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SPECIAL EDITION

Controversies in Surgery for Thoracic Aorta

Is there a prospect for hybrid aortic arch surgery?

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Abstract
The surge of endovascular repair of aortic aneurysm in current modern aortic surgery practice has been the key for surgical management of elective cases of thoracic aortic aneurysms. This has paved way for the combined hybrid approach to be amongst the armamentarium for the management of aortic arch disease. The pivotal understanding of the aortic arch natural history coupled with device technology advancement allowed surgeons insight into delivery of hybrid surgery with acceptable morbidity and mortality results. This review article provides current insights into hybrid technique of aortic arch aneurysm repair and the evidences behind its applicability to arch surgery. It is aimed to highlight the challenges encountered for this innovative approach and correlate its challenges to those that are met by the conventional open aortic arch repair.

Keywords Aortic surgery · Aortic arch · Hybrid · Endovascular · Arch aneurysm

Introduction

Aortic arch surgery remained an unobtainable goal until the latter half of the twentieth century. The advent of cardiopulmonary bypass facilitated the first successful aortic arch aneurysm repair by DeBakey and colleagues [1] and it has technically paved the way for further aortic arch surgery to be done and the emergence of complex aortic arch surgery as we know it today. The unique location of the arch necessitates special considerations not only concerning the heart itself, but also cerebral protection. Notably, the introduction of hypothermic circulatory arrest, which was first performed in 1975 by Griepp et al., and this has reduced morbidity from stroke and mortality [2], as has the adoption of retrograde and then antegrade cerebral perfusion [3].

In June 1991, the Ukrainian surgeon Nikolay Volodos and his colleagues performed the first hybrid aortic arch repair [4]. They combined open surgery for debranching of the aortic arch with stent grafting of anastomotic dissections that was remnant from the patient's previous operation for coarctation. Volodos subsequently reported that the patient was still alive in February 2013 and the endoprosthesis was stable [5]. The open-type stent was also first reported by Kato et al. in 1996 [6], which was later renamed to the frozen elephant trunk by Usui et al. [7].

The surge of endovascular technology coupled with the rapid adoption of various catheter-based aortic repair techniques, and the development of hybrid techniques inevitably steered aortic arch repair toward hybrid arch techniques and thus avoiding perioperative morbidity and mortality rates associated with traditional open aortic arch surgery. In patients with multilevel thoracic aortic pathology, there are three main techniques to fix the pathology, the most advanced one is hybrid technique which is defined as repair of the aortic arch through debranching of the supra-aortic vessels and stenting the remaining diseased part of the aortic arch and descending thoracic aorta at the same time, and this has been developed as an effective alternative therapy to the two-stage conventional open repair, which is performed through median sternotomy and utilization of cardiopulmonary bypass, adjunct cerebral perfusion and hypothermia, and the third option is the frozen elephant trunk which is utilizing similar cardiac and brain protection mechanisms; however, it involves arch replacement and elephant trunk

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installation with stented graft. The hybrid technique is in particular value, given the population age and patients who were previously considered to be at too high a risk for an open repair are now being offered an alternative with custom-made devices and "hybrid" options [8].

As with every prospect of device technology, hybrid aortic arch necessitates custom-built product that is match fit for each patient's anatomy and pathologic condition. Hence, this contemplated many questions including device's durability [8, 9], ability to withstand increased shear forces close to the origin of the brachiocephalic vessels [9, 10], false lumen thrombosis [10], morbidity and mortality [9, 10], long-term survival [10] and cost implications [11]. There are also other intricacies that need to be addressed when embarking on a hybrid aortic arch approach. Most importantly are the nature and extent of aortic diseases and the correlation of such to the different landing zones during the endovascular stenting.

In this review, we aim to highlight the challenges encountered for this innovative approach and correlate its challenges to those that are met by the conventional open aortic arch repair.

Who benefits most from hybrid arch repair?

