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Hybrid-procedures for the Treatment of Thoracoabdominal Aortic Aneurysms and Dissections

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Aim. *The conventional open repair of thoracoabdominal aneurysms and dissections remains complex and demanding and is associated with significant morbidity and mortality. We present our experience of hybrid open and endovascular treatment of thoracoabdominal aneurysms and dissections.*
Methods. *Within an experience of 226 aortic stent-grafts between 1998 and April 2006, 6 of the patients (median age 60 years, range 35 to 68 years) with thoracoabdominal aneurysms (Crawford type I, II, III, and V) were treated with a combined endovascular and open surgical approach. Five men and one woman, with median aneurysm diameter of 75 mm (range 70–100 mm), received revascularization of the renal arteries, the superior mesenteric artery, and the coeliac trunk accomplished via transperitoneal bypass grafting. Aneurysmal exclusion was then performed by stent-graft deployment.*
Results. *The entire procedure was technically successful in all patients. The patients were discharged a median of 9 days after the operation, while the postoperative studies revealed the patency of the vessels and no evidence of type I endoleak or secondary rupture of the aneurysm. During follow up (1 to 22 months) spiral-CT scanning revealed distinct shrinkage of the aneurysm, no graft migration or endoleak and patency of all revascularised vessels, except one renal artery in two patients. No patient experienced any temporary or permanent neurological deficit, and no dialysis was necessary.*
Conclusion. *The combined endovascular and open surgical approach is feasible, without cross clamping of the aorta and with minimized ischemia time for renal and visceral arteries, and seems to be an appropriate strategy for patients with a thoraco-abdominal aortic aneurysm or dissection.*

Keywords: Thoraco-abdominal aortic aneurysm; Hybrid procedure.

Despite incremental improvement in outcome after intact thoracoabdominal aneurysm (TAAA) repair over the last decade, the mortality in national data sets continues to be about 20%.[1] Single institutional series suggest results can be better with peri-operative mortality after repair of intact TAAA ranging from 4% to 16%.[2–6] Furthermore, despite the use of adjuncts, postoperative complications are often severe and include acute renal failure (2.3 to 12.7%), paraplegia (1 to 12%), myocardial ischemia, myocardial infarction, and respiratory failure (4.4% to 33%) with prolonged ventilation.[7]

With the promising results of endovascular repair of abdominal aortic and thoracic aneurysms[8–16] several centres have developed a new treatment option for TAAA. The hybrid technique involves primary open revascularization of the renal and visceral arteries to provide a suitable landing zone for subsequent endovascular grafting for the exclusion of the TAAA.

The present paper deals with our own experience of the hybrid procedure in six cases of TAAA and summarizes the peer-reviewed worldwide literature.

Patients and Methods

Within an experience of 226 stent grafts between November 1998 and March 2006, six patients with TAAA (median maximum aneurysm diameter 75 mm; range 70 to 100 mm) (Table 1) underwent revascularization of their renal and visceral arteries subsequently followed by thoraco-abdominal aortic placement of stent grafts (Table 2). The median preoperative serum creatinine level was 1.1 mg/dl (range 0.8 to 2.2 mg/dl).

All patients underwent CT scanning of the thorax, abdomen and pelvis performed with a four-detector

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Table 1. Patient and aneurysm characteristics

PT	Age, gender	Comorbidities	ASA	Aneurysm type
1	68, m	HTN, cRI	IV	type II TAAA[a] contained rupture with pleural effusion
2	64, m	HTN, CAD, COPD, PAOD, cS, DM, PTAS (1998)	IV	type V TAAA, contained rupture
3	57, f	HTN, cS,	II	type II TAAA,
4	53, m	HTN	III	chronic dissection (Stanford type B) with aneurysm (type II TAAA), thoracic pain, pleural effusion
5	63, m	HTN, COPD, PCS, PTAS	III	chronic dissection (Stanford type B) with aneurysm (type V TAAA)
6	35, m	cRI	III	type I TAAA, right subclavian artery aneurysm

