through a cervical approach that avoids a median sternotomy, if the brachiocephalic artery must be covered by the stent graft. A device with a single side branch, currently under investigation in the United States, is another solution to revascularizing the brachiocephalic artery. There are also other endovascular solutions involving the chimney, snorkel and periscope techniques.

A homogenous diameter at the landing zone is required, and it has been suggested that a maximum STJ diameter of 38 mm should be used as a cutoff to determine candidacy for AA stenting (15). With the 45- and 46-mm diameter endografts currently available, a maximum STJ diameter of up to 40–42 mm could be considered.

Physiologic considerations

The AA, by virtue of its proximity to the left ventricle, is subject to higher pressures from the cardiac output. Consequently, using rapid ventricular pacing is advisable to decrease the cardiac output and allow more precise placement of the proximal end of the stent graft. This is especially important for patients in whom the TEVAR needs to land adjacent to the STJ or close to coronary arteries.

The diameter of the AA varies more than that of the DTA during the cardiac cycle, which can make appropriate sizing more challenging. Our preference for the AA is to oversize by 20% in cases of chronic dissection, while approaching acute dissections more cautiously with 0–10% oversizing. This is similar to the recommendations of 15–20% for DTA aneurysmal disease and 0–10% for acute DTA dissection (16,17). All our measurements for AA

grafts are taken with thin-slice 3D computed tomography angiography. We use the cross-section, perpendicular to the centerline of flow, as others do (18,19).

Blood flow characteristics have also been shown to differ between the AA and DTA. Magnetic resonance velocity mapping with cardiac-gated 3D data showed that particle paths follow a 360° right-handed helix pattern in the AA. In contrast, a straight pattern or left-handed helix was seen in the DTA (20). These flow patterns suggest that AA and DTA stent grafts are subject to continuous pressure at different points.

Finally, concomitant aortic valve insufficiency does not preclude TEVAR in type A dissection, as it may improve after stenting. This improvement is attributed to remodeling of the STJ and its return to normal anatomical position.

Outcomes

In a recent study, among 686 patients with acute type A aortic dissection treated during a ten-year period, 7.7% (53 patients) were classified as inoperable. After detailed imaging analysis, the interesting finding was that among these patients for whom open surgery posed prohibitive risk, only one-third were found to be at prohibitive risk from any intervention. This means that specially designed endovascular stent grafts could allow intervention and treatment in the majority of patients with any challenging pathology of the AA (21).

Unfortunately, data concerning the use of TEVAR in the AA are scarce. The commonly treated conditions are acute type A dissection (entry tear in the AA), retrograde dissection (tear in the proximal descending aorta), IMH, pseudoaneurysm and chronic dissection. As with any new technology, reported results inevitably include a mixture of clinical entities because of limited sample sizes, even though these pathologies represent a wide spectrum of aortic disease with different outcomes. A systematic meta-analysis by Muetterties et al. encompassed forty-six publications, for a total of 118 patients who underwent TEVAR for AA. The most common indication was type A dissection (in 50% of the cases), followed by pseudoaneurysm (29.7%), aortic aneurysm (5.1%), penetrating aortic ulcer (4.9%) and aortic rupture (2.5%). The majority of the cases consisted of type A dissection, suggesting that TEVAR was used in the AA primarily in emergency situations. Of note, 71.2% of the time, a thoracic stent graft was deployed, while 11% of the

stent grafts used were expander cuffs. Overall mortality was 15.2%, while the rate of deaths related to the aorta was 5%. These results suggest that in a cohort consisting primarily of patients with type A dissection, which presents a significant mortality risk on its own, the outcomes were reasonable (13). The average follow-up for this study was relatively short at 17.2 months.

Another study, which offered long-term data, was conducted by Roselli et al., who followed-up 22 patients over five years. These high-risk patients with significant comorbidities were treated with TEVAR for acute type A dissection, chronic dissection, IMH, pseudoaneurysm, chronic dissection and aorta-cardiac fistula. They found a relatively low thirty-day mortality rate at 14%, which gradually increased to 25% after five years. Considering the pathologies treated, combined with prohibitive surgical risk, these results are encouraging (16).

Recently, Hsieh et al. published their findings in six patients who had acute type A dissection or IMH. Their mortality was 16.7%, and there was one conversion to open surgery. However, the authors noted the subsequent regression of the false lumen in four patients. The authors concluded that although endovascular repair is feasible, it becomes technically challenging when the entry tear is located in the proximal half of the AA (22). Another series, from Vallabhajosyula and colleagues, showed no in-hospital or thirty-day mortality in six patients treated for ascending aortic pathology, two of whom were treated for acute type A aortic dissection (23).

Because of the anatomic and physiologic characteristics described here, the AA appears to be more prone to landing zone complications than the DTA, even if the AA is replaced with a Dacron graft. A study by Kotha et al. examined hybrid arch repair with proximal landing in a Dacron graft in the AA and found that of the 20 patients, almost 60% had bird-beaking (i.e., >5 mm of nonapposition), and 20% had type 1A endoleak, graft migration or infolding (24). This would suggest that the proximal position of the stent graft can be problematic, even if it is landed inside a Dacron graft.

The recently developed Gore Ascending Stent Graft, whose feasibility is being tested preliminarily in the ARISE trial, has special features that enable the stent graft to shorten its inner curvature to avoid bird-beaking and to better appose to the inner and outer aortic wall of the AA. As of May 2021, results of the ARISE study are still pending.

Conclusions

Currently, open surgical repair remains the treatment of choice for AA pathologies, with excellent outcomes as shown by robust long-term data. However, endovascular repair of the AA is a new and emerging technology that is still under investigation and, at present, could offer a solution for high-risk patients. Our prior data (19), in conjunction with the existing literature (13,16), suggest that endovascular repair is currently a feasible option in high-risk patients for whom surgery is prohibitively risky. In our experience, the number of patients with acute disease who could benefit from TEVAR is significant. This number would encompass frail and elderly patients, as well as individuals with complex surgical histories, which often include multiple sternotomies.

Although this is a promising new direction for the treatment of AA, the main barrier to widespread use is the lack of devices designed and approved specifically for treating the AA. Although several centers have used improvised devices off label for compassionate use, a device and delivery system specific to the AA would be invaluable. In addition, a TEVAR device for AA interventions would be designed with the unique flow characteristics of the AA in mind, which could enhance the device's durability and improve long-term outcomes.

Undoubtedly, when FDA-approved devices become available, standardized studies will be the norm; allowing each device to be approved for specific indications. This will help surgeons choose between surgical and endovascular repair according to the specific patient's risk profile, as well as the established treatment outcomes for each pathology.

Footnote

Conflicts of Interest: Dr. OP serves as a consultant for W. L. Gore and Associates and for Terumo Aortic. She has also received travel expenses paid by Medtronic, Inc., and Cook Medical in the past. Dr. JSC consults for, receives royalties and a departmental educational grant from, and participates in clinical trials for Terumo Aortic; consults and participates in clinical trials for Medtronic, Inc., and W.L. Gore & Associates; and participates in clinical trials for Abbott Laboratories, Edwards Lifesciences, and CytoSorbents. The other authors have no conflicts of interest to declare.

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