MINIMALLY INVASIVE TECHNIQUES FOR TOTAL AORTIC ARCH RECONSTRUCTION

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Abstract

The cumulative experience with endovascular aortic repair in the descending thoracic and infrarenal aorta has led to increased interest in endovascular aortic arch reconstruction. Open total arch replacement is a robust operation that can be performed with excellent results. However, it requires cardiopulmonary bypass and circulatory arrest and, therefore, may not be tolerated by all patients. Minimally invasive techniques have been considered as an alternative and include hybrid arch debranching, parallel stent graft deployment in the chimney and snorkel configurations, and complete endovascular branched reconstruction with multi-branched devices. This review discusses the evolving use of endovascular techniques in the management of aortic arch pathology and considers their relevance in an era of safe and durable open aortic arch reconstruction.

Introduction

Aortic arch reconstruction is performed with excellent results in high-volume centers due to refinements in surgical technique, perfusion strategy, and patient selection.[1,2] Open repair provides a durable reconstruction and remains the standard against which all new techniques must be compared. The need for cardiopulmonary bypass and deep hypothermic circulatory arrest may not be tolerated by all patients due to extreme surgical risk. Consequently, minimally invasive techniques have been developed to expand the suitability of aortic repair to medically and anatomically unfavorable patient populations. Both hybrid repair and total endovascular arch repair, which includes custom-made and physician-modified fenestrated and branched devices as well as chimney/snorkel techniques, allow for minimally invasive aortic arch reconstructions in patients who are considered at high risk for open repair.

Hybrid Arch Reconstruction

Experience with thoracic endovascular aortic repair (TEVAR) for descending aortic pathology originated with stent graft deployment distal to the left subclavian artery in Ishimaru Zones 3 and 4. This success has led to attempts to extend endovascular repair proximally into the aortic arch. To create a landing zone for thoracic endograft deployment extending to Ishimaru Zone 1, cervical extra-anatomic revascularization is required (Figure 1). Further extending the landing zone into Zone 0 requires a sternotomy with direct inline revascularization of the great vessels from the ascending aorta (Figure 2). This hybrid repair, with total arch debranching and subsequent thoracic endovascular aortic repair, is now an accepted strategy for high-risk patients requiring total arch reconstruction.

Complete aortic arch debranching to create a landing zone in the tubular portion of the ascending aorta can be done with or without ascending aortic replacement. A type 1 hybrid reconstruction does not require ascending aortic replacement and, therefore, avoids aortic cross-clamping and cardiopulmonary bypass.[3] This repair is completed through a median sternotomy with tangential aortic clamping to create a bypass to one or more supra-aortic trunks. Following arch debranching, an endograft is deployed distal to the bypass in Zone 0. While this hybrid repair avoids cardiopulmonary bypass, instrumentation of the aortic arch during both the debranching and endovascular portions of this procedure has been associated with retrograde aortic dissection.[3-5] This well-described complication is related to tangential clamping of the aorta or due to alterations in hemodynamics and compliance mismatch between the covered stent graft and the native aorta.[4] Retrograde type A aortic dissection has been reported in 6% of patients when a stent graft is deployed in the native ascending aorta following debranching and is associated with a 42% mortality rate.[5] In addition to retrograde dissection, degeneration of the native ascending aorta may lead to subsequent aneurysm or late type 1 endoleak formation.

To address these potential complications, some have advocated for native ascending aorta replacement during debranching to remove the risk of subsequent dissection or aneurysmal degeneration.[5] This debranching strategy is known as a type II hybrid reconstruction.[3] In a combined Canadian and American series of 20 patients presenting with both acute and chronic arch pathology, Kent and associates used a prefabricated branched Dacron graft to replace the ascending aorta and debranch the aortic arch.[5] The reported mortality rate was 10%, with a 5% cerebrovascular accident (CVA) rate and 20% transient paraplegia but with no permanent paraplegia noted.

