Hybrid Approach to Emergent and Urgent Treatment of Complex Thoracoabdominal Aortic Pathology

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WHAT THIS PAPER ADDS
This study is the first single-center study to describe the outcome of patients with thoracoabdominal aortic aneurysms undergoing a non-elective hybrid procedure. As such, it highlights technical aspects and has its focus on perioperative mortality and morbidity in the urgent and emergency situation.

Objectives: The aim was to report a single center experience with hybrid procedures in the emergency treatment of patients with thoracoabdominal aortic pathology. Thoracoabdominal aortic aneurysm (TAAA) repair is primarily conducted by conventional surgery in the urgent and emergency setting. The role of hybrid procedures with stent graft coverage of the aorta and extra-anatomical debranching of the renovisceral arteries has so far not been defined in this context.

Methods: From 2007 to 2013 30 patients (21 males, 9 females) undergoing an emergent or urgent TAAA hybrid procedure were included in a data register. The mean aneurysm diameter was 72 mm. Etiology was atherosclerosis in 23 patients (76.7%) and aortic dissection in seven patients (23.3%). Nineteen patients (63.3%) required emergency surgery. In 11 cases (36.7%), surgery was indicated for symptomatic aneurysms. Mean follow-up was 16 months (range 1–72 months).

Results: The hybrid procedure was completed in all patients. Renovisceral revascularization was performed with a total of 101 grafts (25 to the celiac, 30 to the superior mesenteric, 25 to the right renal, and 21 to the left renal artery). The 30-day and 1-year primary graft patency was 97.3% and 95.3% respectively. A median of three stent grafts per patient was deployed. One patient underwent surgical intervention for early endoleak (3.3%). Three patients (10%) developed spinal ischemia with persistent paraplegia. Two patients (6.7%) required chronic hemodialysis. Thirty-day mortality reached 26.7% (N = 8), being 36.8% in emergency patients (7 of 19) and 9.1% in the urgent group (1 of 11 patients). The cumulative postoperative survival rate after 12 months was 57.8%.

Conclusions: Hybrid procedures have the potential to be an alternative treatment option for complex thoracoabdominal pathology in the urgent and emergency setting. The procedure is readily available and enables adequate surgical repair with enduring results. Nevertheless it is still associated with significant mortality and morbidity.

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INTRODUCTION
Thoracoabdominal aneurysms are a rare clinical entity involving significant perioperative risks for the patient. Early elective treatment by open conventional repair has been established as the gold standard and shows ongoing good results. 1 In recent years endovascular treatment has been brought into focus due to promising results in elective cases. 2,3

In emergency patients presenting with aortic rupture, mortality after open repair still remains high, with significant morbidity in those surviving. 4,5 In this setting, custom-made endografts, which suit the specific anatomical requirements, may not be readily available. Few reports describe the treatment of symptomatic TAAA with off-the-shelf branched devices 6 and even more rarely have these devices been used in the treatment of ruptured aneurysms. 7,8 Moreover, the chimney and sandwich techniques are discussed as a timely available endovascular treatment option for ruptured TAAA. However, there is still very limited experience with these techniques, which are only performed in specialized centers. 9
Hybrid procedures have been developed primarily as an alternative to elective open repair in high-risk patients with TAAA. Depending on aneurysm morphology, the hybrid repair consists of three steps: an optional infrarenal repair, extra-anatomic debranching of renovisceral vessels and deployment of stent grafts. There have only been few cases of emergency treatment using the hybrid approach. Data on these patients are summarized in cohort studies showing certain positive aspects, but involving significant mortality and morbidity. The role of the hybrid procedure in an emergency situation and its appropriate time course, dependent on anatomic reality, is still not clear. A multi-step hybrid approach shows positive postoperative outcomes in elective cases and might have the potential to reduce perioperative complications in emergency and urgent cases as well.

The authors’ single-center experience of a cohort of 30 patients undergoing a hybrid procedure for TAAA with an emergency or urgent indication for surgical treatment is therefore reported.