[a] Classification of TAAA according to Safi and Co-workers[39]; HTN hypertension, cRI compensated renal insufficiency, CAD coronary artery disease, PAOD peripheral arterial occlusive disease, COPD chronic obstructive pulmonary disease, cS current smoker, DM diabetes mellitus, PCS previous cardiac surgery, PTAS previous thoracic aortic surgery.

row CT scanner (Somatom Plus 4 Volume Zoom; Siemens Medical Systems, Erlangen, Germany). Helical CT images were obtained from the neck to the groins by using a scan collimation of 4 × 1 mm, a pitch of 1.5 at 120 kV, and 130 mAs. Images were obtained during a single breath hold. The scan volume was reconstructed using 1.25-mm-thick slices and a reconstruction increment of 0.7 mm. The CT scanning was performed after the injection of 150 mL Iomeprol 300 (Imeron 300®, Bracco-Byk Gulden, Konstanz, Germany) through an antecubal vein by using a power injector (Medtron, Saarbrücken, Germany) with a flow rate of 4 mL/sec. Imaging was initiated within 4 seconds after enhancement of the descending aorta to 100 HU, as measured with a bolus-tracking technique.

A digital subtraction angiography of the thoracic and abdominal aorta with a calibration catheter was performed for measurement and localizing purposes. According to the proximal extend of the aneurysmal or dissected thoracic aorta and the expected proximal landing zone selective angiograms were achieved for the supra aortic vessels. Selective catheterization of the coeliac trunk as well as the superior mesenteric artery (SMA) was carried out to document the collateralization between the coeliac axis and the SMA via the pancreatic arcades. To evaluate the functional collateralization of the angiographically documented collaterals, the coeliac artery was blocked parallel to contrast injection into the SMA, and vice versa (Fig. 1). In cases of angiographically demonstrable retrograde perfusion of the coeliac trunk through gastro-duodenal collaterals from the superior mesenteric artery, the visceral revascularization was performed only via bypass to the SMA (Cases 1–4). An additional bypass was required if insufficient functional collateralization was present (5th and 6th cases).

If the CT scans revealed significant intercostals and lumbar arteries, selective catheterization of these arteries was attempted to demonstrate essential supply of the thoraco-lumbar spinal cord via the artery of Adamkiewicz. Only in two of the six cases was it possible to angiographically detect the artery of Adamkiewicz.

The 1st case presented with a contained rupture of a type II TAAA. The patient was stable, the preoperative spiral CT scan and angiography studies documented the TAAA with a maximal diameter of 75 mm, the occlusion of the coeliac trunk with

Table 2. Operative and endovascular procedures

PT	Operative procedures		Adjunct procedures	Endovascular procedures
	Donor vessel	Revascularization		
1	aortic bi-femoral graft (20 × 10 mm)	renal arteries (ePTFE 6 mm), SMA (ePTFE 8 mm)		TAG 40 × 200, 31 × 150, 32 × 45
2	aorta distal IMA	renal arteries (PE 12 × 6 mm), SMA (PE 8 mm)		TAG 34 × 200
3	left CIA	renal arteries, SMA	left subclavian artery transposition	TAG 40 × 200, 40 × 100, 37 × 200, 31 × 150, 26 × 100
4	aortic bi-iliac graft (22 × 11 mm)	renal arteries (PE 12 × 6 mm), SMA (PE 8 mm)	prior carotid carotidal bypass, secondary coil embolization left subclavian artery	ZTEG-2PT-42-208
5	aortic tube graft (22 mm)	renal arteries (PE 12 × 6 mm), SMA (PE 8 mm), common hepatic artery (PE 6 mm)		TAG 37 × 200, 31 × 150, 26 × 100
6	aorta distal IMA	renal arteries (PE 12 × 6 mm), SMA (PE 8 mm), common hepatic artery (PE 6 mm)	prior right carotid subclavian bypass	TAG 34 × 100, 31 × 100, 31 × 150, 28 × 150, 26 × 100

PE – polyethylene (Dacron®); ePTFE – expanded polytetrafluoroethylene.