Selection bias has limited the ability to adequately compare open total arch reconstruction with hybrid repair. Patients at high surgical risk are more likely to receive a hybrid repair than an open total arch reconstruction.[6-8] In a single-institution retrospective report, patients who had undergone traditional open repair using antegrade cerebral perfusion, moderate hypothermic circulatory arrest, and a prefabricated branched graft were compared to those who underwent hybrid repair using arch debranching and stent graft deployment.[6] While patients selected for hybrid repair were at significantly higher perioperative risk than those receiving open repair, results showed no significant differences in terms of mortality, paraplegia, or stroke rate. The intensive care unit (ICU) and overall postoperative length of stay was shorter and the reintervention rate was higher in the hybrid group. Of note, there were 4 late type 1 endoleaks that developed in the hybrid patients. In a subgroup of matched patients, no difference between groups was noted in terms of survival, stroke and renal failure. A meta-analysis echoed these results, with no difference in mortality

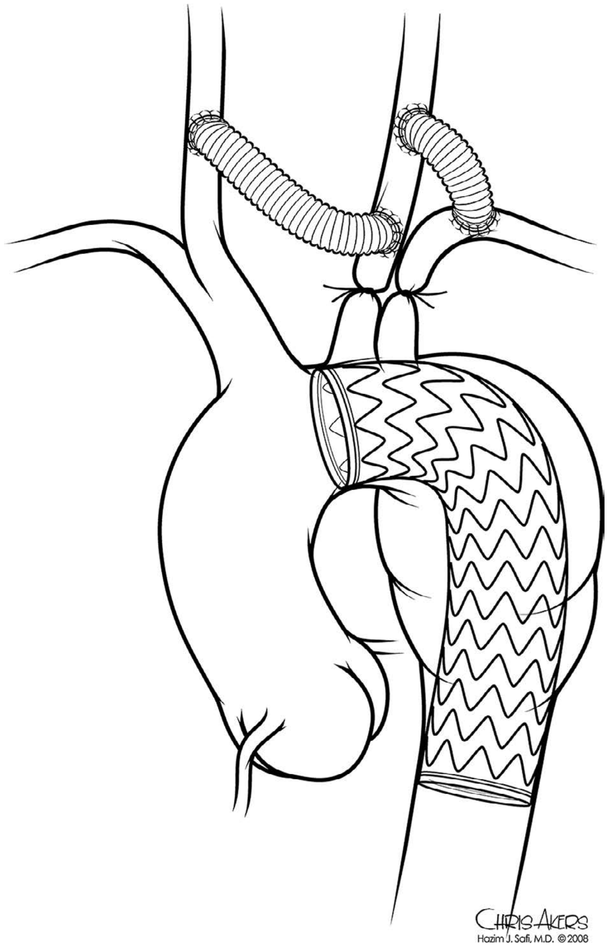

Figure 1. Hybrid endovascular arch repair extending to Ishimaru Zone 1. Supra-aortic branch revascularization using transcervical right carotid to left carotid artery bypass with left carotid to left subclavian artery bypass.

or stroke noted between patients undergoing hybrid versus open total arch replacement.[7]

The literature describing hybrid aortic arch reconstruction was reviewed by Moulakakis.[8] In this pooled analysis, which incorporated 26 hybrid reports, the authors noted that patients were treated for degenerative aneurysms, dissection, pseudoaneurysm, or trauma. The procedure was technically successful in 92% of patients. Perioperative mortality was 11.9%, the CVA rate was 7.6%, and the rate of irreversible spinal cord ischemia was 3.6%. A separate systematic review noted heterogeneous results between studies, with mortality rates varying between 2% and 23.7%, stroke rates between 0.8% and 18.8%, and spinal cord injury between 1% and 14.3%.[9]

These reports highlight the significant differences in patients selected for hybrid repair in the current literature. The durability of the hybrid technique has been called into question, with 20.1% of patients having endoleak reported on follow-up imaging. Surprisingly, the majority of the reported endoleaks on follow-up imaging were type 1, representing 12.9% of the patients.[8]

Total Endovascular Arch Reconstruction

Total endovascular aortic arch reconstructions represent a small portion of TEVAR, with only 4% of them involving a branch or fenestration to a supra-aortic vessel.[10] Total reconstruction may involve prefabricated fenestrated or branched devices, in situ or back-table physician modifications to currently available devices,

