Hybrid procedures for thoracoabdominal aortic aneurysms and chronic aortic dissections – A single center experience in 28 patients

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Objective: **We report our 6-year experience with the visceral hybrid procedure for high-risk patients with thoracoabdominal aortic aneurysms (TAAA) and chronic expanding aortic dissections (CEAD).**
Methods: **Hybrid procedure includes debranching of the visceral and renal arteries followed by endovascular exclusion of the aneurysm. A series of 28 patients (20 male, mean age 66 years) were treated between January 2001 and July 2007. Sixteen patients had TAAAs type I-III, one type IV, four thoracoabdominal placque ruptures, and seven patients CEAD. Patients were treated for asymptomatic, symptomatic, and ruptured aortic pathologies in 20, and 4 patients, respectively. Two patients had Marfan's syndrome; 61% had previous infrarenal aortic surgery. The infrarenal aorta was the distal landing zone in 70%. In elective cases, simultaneous approach (n = 9, group I) and staged approach (n = 11, group II) were performed. Mean follow-up is 22 months (range 0.1-78).**
Results: **Primary technical success was achieved in 89%. All stent grafts were implanted in the entire thoracoabdominal aorta. Additionally, three patients had previous complete arch vessel revascularization. Left subclavian artery was intentionally covered in three patients (11%). Thirty-day mortality rate was 14.3% (4/28). One patient had a rupture before the staged endovascular procedure and died. Overall survival rate at 3 years was 70%, in group I 80%, and in group II 60% ($P = .234$). Type I endoleak rate was 8%. Permanent paraplegia rate was 11%. Three patients required long-term dialysis (11%). Peripheral graft occlusion rate was 11% at 30 days. Gut infarction with consecutive bowel resection occurred in two patients. There was no significant difference between group I and II regarding paraplegia and complications.**
Conclusions: **Early results of visceral hybrid repair for high-risk patients with complex and extended TAAAs and CEADs are encouraging in a selected group of high risk patients in whom open repair is hazardous and branched endografts are not yet optional. (J Vasc Surg 2008;47:724-32.)**

Open repair of thoracoabdominal aortic aneurysms (TAAA) and chronic expanding aortic dissection (CEAD) is the so called, gold standard surgical procedure. Despite the favorable impact of adjunct therapeutic options, such as left heart bypass, hypothermic cardiac arrest, spinal cord protection, and higher standards in perioperative and intensive care, major morbidity and mortality remain a challenge in conventional TAAA repair, even in experienced high volume centers[1-11] (Table I). Especially in high-risk patients, severe comorbidities strongly influence the complication rate and outcome. Furthermore, redo surgery with reopening (thoracotomy) is associated with increased risk. The introduction of endovascular therapy for descending aortic aneurysms by Dake and his group showed promising early and midterm results for this therapeutic alternative.[12,13] The use of stent grafts for more extensive TAAAs was limited by the presence of visceral and renal arteries. Total endovascular aneurysm repair by branched stent graft technology was developed as an alternative evolutionary endovascular step to treat complex thoracoabdominal aortic diseases. Quinones-Baldrich reported in 1999 the first hybrid procedure in TAAA,[14] while this concept of combined vessel debranching and endovascular exclusion has been successfully introduced to aortic arch pathologies before.[15-18] Last year, the group of doctors at St Mary's Hospital in London, UK, published their experience with one-step hybrid repair of TAAAs type Crawford I-III. This represents the largest series worldwide, with 26 patients on an intention-to-treat base.[19] Early experience and technical aspects have been published recently by our group.[20] For critically ill patients, potential advantages in risk reduction compared with classical open repair are the avoiding of aortic cross-clamping, extracorporal perfusion, thoracotomy, and single lung ventilation. These facts may result in lower paraplegia, and renal and pulmonary failure rates. Meanwhile, several centers reported their early results on small patient cohorts.[21-28] The aim of this second largest single-center study is to add our 6-year experience with this alternative treatment option for TAAAs and CEADs, focusing on an analysis of a staged-in-favor of simultaneous approach. Additionally, a review of the small number of publications covering visceral hybrids is discussed.

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Table I. Results after open thoracoabdominal aneurysm repair in selected high volume centers

Author (Ref No)	*Journal (y)*	*Patients (n)*	*30-d mortality (%)*	*Paraplegia/ paraparesis (%)*	*Dialysis (%)*	*1-y mortality (%)*
Crawford ([1])	J Vasc Surg (1986)	605	8.9	6	17	21
Svensson ([4])	J Vasc Surg (1993)	1509	10	16	9	no data
Jacobs ([7])	J Vasc Surg (1999)	52	8	2	0	no data
Sandmann ([10])	Gefässchirurgie (2005)	673	12.5	7.5/6.6	10	no data
Rigberg ([11])	J Vasc Surg (2006)	1010	19	no data	no data	31
Conrad ([8])	Ann Thor Surg (2007)	445	6.8	9.5/3.7	4.6	20
Coselli ([2])	Ann Thor Surg (2007)	2286	5	3.8	5.6	no data
Schepens ([9])	Ann Thor Surg (2007)	500	11.4	no data	no data	17

