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Thoracoabdominal aortic aneurysm repair: open, endovascular, or hybrid?

Joshua M. Rosenblum[1] · Edward P. Chen[1]

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Abstract Successful repair of complex thoracoabdominal aortic aneurysms requires careful surgical planning based on anatomic and patient considerations. Not only are surgical considerations key, but also post-operative care, regardless of surgical approach, can dramatically impact both short- and long-term outcomes. While open repair has been the gold standard for decades, the technical challenges associated with operative repair, a specialty approach requisite for good outcomes, and the unique challenges in the post-operative care of these patients have given providers pause when considering operative intervention. The relatively recent development of elegant endovascular and hybrid approaches to this problem has shown improved short-term morbidity and reasonable durability. Here, we discuss these three techniques for correction of complex thoracoabdominal aortic aneurysms to provide some guidance for optimization of outcomes based on individual patient anatomy and comorbid conditions.

Keywords Thoracoabdominal aneurysm repair · Endovascular TAAA repair · Hybrid TAAA repair

Introduction

Thoracoabdominal aortic aneurysms (TAAA) represent a single disease entity with multiple treatment options and considerations based on anatomic specifications and the patient-specific concomitant medical comorbidities. TAAAs account for only 10% of all aortic aneurysms, and there are 100-fold more abdominal aortic aneurysms (AAA) repaired yearly as compared to TAAAs [1, 2]. Given the relative rarity of the entity, despite the first successful repair being reported in the 1950s, much of our knowledge of TAAA management still comes from large single-center (often single-practitioner) studies. Although surgical management of true TAAAs can be challenging, there is a near-uniform poor prognosis if left untreated, with a 76% mortality at 2 years and upwards of 95% mortality at 5 years [3].

Recognized genetic disorders, including Marfan syndrome, Ehlers–Danlos syndrome, and Loeys–Dietz syndrome, contribute to the generation of TAAA, but the majority are degenerative in nature and are associated with atherosclerosis. Thus, while TAAA and AAA have a different incidence, population distribution, and treatment outcomes, they share similar risk factors of smoking, hypertension, COPD, and peripheral vascular disease [4]. Since the location of the aneurysmal portion of the aorta in relation to upper extremity and visceral segment branches greatly affects surgical approach, the Crawford classification scheme of TAAA is the primary method used to describe this disease process (with some revision by Drs. Coselli and Safi) [5, 6]. Type I aneurysms extend from the origin of the left subclavian artery to the supraceliac aorta. Type II are the most extensive, from the subclavian artery to the aortoiliac bifurcation. Type III involve the distal thoracic aorta and extend to the aortoiliac bifurcation. Type IV are limited to the subdiaphragmatic aorta. Type V (added by Drs. Safi and Coselli) extend from the distal thoracic aorta and occasionally involve the celiac and SMA trunks, but terminates above the renal arteries.

✉ Joshua M. Rosenblum
jrosenblum82@gmail.com

1 Division of Cardiothoracic Surgery, Emory University School of Medicine, Atlanta, GA, USA

Indications for TAAA repair are still somewhat controversial, especially for asymptomatic aneurysms. As a result of the law of Laplace, the risk of rupture is directly related to the transverse diameter of the aneurysmal segment. The annual risk of rupture doubles with each 1 cm of growth over 5 cm, with a 7% annual risk of rupture for a 6-cm aneurysm [7, 8], and some have shown a 43% lifetime chance of rupture for aneurysms greater than 7 cm [9]. Although surgical repair carries a high risk of morbidity, in general, most agree that repair should be undertaken for TAAA: (1) rupture, (2) acute dissection with evidence of malperfusion or other complication, (3) symptomatic, (4) enlargement more than 1 cm per year, and (5) absolute size >6.5 or >6.0 cm in patients with connective tissue disorder. Here, we discuss the considerations for repair of TAAA using standard open approaches and newer endovascular and hybrid techniques.