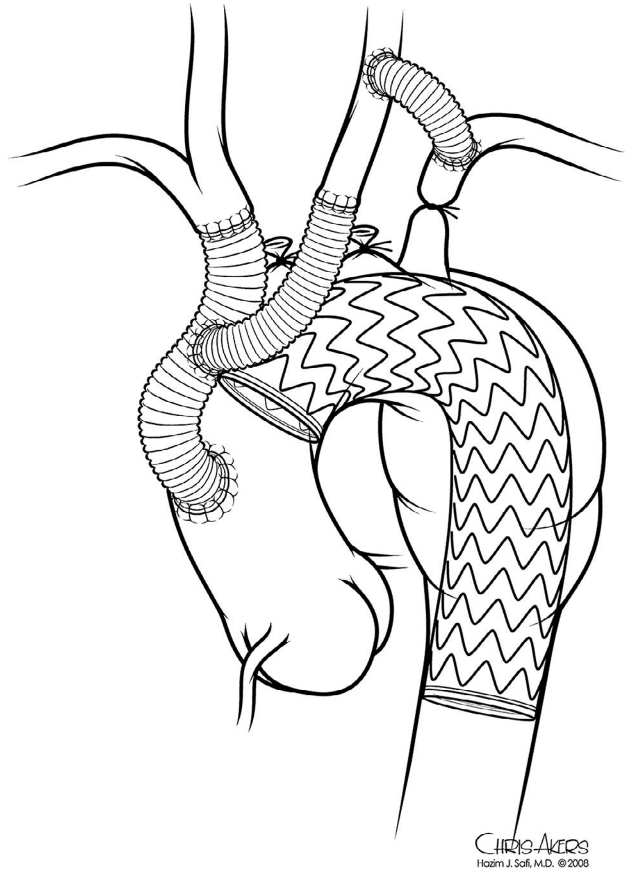

Figure 2. Zone 0 hybrid arch reconstruction with aortic branch revascularization requiring sternotomy and bypass from the ascending aorta.

and parallel aortic and supra-aortic stent grafts in the chimney/snorkel technique. These methods aim to preserve inline flow to the supra-aortic branches using a combination of covered stent grafts to mitigate the risk associated with traditional open arch reconstruction.

The successful use of branched endografts for thoracoabdominal aneurysms has increased interest in modular branched grafts for complete endovascular aortic arch reconstruction. However, the complex 3-dimensional forces and angulation in the aortic arch limit both the short-term technical success as well as long-term durability of branched endografts in the aortic arch.[11,12] The current need for custom-made devices, lack of regulatory approval, and high reported neurologic complication rate in previous reports have limited the experience with arch-branched devices to small case series.[13-18] In a report of six high-risk patients with arch aneurysms, a custom-made stent graft was used with branches to the innominate and left common carotid arteries combined with a left carotid to subclavian artery bypass.[16] Two of the six patients suffered a CVA and two did not have successful exclusion of the arch aneurysm. A review of all patients treated with a commercially available branched aortic arch endograft revealed only 38 patients treated at 10 institutions over a 4-year period.[19] These results reinforce the complexity and risks associated with extensive endovascular repair in the aortic arch. The authors did demonstrate a trend toward improved patient outcomes after a learning curve of 10 cases. Physician-modified branched grafts have been used with some success in the arch, although neurologic morbidity remains an important consideration, secondary to embolic stroke. A unibody branched device can be made by suturing a polytetrafluoroethylene (PTFE) graft to a conventional thoracic graft to allow innominate artery revasculatization.[20]

Excellent results with custom-made fenestrated devices have been reported.[21-23] The Japanese Najuta fenestrated thoracic stent graft (Kawasumi Laboratories, Tokyo, Japan) uses a combination of preformed stainless steel stents, externally attached PTFE, and curved delivery sheaths for total endovascular aortic arch reconstruction. In a study of the first-generation thoracic stent graft in more than 380 patients, technical success was achieved in 95.8% of patients, with a perioperative mortality rate of 1.6%, paraplegia rate of 0.8%, and CVA rate of 1.8%.[22] In a more recent experience, the authors successfully deployed the fenestrated arch device in more than 99% of the 393 patients, with a perioperative mortality rate of 1.5%, stroke rate of 1.7%, and paraplegia rate below 1%.[24] These studies confirm the excellent early results with fenestrated grafts. However, long-term branch vessel patency and late endoleak remain a concern.[21]

Retrograde access to the supra-aortic branches by means of downstream vascular puncture allows in situ fenestration of conventional thoracic aortic grafts. A variety of techniques have been used to puncture the fabric of the TEVAR device, sequentially dilate the fenestration with balloons, and seal the fenestration with a covered stent graft. Although limited to ex vivo testing, Dacron thoracic grafts appear to have less graft degeneration following in situ fenestration compared to PTFE and are the preferred thoracic graft for fenestration.[25]

