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DEBRANCHING PROCEDURES FOR THORACO-ABDOMINAL AORTIC ANEURYSMS

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Open repair of thoraco-abdominal aortic aneurysms (TAAA) has a high mortality and morbidity [1,2]. These risks have persisted despite advances in operative technique (including cardiopulmonary or left heart bypass, hypothermic cardiopulmonary arrest, selective visceral perfusion, spinal cord protection) and higher standards of peri-operative care. The repair of extensive TAAA remains a formidable challenge to vascular surgeons. Despite significant advances in surgical technique and peri-operative critical care, the traditional open repair, even in the best centers in the world, is still associated with a high morbidity and mortality.

Thoracic stent-grafting is limited to the descending thoracic aorta by either the arch vessels proximally or the visceral and renal vessels distally. However, by first revascularizing and/or debranching these vessels, one can subsequently complete aneurysm exclusion by thoraco-abdominal aortic endografting. The less invasive nature of these hybrid procedures represents a viable treatment alternative to those patients that may have previously been declined an open procedure due to advanced age or comorbidities. As endovascular techniques and technology are constantly improving and evolving, the full impact of fenestrated stents and branched grafts on TAAA repair is yet to be realized. Whilst a total endovascular approach is the future of TAAA repair, hybrid surgery will always remain a robust and adaptable method of treating this complex and life-threatening disease process particularly in individuals with unfavorable anatomy.

Evolution of the hybrid repair

In 1991, Parodi et al. [3] described the deployment of the first endovascular stent-graft (EVSG) in an infrarenal abdominal aortic aneurysm. By 1994, as a direct evolutionary step, Dake et al. [4] used an EVSG for isolated descending thoracic aortic aneurysms. This use of EVSG for aortic aneurysms limited to the thoracic segment showed significant early promise. However, their use for extensive TAAA was necessarily limited by the presence of the arch vessels proximally and the visceral and renal vessels distally.

In 1999, Quinones-Baldrich et al. [5] were the first to report a combined endovascular and open surgical approach for a type IV TAAA. Previous abdominal aortic surgery and concomitant visceral artery aneurysms precluded an open repair. Retrograde visceral bypasses from a limb of a pre-existing bifurcated aortic tube graft were performed followed by TAAA stent-grafting. By revascularizing the visceral and renal branches first, total endovascular aneurysm exclusion was achieved by completion endo-grafting.

In 2003, at the Regional Vascular Unit at St Mary's Hospital, we used a similar technique of retrograde visceral/renal revascularization with completion endo-grafting for a 49 year old man with a 9 cm aneurysm of native aorta occurring between a previous infrarenal abdominal and an upper descending thoracic aortic aneurysm repair [6]. Three years later, we then reported the largest published series of these repairs describing a total of 29 attempted *visceral hybrid* procedures [7]. Our unit performs this technique in preference to an open repair for Crawford type I, II, and III TAAA, while an open approach with medial visceral rotation is used for Crawford type IV aneurysms. These repairs are particularly attractive and deemed less invasive as they avoid the need for a thoracotomy, single-lung ventilation, aortic cross clamp, left or full heart bypass as well as the extensive tissue dissection all associated with an open repair.

Visceral hybrid repair

Technique

The patient is placed in a supine position under general and epidural anesthesia. Cerebrospinal fluid drainage is always used. We routinely use cell salvage techniques with rapid infusers available. Arterial and central venous lines, urethral catheterization and transesophageal echocardiography are all mandatory peri-operative invasive monitoring.

A mid-line laparotomy allows for adequate exposure of the abdominal aorta, the origins of the renal arteries, the celiac axis, and the superior mesenteric artery (SMA). The in-flow site for retrograde visceral bypass grafting is determined by the distal extent of aneurysmal disease and previous abdominal surgery. If a previous infrarenal repair has been undertaken, the bypass grafts are anastomosed in an end-to-side fashion to the existing graft. If an infrarenal repair is possible, this is completed first and bypass grafts are subsequently sutured as before. If the infrarenal aorta is normal an arteriotomy is performed and the bypass grafts anastomosed in an end-to-side fashion to the native aorta. If the aneurysmal disease extends to the bifurcation, one external iliac artery can provide the in-flow to the bypass grafts.

Two inverted (14 by 7 mm or 16 by 8 mm) Dacron® trouser-grafts can function as the conduits. Otherwise a single trouser-graft is used with additional side-limbs sutured in an end-to-side manner. This four-limbed "spaghetti graft" is fashioned in a bespoke way during the procedure.