Fig. 1. Pre-operative angiogram with selective catheter position at the SMA and balloon occlusion of the celiac artery documenting the functional collateral perfusion of the hepatic artery via gastroduodenal arcade.

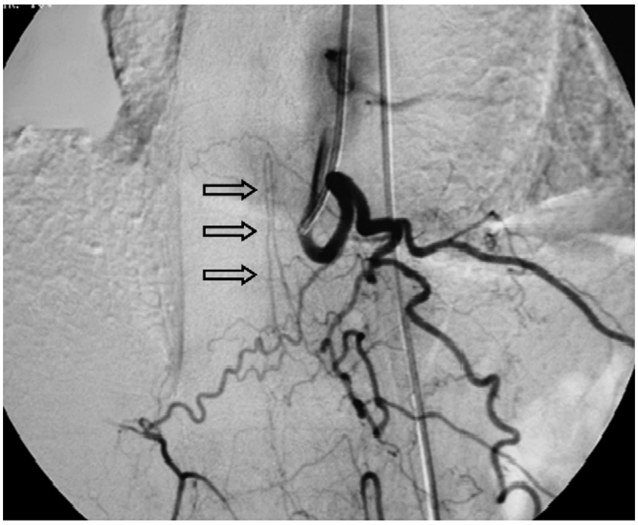

Fig. 2. The selectively catheterization of the left-sided 10th intercostal artery documented the perfusion of the anterior spinal artery (arrows) via the artery of Adamkiewicz.

retrograde collateral perfusion via the superior mesenteric artery and the gastro-duodenal artery, and a high-grade stenosis of the right renal artery. Moreover, the angiogram documented the near total stenosis of the common iliac artery of both sides.

The 2nd case had undergone an earlier repair of a thoracic descending aortic aneurysm. Six years after graft replacement he presented with acute onset of thoracic and lumbar back pain. CT angiogram showed a contained ruptured aneurysm at the diaphragmatic part of the descending aorta with a maximum diameter of 100 mm involving the coeliac trunk. Angiography documented the retrograde perfusion of the coeliac trunk through gastro-duodenal collateral from the superior mesenteric artery.

Another vascular institute transferred the 3rd case, where she was hospitalized due to thoracic and left-sided shoulder pain associated with a hypertensive crisis. The spiral computed tomography detected a TAAA with a maximum diameter of 65 mm extending from the left subclavian artery down below the inferior mesenteric artery. Angiography showed the retrograde perfusion of the coeliac trunk through gastro-duodenal collaterals from the superior mesenteric artery. The selective catheterization of the intercostals and lumbar arteries documented the perfusion of the anterior spinal artery via the artery of Adamkiewicz from the left-sided 10th intercostal artery (Fig. 2). The occlusion of this ostium for a period of 15 minutes was followed by regular somatosensory evoked potentials without clinical signs of spinal cord ischemia. In order to lengthen the proximal landing zone for the planned endovascular stent graft procedure and aiming at preserving potential collaterals from the vertebral artery to the spinal cord, a transposition of the left subclavian artery to the left common carotid artery was performed in this case.

The 4th case had a three months history of thoracic back pain and inter-scapular pain on the basis of a chronic type B dissection. Spiral computed tomography showed aortic dissection from the level of the left subclavian artery to the abdominal aorta with a 75 mm large aneurysm involving the origin of the left subclavian artery.

The 5th case had undergone a repair of a type A aortic dissection by a Bentall procedure in 1992 and coronary bypass grafting in 1998. Both procedures required long post-operative periods of ventilation due to the pre-existing chronic pulmonary obstructive disease. The CT scan revealed a 75 mm diameter aneurysm and a partially thrombosed false lumen involving the SMA. The pre-operative angiogram showed the perfusion of the anterior spinal artery via the artery of Adamkiewicz which originated at the level of the 2nd lumbar arteries 2 cm below the *orifices* of the renal arteries.