PATIENTS AND METHODS

Data collection

Patients, who had undergone an emergent or urgent hybrid procedure for TAAA between July 2007 and August 2013 were included in a prospective registry. Emergency indications were defined as need for immediate surgical intervention, as in the case of aortic rupture. Patients who described an acute onset of back and/or abdominal pain and showed tenderness on palpation but presented no signs of TAAA rupture in CT scans were classified as urgent. Surgery was performed within 24 hours of admission. Postoperatively patients were followed up after 1, 3, 6, and 12 months by clinical examination, duplex ultrasound and CT scan. Thereafter they were followed up annually.

Patients

The patient cohort consisted of 21 male and 9 female patients. Patient characteristics and preoperative comorbidities are summarized in Table 1. The majority of patients (n = 25, 83.3%) were classified as ASA 3 or 4. The median age was 71 years (range 38–78 years). Eight patients (26.7%) had previously undergone thoracic aortic surgery and eight further patients (26.7%) abdominal aortic surgery. Mean follow-up was 16 months (range 1–72 months).

Aneurysm presentation, etiology and morphology

Nineteen patients (63.3%) were classified as emergencies and 11 patients (36.7%) as urgent. Emergency cases included 18 contained ruptures and an acute true lumen collapse of an expanding thoracoabdominal dissecting aneurysm. In seven patients the rupture site was located in the descending aorta, in eight patients in the suprarenal abdominal aorta, and in three patients in the juxta- or infrarenal aorta.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs) Median</td>
<td>71</td>
<td>76.7</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>21</td>
<td>70</td>
</tr>
<tr>
<td>Female</td>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>Arterial hypertension</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Heart failure (NYHA &gt;1)</td>
<td>10</td>
<td>33.3</td>
</tr>
<tr>
<td>COPD</td>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>CAD</td>
<td>16</td>
<td>53.3</td>
</tr>
<tr>
<td>PAOD</td>
<td>5</td>
<td>16.7</td>
</tr>
<tr>
<td>Renal insufficiency</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>Prior aortic surgery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thoracic</td>
<td>8</td>
<td>26.7</td>
</tr>
<tr>
<td>Abdominal</td>
<td>8</td>
<td>26.7</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>5</td>
<td>16.7</td>
</tr>
<tr>
<td>Liver cirrhosis</td>
<td>2</td>
<td>6.7</td>
</tr>
<tr>
<td>ASA 3 or 4</td>
<td>25</td>
<td>83.3</td>
</tr>
</tbody>
</table>

NYHA: New York Heart Association; COPD: chronic obstructive pulmonary disease; CAD: coronary artery disease; PAOD: peripheral occlusive artery disease; ASA: American Society of Anesthesiologists.

The average aneurysm diameter was 72 mm (range 46–106 mm). Aneurysm etiology was predominantly degenerative atherosclerosis (n = 23, 76.7%). Seven patients (23.3%) developed an aneurysm after aortic dissection. Two of those (6.7%) had Marfan’s syndrome. According to the Crawford classification the cohort included eight Crawford I, 10 Crawford II, nine Crawford III, and three Crawford IV aneurysms.

Surgical technique

The hybrid procedure was performed under general anesthesia and normothermia. When feasible, a spinal catheter was placed to monitor spinal fluid pressure. A transabdominal approach through a median incision was used to expose the abdominal aorta, the celiac, the superior mesenteric, and both renal arteries. Depending on aneurysm extent, an infrarenal aneurysm repair was first carried out to create a landing zone for the stent graft, using a tube or bifurcated graft to the iliac or femoral arteries. At least one hypogastric artery was revascularized when an anastomosis distal to the iliac bifurcation was necessary. For visceral debranching, a bifurcation graft with custom-made branches was employed. An end-to-side anastomosis to the infrarenal aorta or graft or the common iliac artery was created. The renal arteries were anastomosed end-to-side or end-to-end, depending on anatomy. The graft to the celiac artery was tunneled behind the pancreas and anastomosed end-to-side to the common hepatic artery. The branch to the superior mesenteric artery was placed behind the left renal vein as a wide C-shaped graft, thus preventing kinking after repositioning of the mesenteric root (Fig. 1). To prevent ischemic organ damage, cold saline (up to 250 mL) was introduced to the renal and visceral arteries through perfusion catheters during the anastomosis. All anastomoses were checked using ultrasonography.
Hybrid Approach for Treatment of Complex Thoracoabdominal Aortic Pathology

RESULTS

Technical data

In all 19 (63.3%) patients with an emergency operation and 11 (36.7%) with urgent surgery the hybrid procedure was successfully completed. Hybrid surgery was performed as a single procedure in 21 patients (70%). In nine patients (30%, 3 emergency with infra- or juxtarenal rupture and 6 urgent indications) a staged procedure was performed. None of these patients suffered an aortic rupture between the stages. Table 2 displays total operation times according to the extent of the repair. No differences were observed between emergency and urgent cases. An average of 7.7 units of blood was needed for patients with aortic rupture (range 2—26, median 6) and 7.1 for those with symptomatic aneurysms (range 0—25, median 6).