Open TAAA repair

The first description of TAAA repair in the United States was by Etheredge in 1955, and subsequent work by Debakey further demonstrated the possibility of aortic replacement for TAAA [10, 11]. Crawford modernized and refined the technique of open TAAA repair using an intra-aortic anastomosis (dispensing with prior reports using aneurysmectomy), cerebrospinal fluid drainage, cardiopulmonary bypass (CPB), and hypothermic circulatory arrest, with excellent results and only one death in 23 cases [12, 13].

Approach to repair of TAAA is via a standard major left thoracoabdominal incision. Single-lung ventilation is employed with a double-lumen endotracheal tube. Patients are placed in the right decubitus position after insertion of a urinary catheter, femoral arterial and venous lines as well as large bore volume delivery venous lines. We routinely employ both motor- and sensory-evoked potential monitoring throughout the case, and a lumbar drain is used for cerebrospinal fluid drainage. Upon incision, the peritoneum and its contents are reflected anteriorly and to the right, and the diaphragm is divided to allow access to the entirety of the thoracoabdominal aorta. In our practice, we prefer the use of an open CPB circuit for left-heart bypass which allows for volume return via the circuit and more controlled temperature management. Additionally, when the aneurysm extends to the arch or when prior arch surgery precludes safe proximal clamping, hypothermic circulatory arrest can be instituted with no significant changes to the operative set up.

Following any necessary exposure of visceral vessels, CPB is initiated, and sequential clamping of the distal aorta and visceral vessels allows for reconstruction with a tube graft or branched graft. This approach minimizes ischemic insult to end-organs. After restoration of antegrade blood flow, protamine is administered. During the post-operative period, maintaining supranormal blood pressure with inotropes and vasoactive agents is critical to maintaining cerebral perfusion pressure while draining cerebrospinal fluid. We wean sedation early to allow for full neurological assessment, especially lower extremity function.

In early reports of open TAAA repair, hospital mortality approached 10% with significant rates of paraplegia or paralysis (14%), stroke (3%), renal failure requiring dialysis (9%), and respiratory complications (33%) [14]. Refinement of surgical technique, emphasis on end-organ perfusion, and recognition that spinal cord protection is key to preventing paralysis has led to slow improvements in contemporary outcomes. The Houston group maintains some of the best results with 5% 30-day mortality and less than 4% spinal ischemia (as low as 1.3% in one report) [13, 15, 16]. In a contemporary series from 2005 to 2012 of more than 800 open TAAA repairs, operative mortality was 8.4% with a 5% permanent spinal cord injury rate and 7.4% of patients requiring dialysis [17]. When stratified by Crawford classification, Extent II and III patients had the highest rates of adverse outcomes approaching 20% with 7.6% permanent paraplegia in Extent III patients.

Based on these studies, it is clear that open repair of TAAA has likely struck a nadir of operative mortality and morbidity. In the hands of high-volume surgeons and centers, acceptable operative mortality is likely 5% with a 5% risk of paraplegia. Other investigators have studied intercostal reimplantation as a means for improving post-operative spinal ischemia, but conclusive findings are lacking. In our practice, we offer open repair of TAAA for younger patients with few medical comorbidities, and complex anatomy not amenable to other options.

Endovascular TAAA repair

After nearly 50 years of improving results with open TAAA repair and in parallel to the development of complex endovascular techniques for AAA repair, the first totally endovascular repair of TAAA was reported using custom-made branched stent grafts [18]. Similar to the benefits of endovascular repair of AAA, there are theoretical advantages to endovascular TAAA repair as compared to open. Perhaps the two greatest benefits of an endovascular approach to TAAA are avoiding the large thoracoabdominal incision with need for single-lung ventilation and elimination of visceral ischemia during reconstruction. One drawback, however, to the endovascular approach is that there is no way to revascularize large intercostal arteries which may have otherwise been reimplanted during an open repair. This has the potential to result in greater rates of spinal cord ischemia in endovascular TAAA repair.

As it stands, endovascular repair of TAAA requires advanced wire and catheter skills and devices which are currently under investigational use. To maintain flow to multiple visceral segments, either separate endograft "snorkels" or "periscopes" are required to supplement the standard tube aortic stent graft, or custom-designed fenestrated stent grafts with openings for the major visceral segments must be created (often on a 6–12-week timescale). This results in challenging implantation and long fluoroscopic times with radiation exposure to both patient and operating staff. Improvements in delivery systems, however, have made much of the device deployment possible via a percutaneous femoral approach, without the need for groin incisions.