The 6th case was a young male with compensated renal insufficiency (serum creatinine level of 2.8 mg/dl) referred with a 30 mm diameter aneurysm of the right subclavian artery and a type I 75 mm diameter TAAA. The right renal artery was occluded at its' origin with refilling through collaterals just proximal to the bifurcation.

All operative procedures were conducted electively and semi-electively under general anaesthesia. No spinal drainage was performed. Via a mid-line transperitoneal incision both renal arteries and the root of the superior mesenteric artery were exposed anteriorly. If necessary exposure of the coeliac trunk and the common hepatic artery was performed by opening the lesser omentum and dissecting the common hepatic artery at the upper edge of the pancreas. The choice of inflow site for the retrograde bypass to the visceral and renal arteries was determined individually by the extent of the distal aortic pathology (Table 2). The renal artery and SMA bypasses were performed in a standardized fashion using an end-to-end renal anastomosis. The central stumps of the renal arteries and the SMA were always oversewn. When revascularizing the coeliac axis, the bypass was passing through a retro-pancreatic tunnel and anastomosed to the common hepatic artery in an end-to-side fashion (case 5 and 6). The coeliac trunk was subsequently ligated near its origin.

After the successful visceral and renal revascularization (Fig. 3), access for the endovascular procedure was achieved by a cutdown to the common femoral artery. An angiography catheter was also inserted through the contralateral femoral artery.

The endovascular procedures to treat the TAAA were performed successively using a reversed trombone technique. Depending on the aortic diameter of the anchoring zones the overlapping was started distally with the grafts showing the lowest diameter, and continued with larger diameters sequentially to the proximal landing zone at the distal arch. Adequate component overlap was at least 5 cm between the stent graft segments.

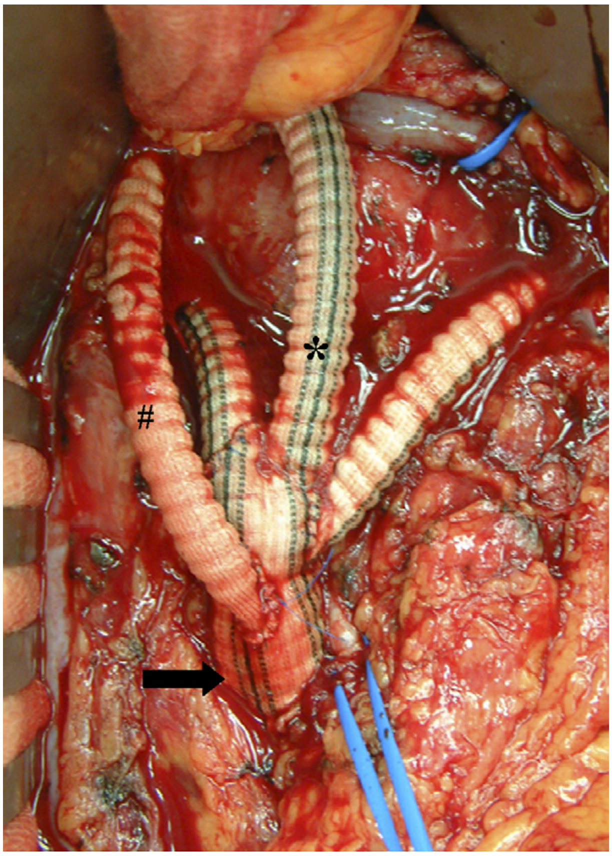

Fig. 3. Intraoperative situs with inverted bifurcated graft anastomosed to the infrarenal aorta as donor vessel (arrow), and conduits to SMA (*) and celiac trunk (#).

