

ORIGINAL RESEARCH

Single Stem Visceral Debranching for Complex Aortic Disease

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Objective: The treatment of complex aortic disease has been described with various retrograde visceral bypass techniques. An original technique with a single stem retrograde visceral graft (SSRVG) is presented.

Methods: This was a single centre retrospective study including 16 patients between 2015 and 2019. Patients were treated for aortic dissection (AD; type A and acute or chronic type B), thoraco-abdominal aortic aneurysms (TAAAs), and visceral occlusive disease. Surgery consisted of visceral vessel debranching from the native infrarenal aorta or from an aortic graft. In the case of AD, surgical fenestration was performed. Additional thoracic endovascular aneurysm repair (TEVAR) completed the treatment when indicated, during the same procedure or later. Patient outcomes and reconstruction patency were studied.

Results: The mean patient age was 64 years (median 68 ± 12.6). Ten (62%) patients were treated for AD, three (19%) for TAAA, and three (19%) for occlusive disease. Sixty-nine target vessels were debranched with this SSRVG technique. Aortic surgical fenestration was performed in eight cases and TEVAR in four. During their hospital stay, three (19%) TAAA patients died, seven cases of renal insufficiency (44%), four cases of pneumonia (25%), and three colonic ischaemia cases (19%) were noted. After a mean follow up of 21 months, no other deaths occurred. All vessels (except two inferior mesenteric arteries) were patent and no endoleak was noted.

Conclusion: The SSRVG technique can be offered in various complex aortic diseases. The use of a single graft is feasible and reduces the volume of multiple branch assembly in the retroperitoneal space. The observed patency rate is high.

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INTRODUCTION

Treatment of complex aortic disease such as thoraco-abdominal aortic aneurysm (TAAA) or aortic dissection (AD) is challenging and the best therapeutic option for a single case remains to be determined. Open repair, despite improvements including distal perfusion and spinal protection, is reserved for fit patients. An increasing number of cases of TAAA and AD have become amenable to a totally endovascular repair due to the constant progress of devices and skills.^{1,2} Nonetheless, uncertainty over long term results, limits in technical feasibility, and the availability of devices still restrict its wide applicability. As a result, there are situations where hybrid repair, combining both open and endovascular techniques, remains an option. Visceral vessels are bypassed first, paving the way for synchronous

or asynchronous exclusion of the aortic lesion by a stent graft.^{3,4} The stemming of visceral debranching from the infrarenal aorta avoids the need for proximal aortic clamping, or thoracotomy, and limits the duration of end organ ischaemia. Various techniques of debranching stemming either from the infrarenal aorta or the iliac arteries have been described, with reserved results,^{3,5} mainly due to the context of an emergency setting or a fragile patient. Nonetheless, when deemed necessary, the technical aspects of this hybrid procedure should be known by surgeons, to optimise outcomes.

An original technique of abdominal visceral debranching using a single stem retrograde bypass to all visceral vessels is reported.

METHODS

Patients and indication

This was a single centre retrospective study. Between 2015 and 2019, 168 patients treated by visceral artery surgery were identified. Patient selection used the French common classification of medical procedure (CCAM) with a specific

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code, namely EDKA003: “remplacement d’une artère digestive par laparotomie”. All medical records were reviewed and patients treated with this particular single branch retrograde bypass technique were identified. Given the nature of the study, a waiver was given by the Sorbonne University review board regarding informed consent of patients. Sixteen patients were identified. The vast majority of other patients were treated for acute or chronic mesenteric ischaemia. During the same period, a mean of 45 TAAA operations were performed annually at the authors’ institution. Data were recorded in a Microsoft Excel spreadsheet on a password protected computer, and included demographics and clinical characteristics, type of disease (TAAA, AD, or occlusive disease), emergency or elective cases, symptoms at presentation, pre-operative workup, intra-operative data, and post-operative course. Target vessel patency was evaluated on the most recent post-operative computed tomography (CT) scan. Patients were offered hybrid treatment when both direct open reconstruction and endovascular repair were ruled out because of patient comorbidities, an emergency context, or for anatomical reasons. All patients (with the exception of emergencies) underwent a pre-operative workup with respiratory, cardiac (including stress test and coronarography), renal and spinal cord arteriography. Spinal fluid drainage was performed when thoracic endovascular aneurysm repair (TEVAR) was performed during the same procedure. Imaging consisted of thin slice CT angiography.