PATIENTS AND METHODS

Patient cohort. Between January 2001 and July 2007, 77 patients were treated for thoracoabdominal aneurysm disease in our department. The majority of these patients (n = 50/65%) were treated by conventional open repair. Since January 2001, 28 patients underwent hybrid revascularization of renal and visceral arteries, followed by endovascular exclusion of a TAAA or CEAD. Prospectively collected data from these 28 consecutive patients were retrospectively analyzed on an intention-to-treat base. Clinical features and risk factors are detailed in Table II. Median age of 21 men and 7 women was 66 years (range, 34-81 years). The etiology was aneurysmatic (TAAA) in 16(57%), secondary to aortic dissection in 7(25%), plaque rupture of the thoracoabdominal segment in four patients (14%), and a Carrel-Patch aneurysm after previous TAAA Crawford IV repair in one patient (4%). The distribution of Crawford TAAA types I-III were 2, 8, and 4, respectively. Previous aortic surgery was performed in 11 patients (40%). The mean aneurysm diameter was 75 mm (range, 45-120 mm). Emergency procedures (30%) were performed in four patients with ruptured aneurysms and in four patients with symptomatic aneurysms. The remaining 19 patients were treated electively. In March 2005, timing of elective procedures was switched to sequential repair in order to potentially reduce morbidity and mortality. Group I (n = 17, including the eight emergency cases) was operated simultaneously and group II (n = 10) in a staged approach. Mean follow-up was 22 months (range 1-78 months).

Definitions. Preoperative cardiopulmonary assessment, including echocardiography and lung function test, was performed to evaluate the severity of comorbidities. Indications for high-risk patients were respiratory distress (COPD, FEV1 < 1.0), cardiac dysfunction (ejection fraction < 35 %), and preoperative renal insufficiency (creatinine > 1.2 mg/dl). Patients were scored using the ASA-classification.

High-risk patients were defined by serious cardiovascular comorbidities (>3, such as COPD, congestive heart failure, coronary artery occlusive disease), ASA score >3, previous aortic surgery especially thoracotomy, and infrarenal aortic replacement (elevated risk for paraplegia). To classify the endograft landing zones, the anatomical arch map with zone 1-4 published by Mitchell[29] was applied.

Table II. Patient comorbidities and risk factors classifying high risk patients

Comorbidity, risk factors	*Total (%) (elective and emergencies)*	*Group I (%) elective simultaneous approach (n = 9)*	*Group II (%) elective staged approach (n = 10)*
Arterial hypertension	100	100	100
Previous myocardial infarction, coronary stent, or bypass	52	56	50
Cardiac insufficiency (NYHA > 1)	48	67	30
Pre-existing renal insufficiency	44	44	60
ASA = 3 or more	94	67	100
Previous aortic surgery	40	56	60
More than 3 risk factors (see above)	96	67	100

ASA, American Society of Anaesthesiologists; *NYHA*, New York Heart Association.

Major postoperative complications were defined as prolonged respiratory support (>3 days), tracheotomy, renal impairment (=creatinine > 2 mg/dl, temporary or permanent dialysis), paraplegia, prolonged medical inotropic support (catecholamine) >3 days, and any indication for redo-surgery. Urgent operation was defined as rupture or acute aortic syndrome necessitating invasive monitoring on intensive care unit (ICU) and operative repair within 48 hours.

Surgical and technical aspects. All operations were performed under combined general and epidural anesthesia in a supine position. Blood cell savage, rapid infusing systems for transfusion, and warm water body-wrapping (Thermowrap, MTRE Advanced Technologies Ltd, Or-Akiva, Israel) were used. There was no need for left heart bypass, hypothermic cardiac arrest, or suprarenal aortic clamping. A conventional abdominal approach via median laparotomy was used with subsequent exposure of the infrarenal aorta and the origins of the renal arteries (RA), the superior mesenteric artery (SMA), and the celiac trunk (CT). Infrarenal aortic reconstruction was performed in 17