The renal arteries are sequentially anastomosed in an end-to-side fashion. The two remaining graft limbs are routed along the base of the small bowel mesentery to the celiac axis and SMA in an end-to-side fashion. If Doppler signals are satisfactory in the bypass grafts (with the origins of the native vessel clamped) they are subsequently suture-ligated to prevent retrograde flow into the aneurysm sac (type II endoleak).

Following successful visceral and renal bypass a suitable access site is chosen for endovascular stent deployment. A dedicated conduit attached to the common iliac artery or the abdominal aorta is common but native vessels are also used provided they are of suitable caliber. An angiogram catheter is introduced on the contra-lateral side and the stents are deployed in a sequential fashion from the left subclavian artery through the thoracic aorta to the landing zone (Figure). Completion angiography after adjunctive procedures (extension cuff, giant Palmaz stent, balloon moulding) then confirms exclusion of the aneurysm.

Other experiences of hybrid repairs of TAAA

Several centers around the world have published individual cases/small series (<5) of hybrid

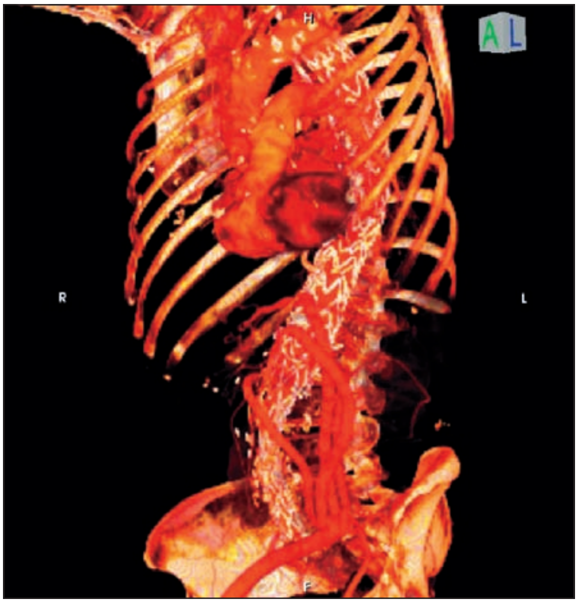

FIGURE Type III TAAA repaired with visceral hybrid procedure.

approaches to TAAA [5,6,8-23]. The results of these cases are encouraging considering the complicated nature of the TAAA disease process as well as the patients' comorbidities. Of the 30 patients in this combined series, spinal cord ischemia appeared to be rare or went unreported. Other postoperative complications were greatly reduced and intensive care stay was less than that of open TAAA surgery. Of note, no standard operative technique was employed and there was much variation in the EVSG used.

Resch et al. [24] have reported their series of 13 staged hybrid repair of TAAA. They all underwent retrograde visceral bypasses (11 ilio-visceral and 2 infrarenal aortic-visceral) as a first procedure prior to completion with EVSG. They report a 30-day mortality of 23% (3/13) for all patients. Their mean follow-up in the 10 surviving patients was 23 months (1-45) during which time a further 2 deaths were related to the hybrid repair. Two patients unfortunately suffered paraplegia and 2 further patients had transient parapetic events.

Zhou et al. [25] published their series of 31 high-risk patients undergoing hybrid approaches to TAAA. Although there were a variety of hybrid approaches used for these TAAA, 18 of these patients had aneurysms involving the visceral vessels: Crawford type I (3), III (8) and IV (7). They reported that 15 patients required iliac to celiac artery bypasses, 15 required iliac to SMA bypasses and 10 required iliac to renal artery bypass grafting. There was no incidence of stroke or paraplegia reported in their series.

Donas et al. [26] recently analyzed published data in their systematic review of "hybrid open-endovascular repairs of TAAA" (Table). Their study eligibility criteria were as follows:

1) TAAA was diagnosed on the basis of the Crawford classification, modified by Safi;
2) hybrid open-endovascular repair (visceral bypass followed by endovascular stent-graft implantation) was the intended repair strategy and was completed in all patients;
3) there had been a minimum follow-up period of 4 months;
4) diagnosis of complex TAAA had been made according to computed tomographic scans of the thorax, abdomen and pelvis;
5) at least one of the basic outcome criteria (neurological, renal, respiratory morbidity, visceral vessel patency and endoprosthesis related complications, as well as the primary technical success rate, and the total mortality rates were stated;
6) articles were excluded if TAAA repair was only by surgical or endovascular approaches alone.