Results of endovascular TAAA repair have been promising in the hands of experienced operators and centers [19–21]. In single-center reports, operative 30-day mortality has been low, ranging from 2 to 6% (although one early report had 21% operative mortality). Renal failure requiring dialysis was present in less than 5% of most cases. Unfortunately, spinal cord ischemia still complicated a substantial number of repairs, with transient paraplegia reportedly as high as 20% and permanent injury ranging from 4 to 8%. Cardiorespiratory complications were uniformly low. As evidence of the complex nature of this operation, fluoroscopy times ranged from 110 to 145 min. Long-term durability is still questionable. All-cause survival in one study was only 60% at 3 years [18], but another study showed that TAAA-specific survival was 80% at 3 years [21]. In that group, however, the mid-term reintervention rate was high at 50% at 3 years.

While a purely endovascular approach to TAAA repair is appealing for many reasons, the questionable durability, long fluoroscopic times and radiation exposure, and lack of reasonable comparison to open repairs still limits implementation to a small number of highly specialized centers. Furthermore, clinical applicability in connective tissue disorders, chronic dissections, and mycotic psuedoaneurysms is unclear, and there is no role for endograft placement in the setting of prosthetic infection. In our practice, only high-risk open surgical patients and those with aneurysm anatomy amenable to endovascular repair are offered this technique. With the worry of spinal cord ischemia, we still employ cerebrospinal fluid drainage and supraphysiologic blood pressure parameters for these patients in the perioperative period. Additionally, since delayed development of endoleaks and resultant continued expansion of the aneurysm sac is a known possibility with endovascular TAAA repair, all patients must obtain routine (yearly) cross-sectional imaging to survey the durability of the repair. Despite this, there is still a small subset of patients who will clearly benefit from endovascular TAAA repair who would otherwise not survive a standard open operation.

Hybrid TAAA repair

Owing to the challenges of complete endovascular repair of TAAA and the inherent risks of major morbidity from open repair, some groups have developed and implemented a hybrid approach to TAAA repair. In a single setting or staged fashion, open debranching of visceral segments precedes placement of an endovascular stent graft to exclude the aneurysmal aortic segment. Theoretically, this technique has the advantages of avoiding the thoracotomy, single-lung ventilation, and prolonged ischemic times due to aortic cross-clamping necessary in open TAAA repairs, and allows for repair of aneurysms with anatomy that would otherwise be prohibitive of totally endovascular repair. Through either a transabdominal or retroperitoneal approach via laparotomy, any involved visceral branches and the renal arteries are bypassed with synthetic tube grafts using retrograde inflow from the distal aorta, the iliac arteries, or a previous aortic graft. Proximal branches are ligated to prevent future endoleak. In either the same setting or in a second operation, an endovascular tube stent graft is placed in the thoracoabdominal aorta to exclude the aneurysmal section.

Early results of hybrid TAAA repairs have been encouraging. In single-center reports, operative mortality was 8.6–13.5%, with 62% 5-year survival, and rates of paraplegia and renal failure match or are better than in open repair series [22, 23]. When compared to a similar group of patients undergoing open TAAA repair, hybrid repair patients showed improved short-term outcomes with equivalent mid-term survival, 95% graft patency rate, and equivalent need for reintervention at 4 years ($\sim$10%) [24]. In a small contemporary series, hybrid TAAA repair patients had exceedingly low rates of perioperative complications, with only 30% rate of post-operative dialysis (none permanent), 10% rate of paralysis (other patients with temporary paraplegia reversed with aggressive cerebrospinal fluid drainage), 0% operative mortality, and zero aorta-related mortalities at mean follow-up of 55 months [25].