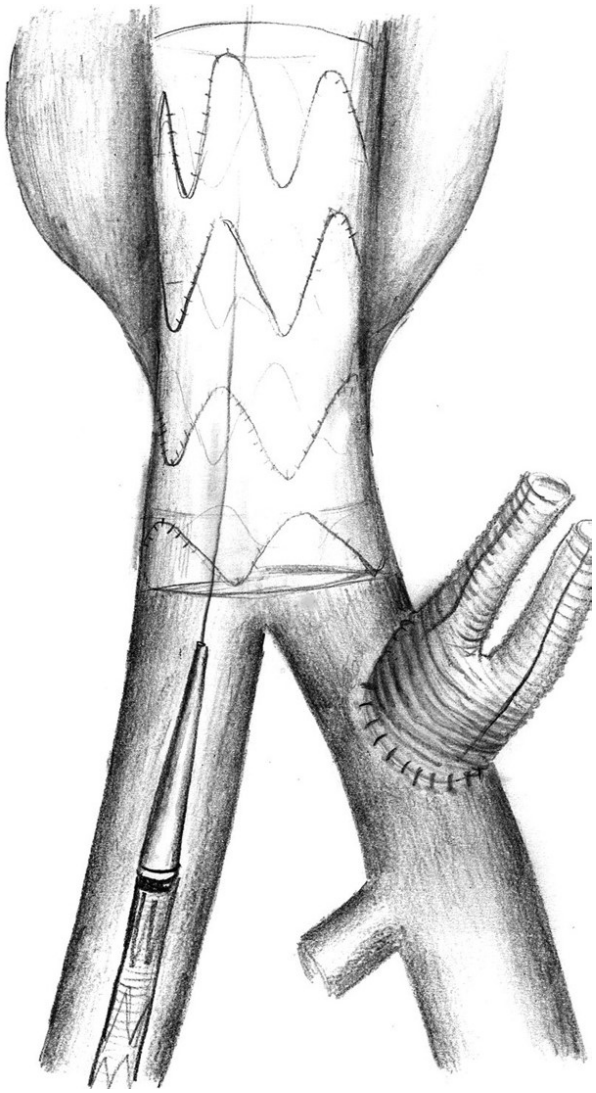

Fig 1. Illustration shows the preferred inflow anastomotic site for a staged procedure.

(61%) patients. If the common iliac artery (CIA) was chosen for the inflow anastomosis of the visceral/renal bypasses, we chose the contralateral CIA for endograft implantation in order to not pass the iliac artery with the bypass attached (Fig 1). In case of large peri- and infrarenal aortic diameters, a trifurcated graft was selected in order to facilitate an end-to-end ante caval anastomosis to the right renal artery. Using bifurcated grafts, the right branch was anastomosed side-to-end to the right RA, and then, this branch was anastomosed in front of the left renal vein to the SMA in a "lazy C" configuration end-to-end as published by Black and coworkers.[19] The left branch was anastomosed side-to-end to the left RA and then tunneled either in front (retrocolic) or behind the pancreas to the common hepatic artery performing an end-to-side anastomosis with subsequent ligation of the proximal CT in order to prevent endoleakage (Fig 2). The grafts were covered by an omentum flap to prevent direct small bowel contact. Graft patencies were shown to be patent by Doppler-flow measurements intraoperatively.

After debranching and revascularization of the visceral and renal arteries, endovascular exclusion of the thoracoabdominal aneurysm was carried out. Until March 2005, all endograft deployments were performed simultaneously in a one-step procedure. From then on, a staged approach was preferred in elective patients in order to reduce operation time, complication rates (eg, bleeding disorder), and to reduce paraplegia risk. The access site for endograft deployment was achieved by femoral (n = 7) or iliac conduit access (n = 1) in staged procedures, and through an additional conduit in simultaneous procedures. The stent grafts were deployed with standard endovascular techniques in a sequential, reversed trombone technique beginning distally with the smallest diameter. Two commercially available stent grafts (Talent/Valiant, Medtronic, Santa Rosa, Calif and TAG, W. L. Gore & Associates Flagstaff, Ariz) were used; they were tailored and sized individually based on preoperative CT-imaging (Aquilion 16, Toshiba, Medical Systems, Tokyo, Japan) and image postprocessing tools (Aquarius workstation, TeraRecon, Inc, San Mateo, Calif; Vitrea2, Vital Images, Inc., Plymouth, Minn) (Fig 3). Three stent grafts (median, range 2-5) were implanted in each patient.

In three patients, debranching and transposition of the supra-aortic vessels was necessary in order to achieve a sufficient proximal landing zone (zone 0) in the aortic arch. Carotid-carotid cross-over bypass and ascending bypass grafting was performed in a three-stage approach: (1) arch debranching, (2) visceral debranching, and (3) endografting. Our experience with aortic arch hybrid procedures was published recently.[15]

Follow-up. Patients were followed by clinical investigation, duplex ultrasound, computed tomography (CT)-angiography, and blood sample tests before discharge, at 6, 12 months, and annually thereafter (Fig 4). Mean follow-up was 22 months.

Literature review. A recent PubMed literature search for TAAA hybrids was undertaken using the following keywords: thoraco-abdominal aneurysm, chronic dissection, hybrid procedure, stent graft, staged approach, and paraplegia.

Statistics. Collected data were sampled in a prospective database and retrospectively analyzed, based on an intention to treat analysis. Overall survival, complication, and reintervention time were calculated by Kaplan Meier analysis. Log rank test was used for survival comparison. Proportion hazards survival model (Cox regression analysis) was used to analyze pre- and postoperative factors affecting survival. For subgroup analysis Pearson χ^2 test with confidence intervals (95%) were used for statistic analysis (Software Statxact V3, Cytel Corporation, Boston Mass). A P value < 0.05 was defined as statistically significant.