Of the 13 studies identified and included in their statistical analysis, the number of patients reported totaled 58 (37 male, 21 female). The mean age of the patients was 68.8 years (range 35-80). There were 15 Crawford type I TAAA, 21 type II, 11 type III, 6 type IV and 5 type V. The mean follow-up period was 14.3 +/- 8.4 months (range 4-36). The mean aneurysm diameter was 7.15 cm (range 5-12 cm).

In this, no patient developed paraplegia or other procedure-related neurological deficits due to spinal cord injury or ischemia. Thirty-day elective and urgent mortality was 10.7% (6/55). Three patients with a ruptured TAAA who underwent a hybrid procedure died. The overall early and long-term mortality for completed procedures was 15.5% (9/58).

ADVANTAGES

The authors perceive several advantages of the visceral hybrid approach over standard, open techniques:

1) no thoracotomy:
   i. fewer pulmonary complications;
   ii. fewer cardiac arrhythmias;
   iii. less pain.

Table SYSTEMATIC REVIEW OF DONAS ET AL. [26] ASSESSING OUTCOME OF HYBRID PROCEDURES

First author [ref.]	*Year*	*Follow-up (months)*	*Number of patients*	*30-day mortality (number)*
Quinones-Baldrich [5]	1999	6	1	0
Black [7]	2006	8	26	6
Macierewicz [8]	2000	22	1	0
Agostinelli [10]	2002	6	1	0
Saccani [11]	2002	4	3	1
Iguro [13]	2003	12	1	0
Kotsis [14]	2003	14	4	1
Flye [16]	2004	14.6	3	0
Donas [27]	2007	21	8	1
Chiesa [28]	2007	12	1	0
Lawrence-Brown [29]	2000	36	2	0
Khoury [30]	2002	21	1	0
Gawenda [31]	2007	12	6	0

2) Reduced hypothermia with subsequent reduction in:
   i. coagulopathy;
   ii. cardiovascular instability.
3) Reduced rate of spinal cord ischemia due to improved cardiovascular stability.
4) Reduced duration of mesenteric and visceral ischemia with reduction in:
   i. acidosis and associated problems;
   ii. gut bacteria translocation/sepsis;
   iii. renal failure/use of renal replacement therapy.
5) Less blood loss/reduced transfusion requirement.
6) Reduced hospital stay:
   i. Intensive therapy unit (ITU);
   ii. absolute.
7) More patients can be treated where comorbidity previously excluded them.

DISADVANTAGES
1) Newer technique requires specialist centers with experience in the procedure;
2) long-term follow-up required for endo-grafting component;
3) still a significant physiological insult to the patient;
4) risk of paraplegia, despite better cardiovascular stability, remains theoretically high due to significant occlusion of aortic side branches particularly in extensive TAAA.

The future of TAAA repair

Although some units have reported spectacular results with the traditional open repair of TAAA [32], Rigberg et al. [33] suggest that normal 30-day mortality statistics underestimate the risk of repair of TAAA and that individual unit data is probably less useful than looking at a larger population as a whole. They identified 1 010 patients (797 elective, 213 ruptured) who underwent TAAA repair in the state of California. Mean patient ages were 70.0 (elective) and 72.1 years (ruptured). Men comprised 62% of elective and 68% of ruptured aneurysm patients, and 80% (elective) and 74% (ruptured) were white. Overall elective patient mortality was 19% at 30 days and 31% at one year. There was a steep increase in mortality with increasing age, such that elective one-year mortality increased from about 18% for patients 50 to 59 years old to 40% for patients 80 to 89 years old. The elective case 31-day to 365-day mortality ranged from 7.8% for the youngest patients to 13.5%. Mortality for ruptured cases was 48.4% at 30 days and 61.5% at 365 days, and these rates also increased with age. Clearly, any treatment modality that improves outcome in patients with TAAA is welcome and current results of the visceral hybrid repair demonstrate a clear improvement over and above some mortality and morbidity reports of the open repair.

The endovascular revolution has significantly impacted on TAAA repair and will continue to do so. Endovascular stent-grafting was integral to the development of the visceral hybrid repair, and now with the advent of fenestrated and branched graft endovascular technology, there are also wholly endovascular options available to select patients. A wholly endovascular approach is clearly the future of TAAA repair. Just as the visceral hybrid repair removed the need for thoraco-laparotomy and aortic cross clamping, a total endovascular repair even removes the need for laparotomy, intra-abdominal dissection and visceral/renal arterial clamping seen in the hybrid. Some are now questioning whether there will be a role for debranching hybrid repairs with the introduction of these newer endovascular therapies although this argument is premature.