As with every aortic operation, the selection process for hybrid arch entails detailed understanding of not only the arch anatomy and whether or not the off-shelf device will match and fit. It should not be perceived that the hybrid technique is intended as a replacement of conventional aortic arch surgery. On the contrary, it is imperative to consider hybrid arch as an addition to the armamentarium of aortic arch surgery. It is very uncommon to receive a patient with isolated pathology involving the aortic arch and if faced with such, conventional approach remains to be first-line option as to non-hybrid surgeon, conventional approach is technically favourable. It is paramount to understand the aim of hybrid aortic arch approach which is favoured as an alternative in patients with multi-segmental thoracic aortic pathology [10]. The underlying pathology of majority of degenerative aorta at the arch and descending is represented by an atherosclerotic aetiology. On the contrary, aortic disease implicated at the level of the root and ascending aorta has a different pathology attributable to either familial or on-familial aortic morphology.

Further consideration for patient selectivity should be looked at from the perspective of procedure urgency. Aortic dissection repair minimalists argue that patient should be given the chance to fight another fight when less moribund; however, proponents argue for a more extensive arch repair utilizing a hybrid aortic arch repair at the time of the initial type A dissection repair. In a separate study by Roselli and colleagues [12], they have noted that patients post-type A aortic dissection repair could have aneurysmal degenerative changes in the arch and descending thoracic aorta which can benefit from hybrid repairs. Due to the lack of randomisation between hybrid approach and conventional minimalist, hybrid aortic arch repairs have become commonplace for this pathology followed with staged (TEVAR) for downstream aorta [13, 14].

What are the issues with hybrid arch durability?

This is a very striking question which is not only difficult to qualify but also to quantify. Hybrid aortic arch surgery is an innovative surgery which is part of the overall armamentarium but not the solo provider for aortic arch pathology including proximal descending aorta. Although hybrid approach comes as an option that is appealing to both the surgeon and the patient, there is no solid evidence to its use in the literature and the process of decision-making is slightly skewed with most decisions made on merits of surgeons, judgement and availability of resources. Current solutions have been reported in case reports or small case series, and they represent an approach that must be considered purely as experimental. Previous studies [15] suggested that hybrid procedure of the aortic arch carries significant risks of death, stroke, and paraplegia with worse results for more proximal procedures. Nowadays, conventional open surgery (OS) of extensive aortic-arch disease remains the treatment of choice even if there are no excellent results for such high-risk patients. Based on the series reported in the literature, a direct comparison between conventional OS and hybrid ones is very difficult due to the following reasons: (a) different operative techniques, (b) different risk-stratification systems, and (c) no uniform inclusion criteria and indications. Moreover, the outcomes should be read carefully as the high-risk patients are excluded from OS.

However, it is reported that the incidence of perioperative mortality is between 3 and 22% in studies of aortic-arch OS and between 0 and 25% in case of hybrid aortic-arch procedures [16].

The Achilles heel for hybrid aortic arch

As with any intervention that entails the aortic arch, one needs to consider the prospect of neurologic deficit. Several groups have shown that arch hybrid procedures can be performed with acceptable mortality, with a very minimal postoperative and long-term endoleak rate [17–23].

However, neurologic complications, including stroke and spinal cord ischemia, remain a significant cause of morbidity and associated mortality in this cohort of patients. In a

systematic review of hybrid arch operations in 1886 patients, pooled mortality was 10.8%, with 15.1% mortality in patients whom their diseases extended to the ascending aorta [17]. Pooled stroke risk was 7%, with a pooled spinal cord ischemia rate of 7%, with no difference seen with respect to the extent of proximal ascending aortic involvement. The other entity that needs to be considered is endoleaks which is ranged from 0 to 15% [24]. Similar to TEVAR, hybrid arch operations with type I and III endoleaks are associated with greater morbidity than those seen with type II endoleaks. In a study by Kotelis and associates, 14 patients undergoing hybrid arch repair with zone 0 proximal landing had lower endoleak rates than those with zone 1 landing [23].

Open versus hybrid aortic arch repair

Thoracic endovascular aortic repair has broadened the spectrum of treatment options for repairing the thoracic aorta and in particular the aortic arch. Bavaria et al. [17] classified the hybrid aortic arch into Type I, II and III. This fundamental understanding paved the way for hybrid arch repair techniques and the results to be achieved with reasonable and feasible outcomes [17].

To date, there has been no prospective, randomized trial that has compared open aortic arch surgical repair versus endovascular stenting approaches. The current published reports are not without significant limitations due to essentially the ambiguity and lack of consensus of the understanding of the natural history of aortic arch disease.