The proximal landing zone of the stent graft was selected according to the aneurysmal involvement of the thoracic aorta. In one case (No. 4), to lengthen the proximal landing zone, a carotid-to-carotid-bypass was implanted with ligation of the proximal left common carotid artery. As a second-stage procedure, one tapered thoracic stent graft was deployed right up to the brachiocephalic trunk. The postoperative CT angiogram revealed a type II endoleak via the left subclavian artery with contrast filling of the proximal part of the false lumen by retrograde perfusion through the stent graft covered left subclavian artery. This leakage was eliminated by trans-brachial interventional coil embolisation of the proximal left subclavian artery. At completion of the procedure the circulation to the renal and visceral arteries was visualized by angiography. All patients were followed-up clinically and by contrast-enhanced computed tomography, initially and at 3, 6, and 12 months, and yearly thereafter.

Results

The entire procedure was technically successful in all patients. The median operative time was 360 minutes (range 330 to 420 minutes). Median measured blood loss was 1700 ml (range 1000 to 3600 ml). The median transfused volume was 1200 ml (range 600 to 1800 ml). The completion angiogram showed no endoleak, and patent renal, mesenteric, and, when performed, hepatic bypasses with satisfactory filling of the coeliac axis.

All patients, except one, were transferred one day after the procedure from the ICU to the ward. Prolonged ventilatory support (>1 day) was necessitated in one patient with pre-existing COPD. During the peri-operative period no patient experienced any temporary or permanent neurological deficit. Visceral ischemia was not apparent. No dialysis was necessary. The creatinine level at discharge (median 0.94 mg/dl; range 0.7 to 2.5) was not significantly different from the preoperative level ($p > .05$).

The patients were discharged a median of 9 days (range 5 to 27) after the operation, while the postoperative CT studies revealed the patency of the vessels and no evidence of type I endoleak.

The stent graft coverage of the left subclavian artery in three of the six cases was clinically inconspicuous.

During a median follow up of 12 months (range 2 to 22 months) spiral-CT scanning revealed distinct shrinkage of the aneurysm (median 12 mm; range 0 to 25), no graft migration or endoleak and patency of all revascularised vessels, except for one renal artery in two patients.

Discussion

Open surgical treatment of TAAA continues to be a demanding procedure, associated with significant mortality, even in highly specialized institutions.[2–6] There is also a significant risk of visceral, renal and the spinal cord ischaemia.[17–22] Despite surgical developments, including cerebrospinal fluid drainage, different kinds of shunts and pumps for multivisceral perfusion,[23,24] spinal cooling,[18] and continuous neurological monitoring,[25,26] the incidence of complications remains high, especially in the treatment of type I and II TAAAs.[22]

Based on the favourable results of endovascular treatment of aneurysms[7–16] the concept of multivisceral revascularization before open inline reconstruction of the thoraco-abdominal aorta was developed.[7,27–29] Preliminary reports published since 1999 based on a few treated patients (Table 3) might imply that the unsatisfactory results of open surgical repair in type I and type II TAAA could possibly be improved by combined open and endovascular treatment i.e. ''hybrid techniques''. This approach reduces the open procedural burden by avoiding the combined thoracic and abdominal access and is accompanied by reduced visceral and renal ischemia time. However, the most important advantage of this concept seems to be the total avoidance of high aortic cross clamping. The technique is especially desirable for patients with severe cardiopulmonary co-morbidities.[30] The combined open and endovascular operation can be performed under hemodynamic stable conditions.

Another approach to minimise visceral ischemia and lessen the cardiac burden is to use the CPB.[2,31] This technique is associated with the use of high doses of heparin resulting in more bleeding complications.

