Perspective

Best surgical option for thoracoabdominal aneurysm repair - the hybrid approach

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Thoracoabdominal aortic aneurysms (TAAAs), defined by the involvement of the visceral vessel origins, tend to present in an elderly population, often with extensive co-morbidities. They may be identified incidentally or present late with symptoms secondary to aneurysm expansion. Untreated, the mortality from aneurysm rupture is high (1). Since the first reported case of surgical reconstruction by Etheredge *et al.* in 1955 (2) and subsequent modifications to the original technique, conventional open TAAA repair became the mainstay of treatment for the next 40 years. Access to the aorta is gained through a thoraco-abdominal incision dictated by TAAA extent. The original clamp and sew technique with revascularization of major aortic branches has been modified over the years and now may involve cardiopulmonary bypass with hypothermic circulatory arrest, single-lung ventilation, cerebrospinal fluid drainage, and epidural cooling, resulting in long operative times, significant blood loss, volume shifts, and prolonged recovery times.

Despite significant advances in surgical techniques, peri-operative adjuncts, and critical care aimed to limit cardiovascular instability as well as the extent of visceral, lower extremity and spinal cord ischaemia, the traditional open TAAA repair remains a formidable challenge. Several high-volume institutions have published results that are considered acceptable when compared with the risk of aneurysm rupture if left untreated (3-6); these figures, however, are not representative of surgical outcomes worldwide, with mortality rates ranging from 3% to 20%. The incidence of peri-operative death at centres with extensive experience reaches 10%. Population studies however, demonstrate a 30-day elective mortality of 19% (40% for octogenarians), with a significant first-year mortality of 31% (7). The 30-day mortality rates associated with emergent TAAA repairs are daunting, ranging from 15% to 50% (6-8). The devastating sequelae of spinal cord ischaemia (SCI) are apparent despite supportive adjuncts, even in centres of excellence with a SCI risk ranging from 4% to 11% (9,10), and reaching 22% in extensive TAAAs (11). Morbidity rates are also significant with a 15% risk of haemodialysis (12), 8% risk of prolonged respiratory wean with an associated mortality of 40% (13), and a significant cardiac morbidity risk with a related mortality of 19% (14). The most important factor that contributes to these outcomes is the TAAA extent, and consequently the magnitude of the operative strategy required, with those patients presenting with type II TAAAs most at risk (5,11,15,16). It is therefore in these elderly patients with large, extensive TAAAs and significant co-morbidity, that the least invasive, cost-effective, and readily applied technique is desirable. In an attempt to ameliorate the risks of conventional TAAA repair, less invasive strategies have been explored aiming at limiting the physiologic derangements associated with aortic cross-clamping and extensive tissue dissection.

The visceral hybrid technique involves extra-anatomic debranching combined with staged or immediate endovascular aortic relining using covered aortic stent grafts. Although the first reported case by Quinones-Baldrich *et al.* in 1999 was in a patient with a type IV aneurysm (17), the technique has since evolved to best serve patients with the most extensive TAAAs. Our institution described one of the earliest visceral hybrid cases for extensive TAAA disease in 2002 (18). Since then, many have described their experience along with modifications of the original technique. Our preferred approach for aneurysms that extend into the thoracic segment (types I, II, and III)

involves aortic debranching with retrograde bypasses to the visceral and renal arteries from the distal aorta, iliac vessels, or a previous aortic graft via a transperitoneal approach. The proximal branch arteries are ligated to eliminate the risk of back bleeding into the aneurysmal sac and the procedure is completed with endovascular aortic relining and subsequent aneurysm exclusion. The absence of a thoracotomy and single-lung ventilation are seen as advantages in patients with respiratory compromise, and the lack of aortic cross-clamping with sequential ischaemia and reperfusion of the visceral and renal vessels allows patients with reduced cardiac reserve to remain haemodynamically stable, limiting the physiological derangements associated with the traditional surgical approach.

Our first published series of 29 cases showed encouraging results, with low mortality and no paraplegia (19). The technique has now been adopted by various centres around the world (20-22). The less invasive nature of the hybrid approach was reflected in a subsequent systematic review by Donas *et al*. in 2007, demonstrating an overall operative mortality rate of 10.7% and a paraplegia rate of 0% in 58 patients from 13 published reports (23). As our experience has grown and we have taken on greater numbers of patients with multiple co-morbidities, the results are now more representative of a major surgical procedure in a high-risk elderly population with atherosclerosis. Our unit reported the largest published series of these repairs for TAAA and aortic dissections in 107 high-risk patients, as a collaborative approach with two other major European centres (24). We observed a 30-day mortality rate of 14.9% and a more expectant paraplegia rate of 8.4%. There was a 3.7% rate of long-term dialysis and a 2.8% rate of gut ischaemia. Graft patency at 30 days was 86.9%. Endoleaks were detected in 29.9% of cases: 56% were type II, and the majority were managed conservatively.