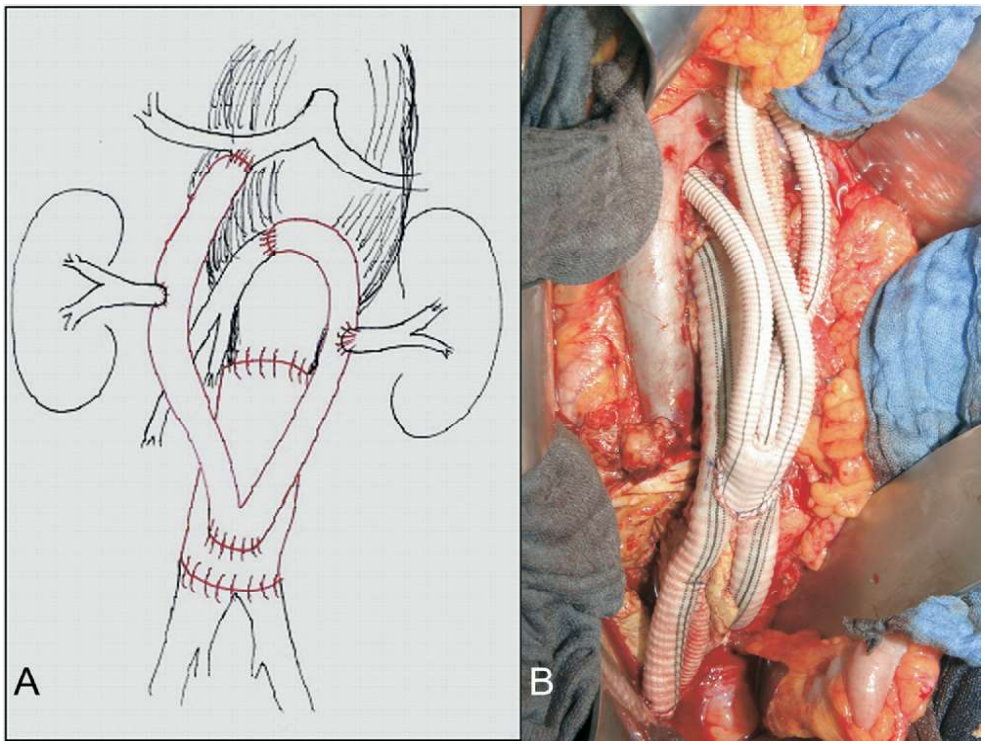

Fig 2. Illustration and intraoperative photograph demonstrates technical approaches of infrarenal replacement and inverted bi-/trifurcated graft as donor vessels for debranching renal and visceral arteries.

RESULTS

Technical success rate with completion was 100% (17/17) for the simultaneous procedure (group I) and 64% (7/11) in the staged approach (group II). Endograft insertion failed in one patient with previous aortic arch surgery (elephant trunk/type A-dissection). Endograft implantation was abandoned due to the inability to cannulate the true lumen and the elephant trunk prosthesis. In the same patient, successful implantation was performed in a second procedure after wire positioning in the descending aorta via a left brachial access. One female patient with successful bypass grafting was scheduled for staged thoracoabdominal endografting, but died on day 4 due to thoracic aortic rupture. In another patient with chronic expanding type B aortic dissection, the left renal artery could not be identified in a chronic expanding and inflammatory operative field and, therefore, not be revascularized. The proximal attachment site was two times in zone 0, four in zone 2, four in zone 3, and 14 times in zone 4.[29]

In four patients (14%), primary over stenting of the left subclavian was performed to achieve a sufficient attachment in landing zone 2. One patient developed dizziness and required secondary surgery for subclavian artery transposition. Debranching of the supra-aortic vessels with extra-thoracic carotid-subclavian cross-over bypass grafting (n = 2) or with partial sternotomy followed by retrograde ascending bifurcated graft insertion (n = 2) were uneventful in all four patients. The distal landing zone of the stent grafts was located in the infrarenal aortic graft in 10 patients, the native infrarenal aorta in 9, the suprarenal aorta in 3, and the iliac arteries in further 3 patients. In total, 25 procedures were completed with total exclusion of the thoracoabdominal aorta. Mean ischemic/clamping time of the RA, SMA, and CT was 20, 15, and 21 minutes, respectively. Mean operating time for the open surgical part of visceral revascularization was 368 minutes (range 230-465 minutes). Mean blood loss was 2000 ml. Mean hospital stay was 26 days (range 8-64 days) with a median stay on ICU of 9 days (range 2-31 days).

Mortality. Overall 30-day mortality was 14.3% (4/28) for all patients and 15.4% (4/26) for patients with completed hybrid procedures. One patient died on day 4 after visceral rerouting due to aneurysm rupture while waiting for the staged endovascular repair. One patient died from pulmonary insufficiency/ARDS, one after non-ST elevation acute coronary syndrome complicated by low-output bowel ischemia, and one due to postoperative bleeding and the sequelae of shock. Overall mortality during follow-up was 30%, all procedure- or aneurysm-related (Table III). Survival rate in group I was 80% and 60% in group II ($P = .234$) (Fig 5, *a, b*).