Surgical technique

Approach. Patients are operated on under general anaesthesia in a supine position with mild lordosis. A transperitoneal median laparotomy is performed in all cases. The retroperitoneum is entered, the left renal vein (LRV) mobilised, and the aorta and iliac arteries exposed. The right (RRA) and left renal artery (LRA), and inferior mesenteric artery (IMA) are then freed distal to any ostial lesion and taped. The superior mesenteric artery (SMA) is exposed through a left lateral approach. The coeliac trunk is approached through a section of the lesser omentum. A retropancreatic tunnel is created from the left lateral side of the suprarenal aorta to the left lateral side of the coeliac trunk by severing the left crux of the diaphragm.

Great care should be taken to choose the optimal inflow site. The authors favour the use of an aorto-aortic, aorto-bi-iliac, or aortobifemoral prosthetic graft.

Preparation of the graft. A custom graft is created by assembling a main graft (MG) (Albograft or Lemaitre; Burlington, MA, USA) with a retrograde visceral graft (RVG) using a polyester coated polytetrafluoroethylene graft (Fusion 10 or 8; Maquet Getinge, Merrimack, MA, USA). An elliptic hole is created on the left lateral side of the body of the MG using cautery. The hole is positioned 2 cm above the aortic bifurcation or the bifurcation of the graft, in order to maximise the length of the MG proximal to the anastomosis with the RVG and to leave a sufficient landing zone. A bevelled retrograde anastomosis is then made using a

running polypropylene 5/0 suture between the end of the RVG and the side of the MG.

Visceral debranching and repair. Visceral debranching and repair is then performed in a caudad to cephalad order, which was found preferable in order to give the main graft a final harmonious aspect: IMA (if deemed necessary); most distal renal artery; most proximal renal artery; SMA; and coeliac trunk. Except for the IMA, every visceral artery to be treated is ligated or clipped at its ostium and sectioned at its most healthy level. The distal section is bevelled if smaller than 4 mm or to give a good direction, and transposed side to end to a hole punched on the RVG using a running suture of 5/0 or 6/0 polypropylene. The best position for the renal arteries is the ipsilateral aspect of the RVG behind the taped LRV. The RVG must therefore be tunnelled behind the LRV. For the RRA, especially if its level of origin from the aorta is close to the ostium of the SMA, it is practical to sever the SMA first, to facilitate the access to the RRA. All anastomoses to the visceral arteries must be made without tension. For this reason, it is important to free a sufficient length of the artery to allow for it arriving at the RVG without tension. The RVG is then tunnelled behind the pancreas and anastomosed end to end to the distal section of the CT. Flow to every target artery is then checked using a continuous sterile Doppler probe. In most cases, the RVG is covered using the left mesocolon and the pre-aortic lamina. In thin patients, it is often necessary to wrap it with a transmesocolic omentoplasty.

Post-operative course and follow up. All patients were admitted to the intensive care unit (ICU) for the first post-operative days. Major neurological, respiratory, renal, cardiac, and digestive adverse events that occurred up to discharge were recorded. Patients had duplex ultrasound and CT performed before discharge. After discharge, patients were followed up at one and six months, and yearly thereafter, clinically, and with duplex ultrasound or CT.

Throughout the paper, data are presented as mean \pm SEM or as n (%), unless stated otherwise. Statistical analyses were performed using Microsoft Excel.

Table 1. Patient demographics and comorbidities.

Age – y	68 \pm 12.6
Male	12 (75)
Female	4 (25)
BMI – kg/m ²	24.7 \pm 5.1
<i>Comorbidities</i>	
Diabetes	1 (6)
Hypercholesterolaemia	6 (40)
Smoking	3 (20)
Renal insufficiency	1 (7)
Hypertension	10 (67)
Coronary artery disease	6 (40)
Peripheral artery disease	4 (27)
Median ASA	3 (1–3)

Data are presented as n (%), median \pm SEM, or median range. BMI = body mass index; ASA = American Society of Anesthesiologists.