In a recent review by Abraha et al. [25], they found no published or unpublished evidence to assess the efficacy of TEVAR over conventional aortic surgical repair. The authors concluded that there is a need to carry out a quality randomized control trail to compare the clinical outcomes and cost-effectiveness between TEVAR and open repair. The trials should have adequate follow-up and be enough to evaluate the durability of endovascular treatment in terms of endoleak rate, re-intervention rate, open-conversion rate, and rupture-free survival. In addition to the clinically relevant outcomes including early and late mortality, major complications, and hospital and intensive care unit stay must be also considered.

Despite the aforementioned, studies by Orandi et al. [26] and by Walsh et al. [27] suggested that endovascular techniques are considered safer and less invasive with mortality and morbidity that are similar to conventional open aortic surgical repair alone. Orandi et al. found that among a total of 1030 patients who underwent open thoracic aortic aneurysm repair and 267 who underwent TEVAR, there was no significant difference in mortality between open aortic repair and TEVAR.

They have also added that although open repair patients were more likely to have cardiac, respiratory, and haemorrhagic complications, patients undergoing TEVAR were more likely to be discharged home and had a decreased length of hospital stay.

On the other hand, Walsh et al. [27] based their conclusion on series of comparative studies that solely looked at stent grafting to the descending aortic aneurysm without any reference to the ascending and aortic arch aneurysms and the surgical management of this entity.

On the other hand, Benedetto et al. [28], in a meta-analysis of four observational studies comparing total arch replacement (TAR) with hybrid aortic arch repair in a total of 378 patients, the operative mortality was not improved with hybrid aortic arch repair (OR = 0.67, $P = 0.92$). There were no significant increases in permanent neurologic deficit with hybrid repairs versus TAR (OR = 1.93, $P = 0.10$) and late mortality (OR = 1.73, $P = 0.10$).

Tokuda and colleagues [29] examined 124 patients undergoing TAR and compared them to 58 high-risk patients who underwent hybrid aortic arch repair. The hybrid aortic arch group was older (77 ± 6 versus 69 ± 9 years, $P < 0.0001$) and had a higher logistic EuroSCORE (31 ± 18 versus 20 ± 15, $P < 0.0001$). There were 38 matched pairs utilized in the propensity score matching. The hybrid group had significantly shorter cardiopulmonary and circulatory arrest times, but no difference in operative mortality. At a mean follow-up of 52.5 months, the hybrid arch patients had a higher rate of re-intervention (21 versus 1% at 24 months, $P < 0.0001$). This study concluded that hybrid aortic arch repairs should be considered predominantly in high-risk individuals.

Bavaria et al. [30], reported on the results of 47 patients who underwent extensive hybrid arch repairs with either antegrade or retrograde TEVAR of the aortic arch. The mean age of the group was 71 ± 8 years, and 14% of the group had a prior history of a sternotomy. The mean circulatory arrest time was 19 ± 10 min. The in-hospital mortality was 8%, with a stroke and paraplegia rate of 8 and 5.5%, respectively. There were no endoleaks noted, and the aortic re-intervention rate was 3% over a median follow-up of 30 ± 21 months. This series demonstrates that hybrid aortic arch can be done safely with favourable short-term and mid-term outcomes with careful selection of patients in experienced centre.

Conclusion

The hybrid approach to the treatment of aortic arch aneurysm continues to evolve, with an increasingly important role especially in patients with a high comorbid index and old age. Hybrid approaches for the treatment of aortic arch aneurysmal disease are being performed with increasing frequency due to rapidly evolving endovascular technology

which permits successful landing of stent grafts in the proximal thoracic aorta. Open total arch procedures can be accomplished using complex circulatory management [30] and adjunct cerebral protection [31], but subgroups with multiple comorbidities may still experience significant morbidity and mortality from both neurologic and cardiovascular complications [32]. Combining open surgical and endovascular techniques, the hybrid arch repair seeks to limit operative, bypass, and circulatory arrest times by simplifying and shortening the arch repair. Hence, given the surge in device technology and existence of platform to perform hybrid procedures couple with our understanding for pathology, the hybrid approach has a long mileage to run.

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