A stent graft deployed parallel to a thoracic endograft can be used to maintain supra-aortic branch patency and extend the landing zone proximally in endovascular aortic arch reconstruction. This technique—known as a “chimney” if antegrade flow is preserved or a “periscope” in cases of retrograde flow—has been most commonly used with TEVAR for the descending thoracic repair. Although multiple supra-aortic branches can be revascularized with chimney stent grafts, a single chimney allows extra-anatomical reconstructions of the supra-aortic branches. In a review of 26 patients treated with the chimney technique, successful graft deployment with maintenance of branch vessel patency was achieved in all patients.[26] There was one perioperative death due to CVA, and the overall postoperative stroke and paraplegia rate was 17% and 7.7%, respectively. At 3-year follow-up, 90% branch patency was reported. However, the group noted a type 1 endoleak rate of 23%.[26] In a systematic review, the majority of chimney cases involved a single aortic branch revascularization. The perioperative mortality and stroke rates were 5.9% and 7.8%, respectively. Early type 1 endoleak occurred in 11.8% of the patients, but no late type 1 endoleaks were found in this review.[27]

The small number of patients treated with a complete endovascular arch repair limits meaningful comparison between techniques. In a review of the Cleveland Clinic experience, custom-made branched devices were compared to the chimney technique.[10] Of the 33 total patients analyzed, 18 had a chimney repair and 15 had a custom-made branched device. As such, the majority of these cases extended the seal zone into Zone 1 with only two cases involving repair extending to Zone 0. Overall, the mortality rate was 12%, and the spinal cord and stroke rate were each reported at 6%. Also, 12% of patients experienced branch vessel stent complication, defined as stent occlusion or migration, and 9% required an open conversion within 6 months for either retrograde dissection or type I endoleak. Despite the fact that these patients were at high anatomic and physiologic risk, the poor outcomes led the authors to suggest alternate treatment strategies for patients requiring aortic arch reconstruction.[10] There was a trend toward improved outcome among those having a custom graft. However, the indication and urgency of repair was not similar in the two groups.

Conclusion

The complexity of aortic arch reconstruction is highlighted by the unique difficulties facing endovascular approaches in this region. Angulation, risk of dissection, and the intolerance of the supra-aortic branch vessels to any complications have dampened the success of minimally invasive surgery when compared to the experience with distal aortic repairs. Hybrid open and endovascular reconstruction is the most popular current method of minimally invasive arch reconstruction. Advancements in technology are likely to increase the utilization of endovascular techniques for treatment of patients unsuitable for open aortic arch repair.

Conflict of Interest Disclosure: Dr. Estrera is a consultant with W. L. Gore & Associates, Inc.

Keywords: endovascular aortic repair, aortic arch reconstruction, aortic arch debranching, hybrid endovascular construction

References

1. Safi HJ, Miller CC 3rd, Lee TY, Estrera AL. Repair of ascending and transverse aortic arch. J Thorac Cardiovasc Surg. 2011 Sep;142(3):630-3.
2. Estrera AL, Miller CC 3rd, Huynh TT, Porat EE, Safi HJ. Replacement of the ascending and transverse aortic arch: determinants of long-term survival. Ann Thorac Surg. 2002 Oct;74(4):1058-64.
3. Vallabhajosyula P, Szeto WY, Desai N, Komlo C, Bavaria JE. Type II arch hybrid debranching procedure. Ann Cardiothorac Surg. 2013 May;2(3):378-86.
4. Czerny M, Schmidli J, Carrel T, Grimm M. Hybrid aortic arch repair. Ann Cardiothorac Surg. 2013 May;2(3):372-7.
5. Kent WD, Appoo JJ, Bavaria JE, et al. Results of type II hybrid arch repair with zone 0 stent graft deployment for complex aortic arch pathology. J Thorac Cardiovasc Surg. 2014 Dec;148(6):2951-5.
6. Iba Y, Minatoya K, Matsuda H, et al. How should aortic arch aneurysms be treated in the endovascular aortic repair era? A risk-adjusted comparison between open and hybrid arch repair using propensity score-matching analysis. Eur J Cardiothorac Surg. 2014 Jul;46(1):32-39.
7. Benedetto U, Melina G, Angeloni E, Codispoti M, Sinatra R. Current results of open total arch replacement versus hybrid thoracic endovascular aortic repair for aortic arch aneurysm: a meta-analysis of comparative studies. J Thorac Cardiovasc Surg. 2013 Jan;145(1):305-6.
8. Moulakakis KG, Mylonas SN, Markatis F, Kotsis T, Kakisis J, Liapis CD. A systematic review and meta-analysis of hybrid aortic arch replacement. Ann Cardiothorac Surg. 2013 May;2(3):247-60.
9. Cao P, De Rango P, Czerny M, et al. Systematic review of clinical outcomes in hybrid procedures for aortic arch dissections and other arch diseases. J Thorac Cardiovasc Surg. 2012 Dec;144(6):1286-300.
10. O’Callaghan A, Mastracci TM, Greenberg RK, Eagleton MJ, Bena J, Kuramochi Y. Outcomes for supra-aortic branch vessel stenting in the treatment of thoracic aortic disease. J Vasc Surg. 2014 Oct;60(4):914-20.