Although some authors argue that these results with hybrid TAAA repair do not improve upon the already reasonable outcomes with open repair [26], a direct comparison is not fair at this point, since no randomized or matched trials have been undertaken. Indeed, many patients who are selected for hybrid TAAA repair would not have been candidates for open repair due to significant medical comorbidities, and they would thus not be represented in current open repair series. An additional benefit to hybrid repair techniques is that they can be employed in the urgent or emergent setting of ruptured TAAA or TAAA with malperfusion in patients who have significant respiratory or cardiac comorbidities and would not survive open repair. With current endovascular technology, these patients would otherwise have no options for repair since there are no off-the-shelf fenestrated stent grafts available. In our practice, we consider patients for an elective hybrid TAAA repair if their medical comorbidities preclude them from a major open thoracoabdominal approach and if their anatomy precludes reasonable endovascular stent grafting. Furthermore, if patients wish to avoid long-term surveillance for endoleaks, the hybrid approach is an option. We still employ aggressive perioperative measures to avoid spinal cord ischemia as with all other TAAA repair techniques.

Comments

Clearly, surgical management of TAAA remains a challenging problem. Open repair is the gold-standard approach, but is invasive and complex with significant risks for major comorbidity and mortality. The durability of open repair is well established, and, while left-heart bypass at minimum is generally required, there are no aorta-specific or anatomic constraints. Endovascular repair of TAAA is becoming more prevalent. Universal clinical applicability is still lacking, however, as there are no commercially available stent grafts to manage all Crawford class TAAAs. Commercial development of off-the-shelf fenestrated grafts is on the horizon, hopefully expanding endovascular options for TAAA repair. Long-term durability is yet to be elucidated, and patients still require routine surveillance to monitor for endoleak development. Finally, hybrid approaches bridge the gap to potentially provide the best of both worlds. Complex anatomic considerations can be addressed with open visceral debranching, while the primary TAAA can be covered with an endovascular stent, thus eliminating the need for cardiopulmonary bypass and minimizing the associated ischemic insult. Although long-term durability of the hybrid technique remains unclear, limited studies have shown results and outcomes favorable to open repair.

In our practice, patients who are young with low operative risk are referred for open TAAA repair, and all patients with connective tissue disorders or with difficult anatomy undergo open repair. We consider purely endovascular approaches in high operative risk patients with anatomy favorable for currently available and custom-made stent grafts. For patients who are high risk but do not have anatomy amenable to total endovascular TAAA repair, we pursue hybrid repair with open debranching and endovascular stent grafting. Certainly, TAAA is a challenging disease entity that requires a collaborative, multidisciplinary team to provide safe, long-term durable outcomes for all patient cohorts while minimizing operative risks.