Table 2. Pre-, intra-, and post-operative (immediate and during follow up) details of the patients.

Patient	Sex, age — y	Initial disease	Indication of VD	Previous surgery	Technique	Debranched arteries	Post-operative period	ICU LoS —d	Hospital stay	FU — d/status	Target vessel occlusion/ endoleaks
1	M, 34	Type A AD	Type 2 TAAA	Bentall surgery	VD, TEVAR 2 mo later	IMA, LRA, RRA, SMA, CT	ARF, no dialysis	8	26	1273/well	IMA/no
2	M, 63	Type A AD	45 mm left CIA aneurysm, visceral artery dissection	Bentall surgery	VD + surgical fenestration	IMA, LRA, RRA, SMA, CT	Pneumonia, ARF — no dialysis Ischaemic colitis, medically treated	12	42	858/well	No/NA
3	F, 69	Chronic type B AD	Juxtarenal AAA, visceral artery dissection	Type 1 TAAA 6 y prior	VD + surgical fenestration	IMA, LRA, RRA, SMA, CT	Pneumonia	2	6	400/well	No/NA
4	M, 57	Chronic type B AD	Persistent visceral/renal malperfusion following TEVAR, right kidney infarction, 50 mm AAA aneurysm	TEVAR	VD + surgical fenestration	IMA, LRA, SMA, CT	ARF, no dialysis	11	19	1465/well	IMA/NA
5	M, 75	Chronic type B AD	Mesenteric ischaemia + lower limb claudication	—	VD + surgical fenestration	IMA, LRA, RRA, SMA, CT	ARF, temporary dialysis	12	20	1943/well	No/NA
6	M, 69	Chronic type B AD	Extension of dissection to visceral artery, 40 mm diameter DTA	Aortic arch surgery 7 y prior	VD + surgical fenestration	IMA, LRA, RRA, SMA, CT	Septicaemia	8	22	827/well	No/NA
7	M, 63	Chronic type B AD	Type 1 TAAA	TEVAR, open surgical fenestration	VD	LRA, RRA, SMA, CT	Confusion, septicaemia	13	27	65/well	No/NA
8	M, 67	Acute type B AD	Hypertension (4 drugs) Visceral/renal malperfusion	—	VD + surgical fenestration + aortic arch surgery (thoraflex) 24 mo later	IMA, LRA, RRA, SMA, CT	Uneventful	1	8	1310/well	No/NA
9	M, 38	Acute type B AD	Hypertension (3 drugs) Visceral/renal malperfusion	—	VD + surgical fenestration	IMA, LRA, RRA, SMA, CT	Pneumonia	7	20	292/well	No/NA
10	M, 75	Acute type B AD	Dissection down to SFA, 67mm diameter type 1 TAAA	—	VD + surgical fenestration + aortic arch surgery (thoraflex) 1.5 mo later + TEVAR 6 mo later	LRA, RRA, SMA, CT	Ischaemic colitis (left colon resection), ARF no dialysis	10	80	194/well	No/no