Aneurysms that involve the more proximal descending thoracic aorta or the aortic arch may also require hybrid approaches for successful aneurysm exclusion via extra-anatomic bypasses of the subclavian, brachiocephalic and carotid arteries with subsequent stenting of the distal thoracic segment (25,26). A systematic review of arch hybrid outcomes in 195 patients showed pooled peri-operative mortality and morbidity rates of 9% and 21%, respectively, with an acceptable endoleak rate of 9%, but a significant stroke rate of 7% (27). Most of the series included in this review contained small numbers of patients, increasing the possibility of publication bias. It is evident that there are significant differences between patients requiring carotid-subclavian bypass alone and those requiring full supra-aortic revascularization to facilitate stent-graft placement. It is our experience that in high-risk patients who require extensive intervention, mortality and morbidity remain significant, especially in those with concomitant distal aortic disease (28). We do believe, however, that the arch hybrid repair provides a feasible alternative treatment in those who are at high risk for conventional open surgical repair. Careful patient selection and consideration of morphologic features are essential to achieve satisfactory results.

Rapid advances in stent-graft technology and availability of improved devices offer a minimally invasive alternative to the treatment of TAAA via the wholly endovascular approach. The advent of fenestrated and branched devices, originally designed to extend the proximal sealing zone in infrarenal disease has led to increased adoption of endovascular techniques to treat more extensive aortic pathologies. Much effort is now expended in development of this approach for the management of aneurysms that involve the supra-aortic branches. Published series have shown the wholly endovascular approach to be a safe and effective alternative to open repair in selected patients, with encouraging intermediate-term outcomes. Thirty-day mortality has ranged from 5.5% to 12%, SCI rates from 2.7% to 16.7% and haemodialysis rates between 1.4% and 9.1%, with reduced hospital stays in uncomplicated patients (11,29-31).

Successful results, however, require careful patient selection, appropriate custom-made device design, and technical expertise with endovascular grafting, as well as visceral vessel cannulation and stenting. The implantation procedure can be technically challenging and time-consuming even for experienced operators, especially in the presence of unusual anatomy. Despite a custom-made device design and extensive preoperative planning, graft rotation and misalignment of the fenestration/vessel ostium interface can still occur and vessel cannulation is largely dependent on operator skill. Visualization and control of wire and catheter manipulation becomes less intuitive and less predictable as case complexity increases. Long fluoroscopic times and radiation exposure to both patients and operators are other important factors to consider. Another concern with fenestrated and branched endografting is the inherent delay in manufacturing owing to its bespoke nature, which precludes use in ruptured and urgent cases, even if a patient is anatomically suitable for endovascular repair; off-the-shelf branched and fenestrated devices certainly have the potential to expedite treatment,

but require significant further development. Research in our institution is currently focusing on evolving technologies such as endovascular robotic systems, to address some of the challenges of complex endovascular intervention in an attempt to enhance current endovascular techniques (32). The wholly endovascular approach is currently developing and gaining acceptance; its long-term durability, however, is yet to be proven.

Comparison between published series addressing the outcomes of TAAA repair is difficult for a number of reasons. Most open surgical series report a younger, fitter group of patients, and most fenestrated/branched series, by definition, report outcomes in patients anatomically suitable for endovascular treatment. Not all series classify the extent of aneurysmal involvement; this has resulted in considerable heterogeneity and it is therefore difficult to make good outcome comparisons. Wholly endovascular techniques however are more commonly used to treat aneurysms limited to the supradiaphragmatic and infradiaphragmatic aorta, whereas open and hybrid approaches are more frequently used to treat more extensive aneurysmal disease such as type II and III TAAAs. In the published hybrid series, only 12% of cases involved treatment of type IV extent aneurysms. There is ample evidence to show that open type IV repair via a subcostal incision has a good elective 30-day mortality - 3%, Houston (4), 6%, Edinburgh (33) and 3.5%, St Mary's (34) - and is a durable option with very low rates of aneurysm-related complications in the long term (35). For relatively young and fit patients, therefore open type IV surgery is a proven strategy. If the anatomy is suitable and the funds available, a substantially less invasive fenestrated/branched approach is a safe option if the elective nature of presentation allows time for a bespoke device to be manufactured, and as long as the internal iliac circulation is preserved. It is important to remember, that paraplegia is not eliminated by a totally endovascular approach; in published series with significant numbers of type IV TAAAs, the paralysis rate reaches nearly 3% (11).