References

1. Bickerstaff LK, Pairolero PC, Hollier LH, et al. Thoracic aortic aneurysms: a population-based study. Surgery. 1982;92:1103–8.
2. Cowan JA Jr, Dimick JB, Henke PK, Rectenwald J, Stanley JC, Upchurch GR Jr. Epidemiology of aortic aneurysm repair in the United States from 1993 to 2003. Ann N Y Acad Sci. 2006;1085:1–10.
3. Crawford ES, DeNatale RW. Thoracoabdominal aortic aneurysm: observations regarding the natural course of the disease. J Vasc Surg. 1986;3:578–82.
4. Escobar GA, Upchurch GR Jr. Management of thoracoabdominal aortic aneurysms. Curr Probl Surg. 2011;48:70–133.
5. Crawford ES, Crawford JL, Safi HJ, et al. Thoracoabdominal aortic aneurysms: preoperative and intraoperative factors determining immediate and long-term results of operations in 605 patients. J Vasc Surg. 1986;3:389–404.
6. Safi HJ, Miller CC 3rd. Spinal cord protection in descending thoracic and thoracoabdominal aortic repair. Ann Thorac Surg. 1999;67:1937–9 (**discussion 1953–1938**).
7. Juvonen T, Ergin MA, Galla JD, et al. Prospective study of the natural history of thoracic aortic aneurysms. Ann Thorac Surg. 1997;63:1533–45.
8. Kuzmik GA, Sang AX, Elefteriades JA. Natural history of thoracic aortic aneurysms. J Vasc Surg. 2012;56:565–71.
9. Elefteriades JA. Natural history of thoracic aortic aneurysms: indications for surgery, and surgical versus nonsurgical risks. Ann Thorac Surg. 2002;74:S1877–80 (**discussion S1892–S1878**).
10. Etheredge SN, Yee J, Smith JV, Schonberger S, Goldman MJ. Successful resection of a large aneurysm of the upper abdominal aorta and replacement with homograft. Surgery. 1955;38:1071–81.
11. DeBakey ME, Crawford ES, Garrett HE, Beall AC Jr, Howell JF. Surgical considerations in the treatment of aneurysms of the thoraco-abdominal aorta. Ann Surg. 1965;162:650–62.
12. Crawford ES. Thoraco-abdominal and abdominal aortic aneurysms involving renal, superior mesenteric, celiac arteries. Ann Surg. 1974;179:763–72.
13. Frederick JR, Woo YJ. Thoracoabdominal aortic aneurysm. Ann Cardiothorac Surg. 2012;1:277–85.
14. Svensson LG, Crawford ES, Hess KR, Coselli JS, Safi HJ. Experience with 1509 patients undergoing thoracoabdominal aortic operations. J Vasc Surg. 1993;17:357–68 (**discussion 368–370**).
15. Coselli JS, Bozinovski J, LeMaire SA. Open surgical repair of 2286 thoracoabdominal aortic aneurysms. Ann Thorac Surg. 2007;83:S862–4 (**discussion S890–S862**).
16. Estrera AL, Miller CC 3rd, Chen EP, et al. Descending thoracic aortic aneurysm repair: 12-year experience using distal aortic perfusion and cerebrospinal fluid drainage. Ann Thorac Surg. 2005;80:1290–6 (**discussion 1296**).
17. LeMaire SA, Price MD, Green SY, Zarda S, Coselli JS. Results of open thoracoabdominal aortic aneurysm repair. Ann Cardiothorac Surg. 2012;1:286–92.

18. Ferreira M, Lanziotti L, Monteiro M. Branched devices for thoracoabdominal aneurysm repair: early experience. J Vasc Surg. 2008;48:30S–6S **(discussion 36S)**.
19. Iafrancesco M, Ranasinghe AM, Claridge MW, Mascaro JG, Adam DJ. Current results of endovascular repair of thoraco-abdominal aneurysms dagger. Eur J Cardiothorac Surg. 2014;46:981–4 **(discussion 984)**.
20. Ferreira M, Lanziotti L, Cunha R, d'Utra G. Endovascular repair of thoracoabdominal aneurysms: results of the first 48 cases. Ann Cardiothorac Surg. 2012;1:304–10.
21. Reilly LM, Rapp JH, Grenon SM, Hiramoto JS, Sobel J, Chuter TA. Efficacy and durability of endovascular thoracoabdominal aortic aneurysm repair using the caudally directed cuff technique. J Vasc Surg. 2012;56:53–63 **(discussion 63–54)**.
22. Tshomba Y, Melissano G, Logaldo D, et al. Clinical outcomes of hybrid repair for thoracoabdominal aortic aneurysms. Ann Cardiothorac Surg. 2012;1:293–303.
23. Hughes GC, Andersen ND, Hanna JM, McCann RL. Thoracoabdominal aortic aneurysm: hybrid repair outcomes. Ann Cardiothorac Surg. 2012;1:311–9.
24. Patel HJ, Upchurch GR Jr, Eliason JL, et al. Hybrid debranching with endovascular repair for thoracoabdominal aneurysms: a comparison with open repair. Ann Thorac Surg. 2010;89:1475–81.
25. Vaaramaki S, Suominen V, Pimenoff G, Saarinen J, Uurto I, Salenius J. Hybrid repair of thoracoabdominal aortic aneurysms is a durable option for high-risk patients in the endovascular era. Vasc Endovasc Surg. 2016;50:491–6.
26. Yamaguchi D, Jordan WD Jr. Hybrid thoracoabdominal aortic aneurysm repair: current perspectives. Semin Vasc Surg. 2012;25:203–7.