In 13 patients (43.3%) an infrarenal aneurysm repair was performed. A tube (n = 6) or bifurcated graft to the iliac (n = 5) or femoral arteries (n = 2) was used. The inferior mesenteric artery showed inadequate backflow in 10 of those patients and we therefore decided to reimplant it.

Overall, 101 target vessels were revascularized. In all 30 patients a bypass to the superior mesenteric artery was performed. The celiac artery was revascularized in 25 patients (83.3%). In four cases, chronic occlusion of the celiac artery was diagnosed on computed tomography (CT) scan. Intraoperatively, adequate collateral perfusion via the superior mesenteric artery was observed. One further patient presented with an anatomical variation, in which the hepatic artery originated from the superior mesenteric artery.

In two patients with Crawford I aneurysm a debranching of the renal arteries was not necessary. Renovascularization of the renal arteries was not performed in one patient with pre-existent hemodialysis, as well as in patients with chronic occlusion of the right (n = 2) or left (n = 6) renal artery and atrophic kidneys. Both renal arteries were revascularized in 19 patients (63.3%). Six patients (20%) received a single graft to the right and two patients (6.7%) a single graft to the left renal artery.

All stent grafts were placed without compromising the left subclavian artery. The infrarenal aorta or infrarenal aortic grafts served as distal landing zone in 28 patients (93.3%). In the remaining two patients (6.7%), the stent grafts were anchored proximal to the renal arteries. A median of three stent grafts was used per patient (range 2—4). The Valiant® thoracic stent graft was used most often. Talent® and Relay® thoracic stent grafts were also implanted in three and two patients, respectively.

In this cohort no emergency patient and all but one urgent patient received a spinal catheter (n = 10).

Intensive care and length of stay

All patients were admitted postoperatively to an intensive care unit (ICU). For surviving patients, median ICU stay was 7 days (range 1—51 days), median postoperative invasive ventilation time was 2 days (range 0—45 days), and median

<table>
<thead>
<tr>
<th>Extent of repair</th>
<th>Range (min)</th>
<th>Average (min)</th>
<th>Median (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250—367</td>
<td>308.5 ± 82.7</td>
<td>308.5</td>
</tr>
<tr>
<td>2</td>
<td>355—693</td>
<td>523.3 ± 99.9</td>
<td>539.5</td>
</tr>
<tr>
<td>3</td>
<td>519—950</td>
<td>670.1 ± 130.3</td>
<td>658.5</td>
</tr>
</tbody>
</table>

length of stay was 38 days (range 11–108 days), which depended on postoperative morbidity (Table 3).

**Gastrointestinal complications**

In four patients (13.3%) resection of the small intestine or colon was performed due to bowel ischemia despite patent grafts. Another patient developed a distal esophageal perforation on day 12, which was treated endoscopically with a stent (Polyflex Esophageal Stent™). All these patients had presented with aortic rupture. In the follow up no early or late complications related to intestinal resection or cholecystectomy were seen.

**Cardiac complications**

One patient with myocardial infarction required coronary angiography with placement of four stents. One patient suffered a non-ST-elevation myocardial infarction, which was treated medically.

**Pulmonary complications**

Three patients from each group (15.8% for the emergency and 27.3% for the urgent group) developed a bacterial or fungal pneumonia. Another patient suffered an asymptomatic, segmental pulmonary embolism, which was detected on a CT scan, but had no clinical relevance.

**Neurological complications**

The cumulative rate of permanent spinal cord ischemia reached 10% (n = 3). Two patients with ruptured TAAA and one patient with a symptomatic aneurysm and history of thoracic endovascular repair developed permanent paraplegia or paraparesis. One patient in the emergency group developed transient spinal cord ischemia with complete recovery. All patients survived the first postoperative year.