Morbidity. Overall major complication rate was 59%. Major intraoperative complications included bleeding disorders in two patients and two graft thrombosis with prolonged renal and mesenteric ischemic time were treated immediately by thrombectomy without further sequelae.

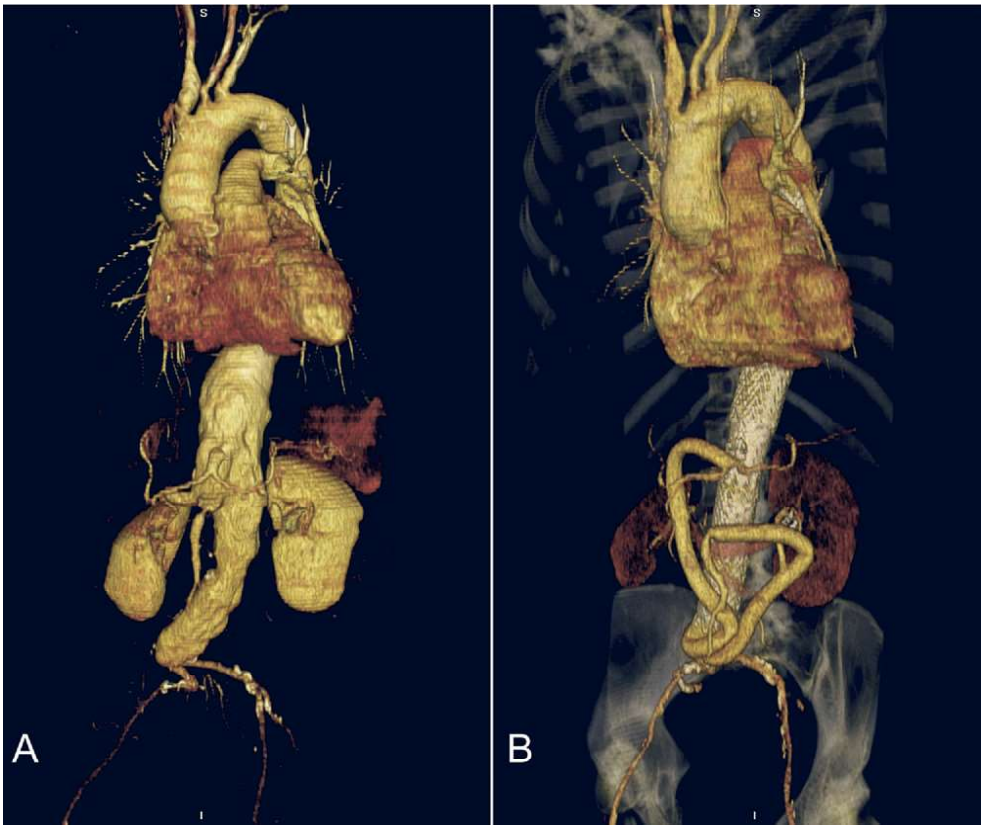

Fig 3. Pre- and postoperative computed tomography angiography (CTA) showing a thoracoabdominal aortic aneurysm Crawford type III being treated successfully with hybrid procedure.

Fig 4. Computed tomography angiography (CTA) axial views demonstrate preoperative (**A**), 3 months (**B**), and 35 months (**C**) follow-up examination with relevant aneurysm shrinkage.

Four patients developed paraplegia (16%) after completion of the hybrid procedure. Overall, five patients showed primary endoleaks at the postoperative CT-scan (20%). Two patients showed proximal type I endoleaks. One endoleak resolved spontaneously at 3-month follow-up. The other endoleak was treated successfully by partial sternotomy, ascending bypass for debranching of the supra-aortic arteries, and subsequent additional proximal stent grafting. Type II endoleaks in three patients were observed and followed by regular CT-scans. In one patient, proximal ligation of the celiac trunk after visceral debranching was forgotten after a 6-hour operation. The patient developed an extended type II endoleak and unfortunately, died during the attempt of coil embolization due to rupture (Fig 6). After a median follow-up of 13 months, graft patency was 86% (24/28). Postoperative renal insufficiency was observed in eight patients (32%) with temporary dialysis in five patients (18%). In three patients, renal artery bypasses occluded; after unsuccessful thrombectomy they developed consecutive permanent dialysis (11%). Reintervention due to bleeding was necessary in five patients (18%). Cox regression analysis showed chronic obstructive pulmonary disease (COPD) to be an independent predicting risk factor for overall survival (Table IV).

Table III. Causes of early (n = 5) and late (n = 4) deaths in 28 patients

	Early deaths	*Late deaths*
Aneurysm rupture before stent grafting	1	—
Postoperative bleeding, hemorrhage, MOF	2	—
Respiratory failure	1	—
Myocardial infarction, mesenteric ischemia, MOF	1	1
Type II endoleak (CLT), repressurization, rupture	—	1
Renal failure, SIRS	—	1
Septicemia, MOF	—	1

MOF, Multiorgan failure; *SIRS,* systemic inflammatory response syndrome; *CLT,* celiac trunk.