11	F, 77	Type 1 TAAA Surgery delayed due to coronary stenting	Emergency (chest pain, left pleural effusion)	—	VD TEVAR during same procedure	LRA, RRA, SMA, CT	Pneumonia, secondary (day 3) paraplegia, MOF	45	45	45/death	NA/NA
12	M, 69	Type 3 TAAA	Severe comorbidities, kidney cancer (left nephrectomy)	AAA open repair, 8 y prior	VD from previous aortic graft	RRA, SMA, CT	ARDS, ischaemic colitis, MOF, death before second stage	2	2	2/death	NA/NA
13	M, 78	Type 2 TAAA	60 mm visceral patch aneurysm	Open repair of type 2 TAAA 8 y prior	VD from previous aortic graft, TEVAR 14 days later	LRA, RRA, SMA, CT	ARF, no dialysis	24	31	51/death (food swallowed wrong way)	No/no
14	F, 65	Occlusive disease	Chronic mesenteric ischaemia and lower limb claudication	Iliac and SFA stenting	VD	IMA, SMA, CT	Uneventful	1	7	145/well	No/NA
15	M, 71	Occlusive disease	Chronic mesenteric ischaemia and lower limb claudication	Kissing iliac stenting CT stenting	Median laparotomy, aortobifemoral bypass, visceral debranching	LRA, SMA, CT	Pneumonia, acute renal insufficiency, ACS (stent), duodenal bleeding, confusion	26	47	85, wel	No/NA
16	F, 68	Occlusive disease	Chronic mesenteric ischaemia and lower limb claudication	No	Median laparotomy, aortobifemoral bypass, visceral debranching	IMA, LRA, RRA, SMA, CT	ARF, no dialysis Ischaemic colitis (medical TTT)	4	8	523/well (visceral herniation)	No/NA

Indication for visceral debranching (VD), previous surgery, and intra-operative and post-operative details are provided.

M = male; AD = aortic dissection; TAAA = thoraco-abdominal aortic aneurysm; TEVAR = thoracic endovascular aneurysm repair; IMA = inferior mesenteric artery; LRA = left renal artery; RRA = right renal artery; SMA = superior mesenteric artery; CT = coeliac trunk; ARF = acute renal failure; CIA = common iliac artery; F = female; AAA = abdominal aortic aneurysm; NA = not applicable; DTA = descending thoracic aorta; SFA = superior femoral artery; MOF = multiorgan failure; ARDS = acute respiratory distress syndrome; ACS = acute coronary syndrome; TTT = treatment.

RESULTS

Intra-operative results

From January 2015 to December 2019, 16 patients were treated with this technique.

Mean patient age was 64 years (range 38–78; median 68 \pm 12.6). Other demographics and cardiovascular risk factors are given in Table 1. Table 2 details indications for surgery and outcomes. The indication was AD in 10 (62%) cases, a TAAA in three (19%), and mesenteric occlusive disease in three (19%). Ten patients had had prior vascular interventions, three of which included abdominal aortic replacement providing for a suitable MG at the time of debranching.

A total of 69 target arteries were debranched and repaired through a single stemmed RVG: five target arteries were treated in eight (50%) cases, four in five (31%) cases, and three in three (19%) cases. Aortic fenestration was performed in eight (50%) cases. Four (25%) procedures included the insertion of a tubular aortic stent graft, two during the same anaesthetic and two during a second later anaesthetic. Median operation time was 387 \pm 84 minutes.

Of the four patients who received TEVAR, three had spinal fluid drainage. One, who was operated on as an emergency and was taking two antiplatelet agents, had no drainage and experienced secondary paraplegia. The same surgery was offered for several groups of patients as follows.

Type A aortic dissection: patients 1 and 2. These two patients had open repair of their AD (Bentall procedure). The first patient developed a type 1 dissecting TAAA during follow up. Several years later, the second patient developed a 45 mm left common iliac artery dissecting aneurysm and all visceral arteries were dissected. The descending thoracic aorta was 42 mm in diameter.

Chronic type B aortic dissection: patients 3–7. These patients were previously treated medically (patient 5), with TEVAR (patient 4), or with open surgery (patients 3 and 6). Later, they developed various degrees of visceral/renal malperfusion, along with enlargement of their descending thoracic aorta or abdominal aorta, requiring aneurysm exclusion and visceral/renal vessel revascularisation. At the time of writing, patient 7 is awaiting a TEVAR procedure.

Acute type B aortic dissection: patients 8–10. Indication was difficult to control hypertension, visceral/renal malperfusion, and/or rapid enlargement of the aorta.

Thoraco-abdominal aortic aneurysm: patients 11–13. These patients had TAAAs and were deemed too frail for total open repair, not amenable for total endovascular repair for anatomical reasons, or were treated in an emergency.