**Renal failure**

Postoperative hemofiltration was required in 11 patients, seven from the emergency (36.8%) and four from the urgent group (36.4%). Preoperatively, six already had impaired renal function. Renal failure with the need for permanent dialysis developed in two patients (6.7%), one from each group.

**Mortality**

The overall 30-day mortality was 26.7%, reaching 36.8% in emergency cases (7 of 19 patients) and 9.1% for urgent indications (1 of 11 patients). Mortality for patients with a Crawford I or II aneurysm was 25% and 30% respectively. For patients with Crawford III aneurysms it was 33%. There was no early mortality for patients with Crawford IV aneurysms. None of the staged patients died. Causes of early mortality are listed in Table 4. In the first year, three more patients died from non-aneurysm related causes. Postoperative cumulative survival at 1, 6, and 12 months was 73.3%, 63.6% and 57.8%, respectively (Fig. 2).

**Endoleak**

In one patient a combined type la and III endoleak was detected and treated by proximal stent graft extension and stent graft coverage of the overlapping zones. The proximal endoleak persisted and one additional stent graft was placed. No type II endoleak was observed. One of the remaining patients had a type III endoleak. This patient developed a septic pneumonia and died. The overall rate of early endoleak (types I and III) was 9.1%. Of the surviving 22 patients, five did not receive a CT scan due to postoperative impairment of renal function. Contrast-enhanced ultrasound showed no endoleak in these patients.

**Graft patency**

Graft patency was checked with CT scans (Fig. 3) or ultrasound in the presence of impaired renal function. The primary graft patency in the surviving patients at day 30 was 97.3% (73 of 75 grafts). At 12 months two graft occlusions

### Table 3. Postoperative morbidity.

<table>
<thead>
<tr>
<th>Renal</th>
<th>Neurological</th>
<th>Pulmonary</th>
<th>Gastrointestinal</th>
<th>Cardiac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dialysis</td>
<td>Transient</td>
<td>Permanent</td>
<td>Pneumonia</td>
<td>Resection</td>
</tr>
<tr>
<td>Group: emergency</td>
<td>5.3% (1)</td>
<td>10.5% (2)</td>
<td>15.8% (3)</td>
<td>21.1% (4)</td>
</tr>
<tr>
<td>Group: urgent</td>
<td>9.1% (1)</td>
<td>9.1% (1)</td>
<td>27.3% (3)</td>
<td>0%</td>
</tr>
<tr>
<td>Cumulative</td>
<td>6.7% (2)</td>
<td>3.3% (1)</td>
<td>10% (3)</td>
<td>20% (6)</td>
</tr>
</tbody>
</table>

### Table 4. Causes of early mortality.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Survival after hybrid procedure (days)</th>
<th>Cause of death</th>
<th>Presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>MOF, visceral ischemia</td>
<td>Emergency</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>Ventricular fibrillation leading to complete thrombosis of the grafts</td>
<td>Emergency</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>MOF</td>
<td>Emergency</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Ventricular fibrillation and EMD</td>
<td>Urgent</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>MOF, hemorrhage</td>
<td>Emergency</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
<td>MOF after ARDS and bilateral pneumonia</td>
<td>Emergency</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Hemorrhage</td>
<td>Emergency</td>
</tr>
<tr>
<td>8</td>
<td>18</td>
<td>MOF</td>
<td>Emergency</td>
</tr>
</tbody>
</table>

MOF: multiple organ failure; EMD: electromechanical dissociation; ARDS: acute respiratory distress.
were observed on CT scan, a graft to the celiac and a graft to the left renal artery. The 1-year patency was 95.3% (41 of 43 grafts).

DISCUSSION

Several investigators have reported elective hybrid procedures for aortic dissections and thoracoabdominal aneurysms, but the description of this procedure as an emergency operation is still limited to case reports or their summaries. The present study represents a single-center experience with hybrid procedures carried out in an emergency or urgent setting. The advantage of a hybrid approach in this setting is apparent. It is readily available and removes the need for thoracotomy and high aortic cross-clamping with its significant morbidity. In comparison to the total endovascular approach using off-the-shelf branched devices or the chimney or sandwich technique, the hybrid procedure facilitates and accelerates endovascular aortic stent graft placement. This is particularly advantageous in emergency surgery and in patients with unfavorable anatomy.