11. Neequaye S, Abraham C. Total endograft replacement of the aortic arch. Ann Cardiothorac Surg. 2013 May;2(3):362-6.
12. Schoder M, Lammer J, Czerny M. Endovascular aortic arch repair: hopes and certainties. Eur J Vasc Endovasc Surg. 2009 Sep;38(3):255-61.
13. Inoue K, Hosokawa H, Iwase T, et al. Aortic arch reconstruction by transluminally placed endovascular branched stent graft. Circulation. 1999 Nov 9;100(19 Suppl):316-21.
14. Chuter TA, Schneider DB, Reilly LM, Lobo EP, Messina LM. Modular branched stent graft for endovascular repair of aortic arch aneurysm and dissection. J Vasc Surg. 2003 Oct;38(4):859-63.
15. Hinchliffe RJ, Krasznai A, Schultzekool L, et al. Observations on the failure of stent-grafts in the aortic arch. Eur J Vasc Endovasc Surg. 2007 Oct;34(4):451-6.
16. Lioupis C, Corriveau MM, MacKenzie KS, Obrand DI, Steinmetz OK, Abraham CZ. Treatment of aortic arch aneurysms with a modular transfemoral multibranched stent graft: initial experience. Eur J Vasc Endovasc Surg. 2012 May;43(5):525-32.
17. Varcoe RL, Lennox AF. Fenestrated aortic arch stent-graft malfunction with endovascular salvage. J Endovasc Ther. 2013 Apr;20(2):242-8.
18. Brar R, Ali T, Morgan R, Loftus I, Thompson M. Endovascular repair of an aortic arch aneurysm using a branched-stent graft. Eur J Vasc Endovasc Surg. 2008 Nov;36(5):545-9.
19. Haulon S, Greenberg RK, Spear R, et al. Global experience with an inner branched arch endograft. J Thorac Cardiovasc Surg. 2014 Oct;148(4):1709-16.
20. Murphy EH, Stanley GA, Ilves M, et al. Thoracic endovascular repair (TEVAR) in the management of aortic arch pathology. Ann Vasc Surg. 2012 Jan;26(1):55-66.
21. Matsuyama M, Nakamura K, Nagahama H, et al. Long-term results of endovascular repair for distal arch and descending thoracic aortic aneurysms treated by custom-made endografts: usefulness of fenestrated endografts. Ann Vasc Dis. 2014;7(4):383-92.
22. Yuri K, Yokoi Y, Yamaguchi A, Hori D, Adachi K, Adachi H. Usefulness of fenestrated stent grafts for thoracic aortic aneurysms. Eur J Cardiothorac Surg. 2013 Oct;44(4):760-7.
23. Mangialardi N, Ronchey S, Malaj A, et al. Case report of an endovascular repair of a residual type A dissection using a not CE not FDA-approved Najuta thoracic stent graft system. Medicine (Baltimore). 2015 Jan;94(3):e436.
24. Azuma T, Yokoi Y, Yamazaki K. The next generation of fenestrated endografts: results of a clinical trial to support an expanded indication for aortic arch aneurysm treatment. Eur J Cardiothorac Surg. 2013 Aug;44(2):e156-63.
25. Riga CV, McWilliams RG, Cheshire NJ. In situ fenestrations for the aortic arch and visceral segment: advances and challenges. Perspect Vasc Surg Endovasc Ther. 2011 Sep; 23(3):161-5.
26. Mangialardi N, Serrao E, Kasemi H, Alberti V, Fazzini S, Ronchey S. Chimney technique for aortic arch pathologies: an 11-year single-center experience. J Endovasc Ther. 2014 Apr;21(2):312-23.
27. Yang J, Xiong J, Liu X, Jia X, Zhu Y, Guo W. Endovascular chimney technique of aortic arch pathologies: a systematic review. Ann Vasc Surg. 2012 Oct;26(7):1014-21.