The hybrid approach seems to reduce the incidence of intraoperative bleeding and postoperative haemorrhage compared to the blood coagulation changes induced by CPB assisted techniques. The paraplegia rate can be reduced from 29% down to 6.6% when

Table 3. Bibliographic research of peer-reviewed literature: ''hybrid procedures in TAAA''

Authors	Lit	Year	Location	*n*	Donor vessel	Revascularization
Bonardelli *et al.*	40	2005	Brescia/Italy	1	LCIA	RRA, SMA, comm. hepatic artery
Chiesa *et al.*	41	2004	Milan/Italy	1	aortic	SMA, CA
Chiesa *et al.*	42	2005	Milan/Italy	4	n.m.	n.m.
Flye *et al.*, Rubin	43,34	2004/2005	St.Louis, Mo/USA	3	1. LEIA 2. LEIA 3. LEIA 4. RLBG 5. RCIA	1. LRA, SMA 2. LRA, SMA, CA 3. SMA, common hepatic artery, RRA 4. CA, SMA, RRA 5. RRA, LRA, SMA
Greenberg *et al.*	44	2005	Ohio/USA	3		mesenteric bypass
Gregoric *et al.*	45	2005	Texas/USA	1	abdominal aorta	SMA, CA
Kotsis *et al.*	38	2003	Ulm/Germany	4	1. LCIA 2. RLBG 3. RCIA 4. aortic	1. SMA, LRA 2. CA, SMA, right hepatic artery 3. SMA, both renal arteries 4. SMA, CA
Lin *et al.*	46	2003	Texas/USA	1	LEIA	LRA
Macierewicz *et al.*	47	2000	Nottingham/UK	1	LCIA	splenic artery, SMA
Quinones-Baldrich *et al.*	48	1999	LA, Calif/USA	1	RLBG	renal arteries, SMA, CA
Ruppert *et al.*	49	2005	Munich/Germany	1	RLBG	renal arteries, SMA, CHA
Lundbom *et al.*	50	2004	Trondheim/Norway	1	REIA	renal arteries, SMA, CHA
Tachibana *et al.*	51	2005	Sapporo/Japan	2	1. aortic 2. aortic	1. SMA, CHA 2. SMA, CHA, splenic artery
Watanabe *et al.*	52	2002	Tokyo/Japan	2	aortic	SMA, CA
Khoury	53	2002	Detroit/USA	1	aortic/RCIA	SMA/RRA
Iguro *et al.*	54	2003	Kagoshima/Japan	1	RCIA	SMA, CHA
Black *et al.*	37	2006	London/UK	29		

RLBG – right limb bifurcated graft; LCIA/RCIA – left/right common iliac artery; LEIA/REIA – left/right external iliac artery; RRA – right renal artery; LRA – left renal artery; CHA – common hepatic artery; CA – celiac artery.

using spinal drainage and distal perfusion.[32] The same type of reduction can been seen when the motor evoked potential is used to localise which intercostal arteries need to be reinserted when doing open repair.[33] The results of thoracic aortic endografting have indicated that direct aortic perfusion of intercostals branches of the spinal cord is not essential as long as collateral pathways are preserved and hypotension is avoided.[34]

A complete endovascular approach in treating thoracoabdominal aneurysms is underway using ''fenestrated and branched stent graft devices'' and the first clinical experiences have been published.[35,36] This methodology is tempting although it can only be used in strictly elective cases as the time lag for these customized devices to be produced still is far too long at around six weeks.

Even though, the number of patients treated by retrograde multivisceral revascularization followed by endovascular repair of thoraco-abdominal aortic aneurysm is still low, and the period of follow up is still short, the preliminary results are excellent. Moreover, these multi-centre experiences have been confirmed by a single centre experience with a cohort of 29 patients from London.[37] In spite of the high risk of spinal cord ischemia in patients with type I and II TAAAs, there was no paraparesis or paraplegia following the endoluminal placement of stent graft. Furthermore, the reports contained only a few serious visceral, renal, or pulmonary complications. In one case of insufficient collateralisation of the coeliac trunk via the superior mesenteric artery localised ischemic complications developed.[38]

However, it remains difficult to reach firm conclusions from these results. The future perspective of this combined approach in the treatment of thoracoabdominal aneurysms will be ultimately determined in larger groups of patients and in a longer follow-up period. Nevertheless, the encouraging results attest the potential of the hybrid procedure and demonstrate the requirement for further investigations.

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