Subgroup analysis. Comparing emergency and elective cases, there was significant difference in 30-day mortality (28% vs 12%), no difference in all cause mortality (P = .71). There was also no significant difference in mortality between patients with aneurysms and chronic dissections (P = .62). Regarding paraplegia and overall complication rate, there was no significant difference between staged or simultaneous approach (P = .75).

DISCUSSION

This study represents with 28 patients the second largest single center experience on visceral hybrid procedures for complex thoracoabdominal aortic pathologies. Last year, Black and coworkers from St Mary's Hospital, London, published their early results with a combined endovascular and surgical approach for the treatment of TAAA type I - III in 29 patients in a single step approach.[19] They demonstrated good feasibility and the encouraging results of reducing the mortality from 31% to 13% and no paraplegia in this high-risk group of patients. Our results are in accordance with these two publications and add further information on visceral hybrid procedures in the thoracoabdominal aorta. We changed the timing of the endovascular step from a simultaneous to a staged approach in March 2006, but could not statistically prove the hypothesis of reduced morbidity and mortality so far, most probably due to small sample size.

In high-risk patients with thoracoabdominal aortic aneurysms (TAAA) and chronic expanding aortic dissections (CEAD), open repair continues to be hazardous. Despite incremental improvement after open repair in the last decade, many centers have been unable to emulate their results when performing traditional transdiaphragmatic repair. Rigberg et al clearly demonstrated in a statewide analysis of 1010 patients a continuing significant mortality after open TAAA-repair from 19% at 30 days, up to 31% at 1 year for elective procedures.[11]

Several investigators published case reports on successful total endovascular repair of TAAA with preservation of visceral and renal arteries with fenestrated and side-branched modular endograft systems.[30-33] Despite these encouraging results of specialized endovascular centers, long-term follow-up is still missing and results of branched and fenestrated grafts are mixed. These devices are custom-made and are subject to an inherent delay of 6 to 8 weeks, during which time the aneurysm might rupture. Branched and fenestrated techniques need to be distinguished because the two are very different. Overall, complete aneurysm exclusion with fenestrated and branched stent graft technology needs further technical refinements, is not yet sufficiently advanced, and is not feasible for all patients.

The hybrid procedure represents an attractive third alternative by avoiding of thoracotomy and cross-clamping. A direct comparison of mortality and morbidity reduction with open surgery or branched graft devices should not be carried out. A bias in patient selection, eg, the definition of high-risk patients is automatically introduced with the discussion of different approaches.

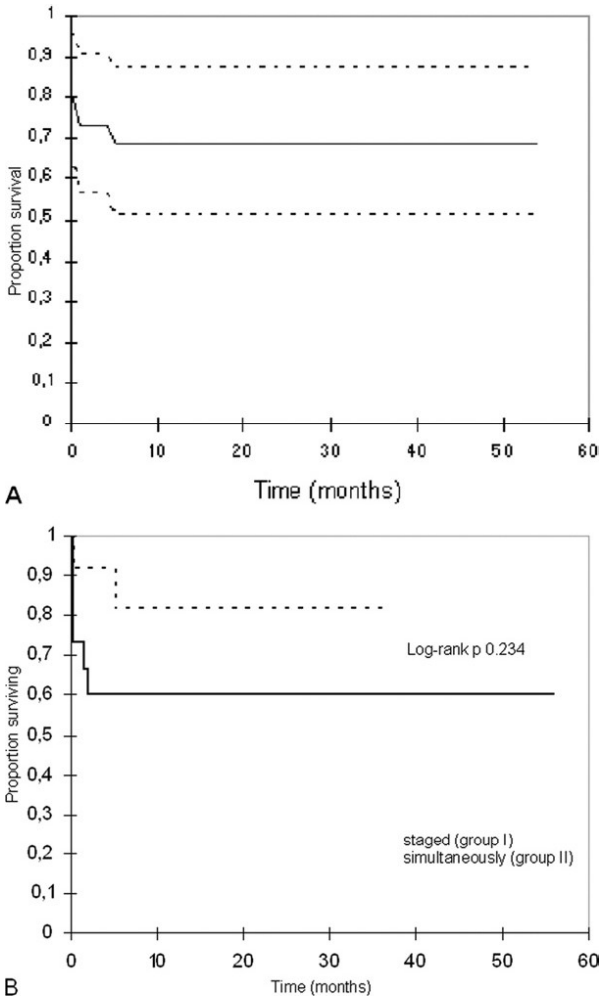

Fig 5. Kaplan-Meier survival plots of the total cohort of patients (**A**) and of subgroups with different time approach (**B**).