Significant advances have been made in the total endovascular repair of TAAA. Roselli et al. [34] recently described 73 patients who underwent wholly endovascular repair of TAAA (for Crawford type I, II or III n=28 and for type IV n=45). The mean aneurysm size was 7.1 cm (range 4.5-11.3 cm). General anesthesia was used in 47% of patients and regional anesthesia in 53%. There were no conversions to open surgery and no ruptures post-treatment. Technical success was achieved in 93% of patients (68/73). Thirty-day mortality was 5.5% (4/73). Major peri-operative complications occurred in 11 (14%) patients and included paraplegia (2.7%, 2/73), new onset of dialysis (1.4%, 1/73), prolonged ventilator support (6.8%, 5/73), myocardial infarction (5.5%, 4/73), and minor hemorrhagic stroke (1.4%; 1/72). A majority of patients had no complications. Mean length of stay was 8.6 days. At follow-up, 6 deaths had occurred. There were no instances of stent migration or aneurysmal growth. From this series, it is clear that known complications of TAAA repair, either open or hybrid, are not entirely eliminated by a totally endovascular approach. However, morbidity and mortality appear to be low, relative to the high-risk population studied.

Even more recently, Chuter et al. [35] have described a similar smaller cohort of patients undergoing wholly endovascular TAAA repair. Self-expanding covered stents were used to connect the caudally directed cuffs of an aortic stent graft with the visceral branches of a TAAA in 22 patients (16 men, 6 women) with a mean age of 76±7 years. All patients were unfit for open repair, and nine had undergone prior aortic surgery. Customized aortic stent grafts were inserted through surgically exposed femoral (n=16) or iliac (n=6) arteries. Covered stents were inserted through surgically exposed brachial arteries. Spinal catheters were used for cerebrospinal fluid pressure drainage in 22 patients and for and spinal anesthesia in 11. All 22 stent grafts and all 81 branches were deployed successfully. Aortic coverage as a percentage of subclavian-to-bifurcation distance was 69% ± 20%. Mean contrast volume was 203 ml, mean blood loss was 714 ml, and mean hospital stay was 10.9 days. Two patients (9.1%) died peri-operatively: one from guide wire injury to a renal arterial branch and the other from a medication error. Serious or potentially serious complications occurred in 9 of 22 patients (41%). There was no paraplegia, renal failure, stroke, or myocardial infarction among the 20 surviving patients. Two patients (9.1%) underwent successful reintervention: one for localized intimal disruption and the other for aortic dissection, type I endoleak, and stenosis of the superior mesenteric artery. One patient has a type II endoleak. Follow-up is more than 1 month in 19 patients, over 6 months in 12, and over 12 months in 8. One branch (renal artery) occluded for a 98.75% branch patency rate at 1 month. The other 80 branches remain patent. There are no signs of stent graft migration, component separation, or fracture.

Fenestrated and branched endografts are still an emerging technology. Careful patient selection is vital, particularly for those patients with challenging aneurysmal anatomies. In addition, the costs of these new stent-grafts are prohibitive to many centers around the world who cannot afford the additional expense, despite potential patient benefits.

The future of the visceral hybrid repair of TAAA can be seen in several ways:

1) There will always be patients with challenging anatomy which renders them unsuitable for a wholly endovascular approach. In these situations, if comorbidities limit an open repair, the visceral hybrid is a robust and adaptable method of treating this complex and life-threatening disease process.
2) A great deal of pre-operative planning is required for successful wholly endovascular treatment of TAAA. Imaging, sizing and bespoke endo-graft construction all require time those symptomatic/peri-rupture patients do not have. In these cases, the visceral hybrid provides an unique way of treating TAAA, particularly if an open repair is prohibited by poor preoperative patient condition.
3) The visceral hybrid could be considered a bridging measure until fenestrated/branched EVSG technology matures to the point of established use.

Further improvement of, and access to, endovascular stent-grafts, and correct patient selection (in light of the EVAR 2 trial results [36] will probably see a reduction in the numbers of visceral hybrid procedures being performed for TAAA. Fenestrated and branched endo-grafts will be increasingly performed. However, in units that are proficient in the visceral hybrid repair, it will remain a reliable method of TAAA repair that, with the correct patient selection, can be used alongside open and endovascular approaches to TAAA repair in this challenging patient population.

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