With regards to the hybrid approach, the literature is somewhat contaminated by many small series very early in the learning curve of the procedure, containing a variety of indications and TAAA extent. Many authors are reporting the technique rather than a defined group of patients to which it has been applied. More than a quarter of the St Mary's patient cohort had had a previous thoracotomy for either cardiac or thoracic aortic surgery, with 82% of patients presenting with an American Society of Anesthesiologists grade greater than 3 and significant co-morbidities, rendering them unfit for an open repair. Taking these adverse factors into account, we believe this procedure represents a real advance in the treatment of unfit patients with extensive TAAAs.

From a technical point of view, the visceral hybrid technique has been adapted to overcome problems and make the outcome more durable. Small and multiple renal arteries remain a challenge for both this and the wholly endovascular approach. This has necessitated splicing renal arteries together and an end-to-end rather than end-to-side anastomotic technique where access is difficult. Some have adopted a sutureless approach by cannulating the target renal artery and deploying a covered stent into it and then anastomosing that to the other grafts (36). One of the unanswered questions relating to these extensive hybrid aneurysm repairs is whether to operate as a single or a two-stage approach. One view is that a cold, hypotensive, and coagulopathic patient who has undergone extensive intra-abdominal dissection and significant cardiovascular instability, should not immediately undergo stent-grafting (with resultant intercostal occlusion) due to an increased risk of paraplegia. In this scenario, it is safer to stabilize the patient and then proceed to endovascular aneurysm exclusion. Against this view are those who cite the risk of interval rupture, which we have experienced first hand, and the risk of embolic occlusion of visceral grafts when passing multiple stent grafts through the iliac segment at a later stage. There is a strong case for single-stage surgery in patients with large aneurysms who are stable intraoperatively, especially in those with access difficulties and this is our preferred approach. However, each case needs to be judged on an individual basis.

The versatility of the visceral hybrid technique is another important consideration. Whereas the wholly endovascular approach is hindered by poor access, side branch ostial stenosis and tortuosity, these problems are irrelevant in the context of the visceral hybrid. Moreover, chronic dissections that have become aneurysmal can be treated without concerns regarding the intimal flap so pertinent to branched techniques. The visceral hybrid technique has been taken up widely and is now adopted by centres with little previous experience of treating patients with TAAAs. The wholly endovascular procedure however has remained restricted to larger volume centres of excellence, much like most traditional open TAAA repairs. Although it is clearly desirable that as many patients as possible are at least considered for treatment, one would question the wisdom of a centre without extensive open surgical or fenestrated/

branched experience embarking on a treatment program as patients will not be given all the options available.

Conclusions

The published results from high-volume centres would suggest that the gold standard method of treatment for all TAAAs is open surgery. We would agree that this is a particularly good option for type IV aneurysms in fit patients. However, results from centres of excellence are not representative of the cardiovascular surgical community at large, and although these outcomes are considered acceptable in the context of the untreated risk of aneurysm rupture, these extensive operations remain a formidable task. Such a conclusion therefore, can only be applied to those patients afforded the opportunity of treatment in such institutions, and population studies prove that the majority of patients fair much less well.

The minimally invasive nature of the wholly endovascular approach utilizing fenestrated/branched stent-graft technology is beyond question, but anatomic constraints, manufacturing delays, and financial considerations continue to limit its applicability. For anatomically challenging TAAAs this approach is technically difficult, time-consuming and not without its pitfalls. Despite the above, for suitable patients, and when funding allows, a wholly endovascular option remains a desirable alternative. The hybrid approach reduces the total ischaemic insult associated with traditional open surgical techniques, but remains a complex surgical procedure with a significant mortality and paraplegia rate. For unfit patients, however, with types I, II and III TAAAs aortic aneurysms and anatomy unsuitable, or presentation too acute for a totally endovascular approach, the hybrid repair may be the only viable option. If, however, it is applied to too many cases or used indiscriminately, it can be hampered by both the early disadvantages of open surgery and the late complications of the endovascular approach. Nonetheless, as always, case selection is the key and choosing the right procedure for an individual patient is paramount. In centres with suitable expertise, the visceral hybrid repair is a versatile and durable treatment strategy for a high-risk patient population with limited therapeutic alternatives.

If the best option is based on the treatment modality applicable to the largest majority, then the answer would depend on the institution and the patient population served. However, we believe the best option is truly patient-specific and, therefore, the optimal treatment is really provided by the institution that can determine patient suitability and offer all three treatment options. As endovascular techniques and technology are constantly improving and evolving, the full impact of fenestrated and branched stentgrafts on TAAA repair is yet to be realized. However, in the meantime, and in high-risk patients where the wholly endovascular approach is not an option and open surgery is hazardous, the visceral hybrid represents a versatile and robust alternative method of treating this complex and life-threatening disease process.

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