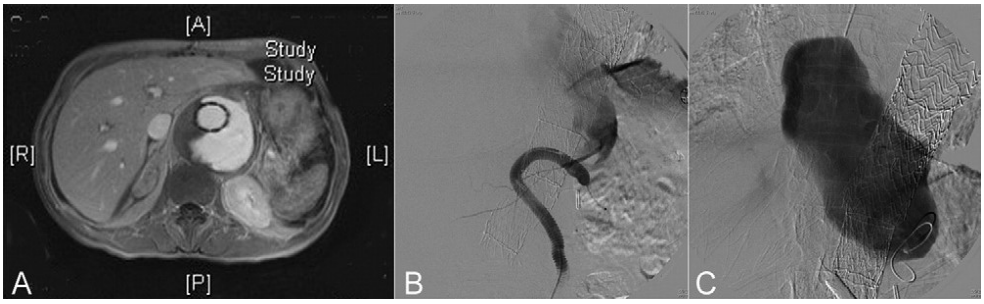

Fig 6. MRA and digital subtraction angiography showing a significant endoleakage originating from an unligated celiac trunk.

Table IV. Risk factor analysis influencing

Variable	*Hazard ratio*	*95% CI*	P *value*
Age >60 y	0.74	0.12 – 4.6	.75
Elective/emergency	1.46	0.34 – 6.21	.61
TAAA/CEAD	0.44	0.04 – 4.43	.49
Renal insufficiency	0.26	0.03 – 2.20	.22
Diabetes	4.28	0.33 – 55	.26
CHD, MI	0.23	0.01 – 2.8	.25
Smoking	9.29	0.52 – 165	.13
COPD	14.4	1.4 – 146	.02

TAAA, Thoracoabdominal aneurysm; *CEAD,* chronic expanding aortic dissections; *CHD,* coronary heart disease; *MI,* myocardial infarction; *COPD,* chronic obstructive pulmonary disease.

Hence, one cannot compare results of open TAAA/CEAD repair with results of hybrid procedures due to selection bias regarding preoperative risk assessment. The high potential of complications and adverse events of open surgery is clearly demonstrated by even well experienced high volume centers (Table 1).

There is a notably low mortality rate in the publication of Black et al.[19] Specifically, our higher rate of emergency procedures (Heidelberg 30%, St Mary's-London 10%) underline the potential of less invasiveness and better outcome regarding survival and major complications while performing hybrid procedures. Gawenda et al published their results of six patients with elective thoracoabdominal hybrid procedures (5 male, mean age 60 years).[26] This group reports no 30-day or follow-up mortality. In contrast, our mortality rate is mainly caused by emergency cases of ruptured aneurysms. Lethal outcome was observed in 28% of the ruptured/symptomatic group.

Already in 2002, Kotsis and coworkers considered in their small number of patients a combined endovascular and surgical approach to be feasible and appropriate in the treatment of thoracoabdominal aneurysms for selected high risk (n = 4 out of 231) and previously operated patients.[21] Patient selection is, therefore, a key issue and a clear definition of a "high-risk patient" is needed. Advanced age, cardiopulmonary comorbidities, and previous aortic surgery are well accepted risk factors influencing surgical outcome.[11] Our cohort included patients with a mean age of 66 years and a mean ASA grade of 3.

General indications and technical aspects of these complex and demanding vascular procedures were published by our group earlier.[20] Although data are limited and sample sizes are small in all major single center series[19] including our experience, the authors do not recommend a hybrid approach in patients with Crawford type IV aneurysms without previous aortic surgery so far. There is no advantage in regard to mortality and morbidity rates compared with open surgery in this subgroup of patients.[19] In this study, one patient with an aneurysmatic Carrell patch with a maximum diameter of 68 mm was selected for a hybrid approach. After previous open Crawford type IV aortic repair and additional infrarenal aortic graft replacement, re-thoracotomy could be avoided. Additionally, patients with previous infrarenal graft replacement for aneurysm are known to be at higher risk for spinal cord ischemia. Six of our patients had previous infrarenal graft replacement (22%).

One main advantage of visceral debranching compared with open repair is the avoiding of aortic cross-clamping, which is associated with renal ischemia and potential dialysis, as well as visceral ischemia and correlated sequelae of reperfusion. The reduction in visceral and renal ischemia is, as mentioned in the publication of Black et al, of great importance. Our mean ischemic times of 15 to 20 minutes show reduction in clamping time by 50% compared with open surgery.

Our concept of staged-in-favor of a simultaneous procedure is based on two unifying hypotheses: (1) reduction of operation time associated with lower complication rates (hypothermia, blood loss, coagulation disorders) and (2) stabilization of spinal cord perfusion. The collateral network concept of spinal cord perfusion was recently published by Griepp,[34] and is proven by numerous laboratory and clinical observations. An axial network of small arteries in the spinal canal, segmental (intercostal) arteries, subclavian, and hypogastric arteries contributes to the blood supply of the spinal cord.