Occlusive disease: patients 14–16. Patients in this group presented with chronic mesenteric ischaemia and aortoiliac occlusive disease; retrograde bypass was favoured over antegrade reconstruction.

Post-operative results

Three (19%) patients died on days 2, 45, and 51, respectively, two from multi-organ failure. The third patient was discharged to a rehabilitation centre where he died of respiratory arrest. In all three, post-operative CT angiography showed that all target vessels were patent. No death was related to RVG occlusion.

Among the survivors, acute renal insufficiency was the most frequent complication, with seven (43%) cases, two of which required temporary dialysis. There were four (25%) pneumonias and three (19%) cases of colonic ischaemia, one of which required a colectomy. Two cases of septicaemia were treated with antibiotics. Overall, two patients did not experience any complications, seven experienced one complication, three experienced two complications, one experienced three complications, and one experienced five complications (Table 2) (see Fig. 1).

Follow up

The median length of ICU/hospital stay was 9 \pm 11.5/21 \pm 20.2 days. Of the four patients who received an endograft, one had residual type 1B endoleak distal to the thoraflex arch hybrid prosthesis. The endoleak was sealed by TEVAR six months later. Over a mean follow up of 21 months, no additional death was noted, and all target vessels were patent except for two IMAs (97% of patency). One patient developed visceral herniation. The four stent grafts remained devoid of any endoleak (Fig. 2).

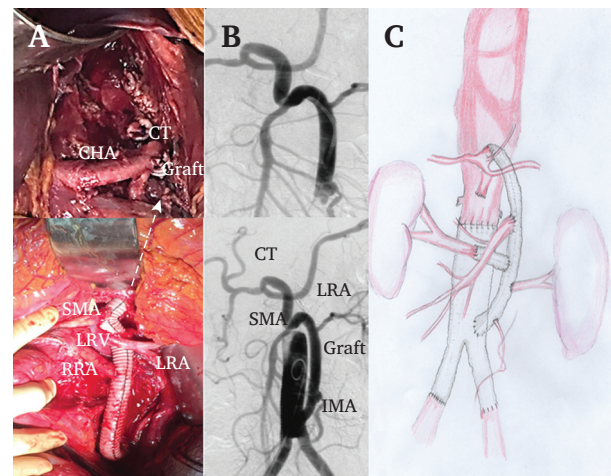


Figure 1. Intra-operative photograph illustrating the single branch montage. (A) Dacron graft starts from the main graft (MG), receives the right renal artery (RRA) via a small Hybrid Maquet Fusion 7 mm diameter graft (so-called “cactus”), is routed behind the left renal vein (LRV) and receives on its left the left renal artery (LRA) and on its right the superior mesenteric artery (SMA). The graft is tunnelled behind the pancreas (white dotted arrow) up to the coeliac trunk (CT; middle panel) where an end to end anastomosis was performed (the CT is ligated). (B) Postoperative arteriography of another patient. The top image shows the overall aspect; the bottom image is a magnification of the retrograde visceral graft. (C) Drawing representing the aspect of the final result. CHA = common hepatic artery.

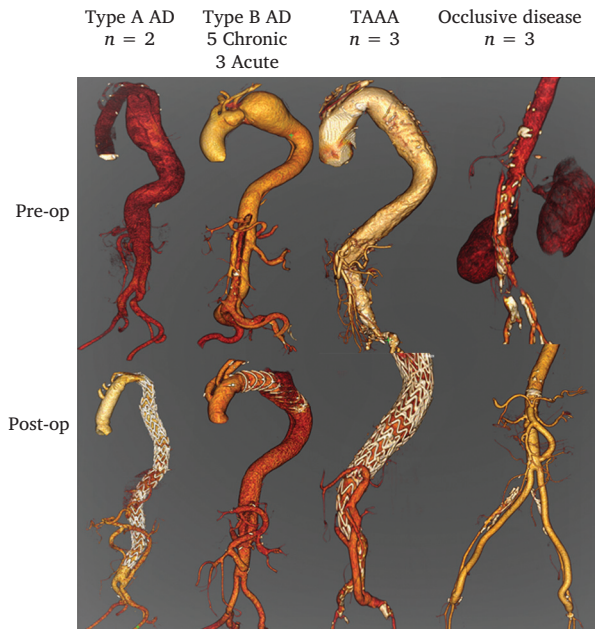


Figure 2. Representative pre- and post-operative computed tomography scan of the different categories of patients. AD = aortic dissection; TAAA = thoraco-abdominal aortic aneurysm.