In hybrid procedures for TAAA types I-III, multiple stent grafts are necessary to exclude the pathology (mean number of 3 stent grafts in this series). Greenberg et al compared total endograft length in patients with and without neurological deficit and showed significant correlation with the paraplegia rate.[35] Carroccio et al confirmed this

Table V. Results after hybrid procedures in TAAA (PubMed: studies with more than six patients)

Author (Ref No)	*Journal (y)*	*Patients (n)*	*Compl. rate (%)*	*Paraplegia/ paraparesis (%)*	*Renal failure/ permanent dialysis (%)*	*30-d mortality (%)*	*Overall mortality in % (follow-up in (mo)*
Black ([19])	J Vasc Surg (2006)	26	61	0/0	15.4/0	13	23 (8)
Resch ([25])	J Endovasc Ther (2006)	13	53	15/15	2/0	23	38.5 (23)
Gawenda ([26])	Eur J Vasc Endovasc Surg (2007)	6	16	0/0	0	0	0 (12)
Chiesa ([27])	J Vasc Surg (2007)	13	30.8	7/7	15.4/0	23	31 (14.9)
Orend ([23])	Gefässchirurgie(2005)	7	42.8	0/0	0/0	28.6	14.3 (21)
Donas ([28])	Int Angiol (2007)	8		0/0	25/0	12.5	12.5 (21)
Wolf/Böckler ([39])	Gefässchirurgie(2007)	20	45	0/10	10	12.6	28
Own results		27	59	16/0	32/11	16	30 (22)

observation of increased paraplegia risk with the length of stented descending aorta.[36,37] In an animal model, we could demonstrate that endoluminal treatment compared with aortic clamping (control group) is associated with significantly less incidence of paraplegia and spinal cord ischemia. In addition, we showed that endovascular repair of the entire descending thoracic aorta in sheep is feasible with moderate incidence of recoverable paraparesis. Blood supply to the spinal canal via dorsal branches after stent grafting or proximal clipping of the intercostal arteries was investigated by demonstrating patency due to retrograde perfusion of spinal vasculature.[38]

Resch et al have reported their series of 13 staged hybrid procedures of TAAAs with a mean follow-up of 23 months.[25] All patients underwent retrograde visceral bypasses (11 iliovisceral and 2 aortovisceral) as a first operation and endovascular aneurysm exclusion in a second staged procedure. They reported a 30-day mortality of 23% (n = 3) and a total procedure-related mortality during follow-up of 30% (4 of 13). Spinal cord ischemia was observed in four patients (30%), two had paraplegia, and two had transient paraparesis; very similar results to our study.

We could not show a significant decrease of the paraplegia rate in the staged compared with the simultaneous approach. We believe this may be due to our small number of patients. All four patients developed hypotension due to several reasons (eg, bleeding, narcotics) and most probably suffered from very low spinal cord perfusion. These results suggest that sacrifice of spinal arteries can be made, even in extensive thoracoabdominal aneurysms and dissections, without neurological injury, provided that no further complication, mainly bleeding, occurs.

Black et al favor the simultaneous approach[19] based on the potential harm to the inflow anastomosis of the inverted bifurcated bypass graft as the main disadvantage of staged transfemoral access and endograft introduction over the iliac axis. We did not observe any adverse events so far in our subgroup of 10 staged stent graft implantations. In this study, primary graft occlusion due to thrombosis occurred during clamping, but not as a result of stent graft insertion. Nevertheless, rupture of the anastomotic site, embolic events into graft branches, even graft occlusion, remain a concern of staged approach. Endograft deployment failed in one patient with previous aortic arch surgery (type A-dissection). Cannulation of the true lumen and the elephant trunk prosthesis failed using a transfemoral access. In the same patient, successful implantation was completed via a transbrachial wire that was positioned in the true lumen. Obviously, a disadvantage for stenting at a later (staged) date is aneurysm rupture before the endovascular procedure is undertaken. We lost one patient on day 4 after successful debranching due to rupture of the descending aorta. Therefore, caution is needed regarding hypertensive episodes (eg, while performing continuous positive airway pressure [CPAP] training between stages).

In summary, this study could not prove significant benefit from a staged approach, may be due to the small patient number. Nevertheless, spinal cord ischemia remains a devastating complication after thoracoabdominal aortic surgery. Therefore, we will continue to implant the endografts in a second operation and follow the strategy of a staged hybrid procedure during the same hospitalization period for the two reasons discussed earlier. (Table III).

CONCLUSIONS

Hybrid surgical procedures for the treatment of TAAAs offer an attractive and encouraging alternative to open repair due to potential benefits, such as avoiding (re-)thoracotomy and supraceliac cross-clamping. According to limited international experience, this combined open and endovascular approach is currently associated with a significant morbidity (16%-61%) and mortality (23%-38%). Risk evaluation beyond early results needs further analysis. So far, the staged procedure did not prove to be superior to the simultaneous hybrid repair in this study.

Hybrid repair of TAAAs may be a bridging method until branched endovascular stent graft technology matures or may be an alternative in patients unsuitable for total endovascular or open repair.

AUTHOR CONTRIBUTIONS

Conception and design: DB
Analysis and interpretation: KK, AD
Data collection: DK, HvTK, KK
Writing the article: DB, KK, DK
Critical revision of the article: JRA
Final approval of the article: KK, HVTK, DB, JRA
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