DISCUSSION

Technique

Single stemmed RVG (SSRVG) is a safe and efficient method for abdominal debranching. All target vessels (except two IMAs) remained patent up to the last follow up. To the authors' knowledge, the use of a SSRVG to revascularise all four (LRA, RRA, SMA, and coeliac trunk), and even five (IMA), visceral arteries is original. In the literature, visceral rerouting techniques include customised Y grafts, reversed bifurcated grafts, trifurcated grafts, or even a four vessel visceral debranching graft, as described previously.^{5,6} All these techniques inherit the disadvantages of the octopus: many retrograde small conduits with questionable haemodynamics; complex routing; and a definite risk of visceral fistula. The single stemmed setup has the opposite advantages: there is only one healthy donor artery; only one proximal anastomosis between two prosthetic grafts; and only one main conduit with a patency maintained by the total flow to all target vessels. The graft is short and large, while optimising its space in the abdomen and is well protected against a visceral fistula behind the LRV and the pancreas. Finally, with some experience, this technique is much easier than the octopus. All the major target vessels (IMA excluded) remained patent to the last follow up, comparing favourably with reported patency rates ranging between 90% and 97%.^{7–9} In the authors' opinion, this is the result of the haemodynamic optimisation brought about by the single stem concept: a high flow in a large conduit. This provides a solution with the lowest possible haemodynamic impedance and is supported by recent computational fluid model work.¹⁰ Yuan et al.¹⁰ showed that, from a haemodynamic standpoint, the use of the

common iliac artery rather than aorta for the inflow site, leads to a dramatic decrease in flow to the visceral organs. Moreover, their haemodynamic model favoured the use of fewer branches to perfuse visceral organs. In the single stem technique, should one target vessel occlude, this would not impact the patency of the others.

The mortality and morbidity in this study was high. In the authors' opinion this reflects the severity of the underlying disease and the comorbidities of the patients rather than the invasiveness of the technique. Indeed, all included patients had contraindications for open repair. Four patients suffered from colonic ischaemia in the post-operative period. Two had IMA revascularisation and two did not. Ischaemic colitis and renal failure were relatively frequent, despite the patency of target vessels, suggesting that the reasons lay rather in haemodynamic failure (low flow), the need for vasopressor drug support, sepsis, and previous small vessel arteriosclerosis. Three deaths occurred in the TAAA group of patients, who were older (77, 78, and 69 years old, respectively), had severe comorbidities (coronary artery disease, severe chronic pulmonary obstructive disease, and cancer, respectively), and, for one of them, treatment was performed in an emergency setting. For patients presenting with fewer comorbidities, direct reconstruction was favoured, as reflected by the modest number of patients compared with those treated with standard TAAA surgery. Mortality rates range between 10% to 15% in the literature,^{3,7,8} but they are highly associated with patients' comorbidities and the context.

This study had several limitations inherent to its retrospective nature and the small number of patients. AD, TAAA, and aortic occlusive disease, which are very different diseases, were reported on, limiting the clinical impact of the results. The focus here was on the technical aspects of the procedure. The majority of the patients had AD complicated by visceral malperfusion and aortic aneurysmal evolution. These patients are increasingly treated by endovascular means and this report is the result of highly selected patients for whom total open or endovascular repair were not feasible. However, for this subset of patients, this technique may represent a readily available technique. Moreover, SSRVG and open aortic fenestration are highly compatible, providing an efficient solution in difficult situations.

Of course, the conclusions deserve confirmation in larger cohorts and with a longer follow up. The authors stress the importance of maintaining a high degree of open surgical competence in vascular surgeons, even in the endovascular era.

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