Before 2011, the hybrid procedure was performed as a single operation in emergency and urgent cases alike. With growing experience, it became clear that staging the procedure might have a positive effect on the patients’ outcome. This is supported by other groups, who reported beneficial results after staged hybrid procedures in regards to early mortality and morbidity. The severity of the postoperative systemic inflammatory response (SIRS) correlates with procedure time and procedure complexity. Postoperative organ failure has been attributed to SIRS after aneurysm repair. The staging of procedures may lead to attenuation of postoperative SIRS. This may be particularly important in the repair of complex TAAA which otherwise require lengthy operation times, as reported by other authors. In an emergency setting with suprarenal or thoracic aortic rupture, the hybrid procedure has to be performed in a single step. In case of infrarenal or juxtarenal rupture, where bleeding may be adequately controlled by cross clamping and open infrarenal repair as well as in patients with urgent indication, a staged hybrid procedure is possible and should be considered depending on the intraoperative situation. In these cases, stent grafts are placed during a second operation, which should be performed in a narrow time range of 12 to maximal 24 hours after renovisceral debranching.

This study shows that patients with TAAA rupture have an inherent higher risk of death and complications. This correlates with other studies. The overall 30-day mortality in this series was 26.7%, reaching 36.8% for emergency indications and 9.1% for urgent cases. In 2009, Von Meyenfeldt et al. reviewed the existing literature (38 articles with 222 performed hybrid procedures), among which 34 urgent cases were included. For these, early mortality of 32% was reported.

Morbidity in this patient cohort included renal failure and postoperative paraplegia, gastrointestinal, pulmonary, and cardiac complications. The postoperative morbidity described in the literature varies widely and has recently been reported to range from 28.8% to 60%. Renal impairment is attributed to warm ischemia, contrast agent, and perioperative changes in renal perfusion pressure. While several patients required some form of temporary hemofiltration, only two (6.7%) required permanent dialysis. Other authors reported similar results.
In this experience, early fluid resuscitation and hemofiltration in cases of renal impairment were crucial for recovery of renal function. The use of covered stents or hybrid grafts (GORE Hybrid Vascular Graft) has been advocated to facilitate bypass grating to renal, as well as visceral arteries.\textsuperscript{21} Since these techniques minimize operation and clamping time, they might help in reducing the incidence of postoperative organ failure.

Spinal ischemia has a multifactorial etiology, involving aortic cross clamping, prolonged perioperative hypotension, reperfusion damage, and extended aortic coverage. In the present cohort, three patients (10\%) developed spinal ischemia with permanent neurological symptoms (two patients with ruptured TAAA, one patient with urgent surgery and a positive history of previous endovascular thoracic aortic repair). Eagleton et al.\textsuperscript{22} showed a significant correlation between the presence of spinal cord ischemia and the coverage of one or more collateral networks, which are thought to supply the spinal cord (subclavian, intercostal, lumbar, and hypogastric arteries). Perfusion of the left subclavian artery was maintained in all patients in this series. In patients with an anastomosis distal to the iliac bifurcation revascularization of at least one of the hypogastric arteries was routinely performed. During staged hybrid procedures, the origin of one of the visceral arteries was temporarily left patent to support spinal cord perfusion. This vessel origin was ligated during the second look operation. So far it has not been possible to validate whether the implementation of this measure has a significant impact on the incidence of spinal cord ischemia due to the small number of patients. Since it also prolongs the total procedure time its use remains doubtful. To prevent postoperative paraplegia, many investigators advocate the use of cerebrospinal fluid drainage\textsuperscript{10,23} but its use is under discussion. Drinkwater et al.\textsuperscript{17} reported similar paraplegia rates between centers routinely or not routinely employing drainage. Similarly, several authors reported no paraplegia at all, even though spinal drainage was not used in all patients.\textsuperscript{17,25} Spinal catheters are used in our patients with urgent indications when feasible.

In four patients (13.3\%), resection of the small intestine or colon was necessary due to bowel ischemia despite patent bypass grafts. This proves that there is a significant perioperative danger for intestinal hypoperfusion due to hemorrhage and hypovolemia especially during emergency TAAA repair. Therefore, perfusion catheters are placed to introduce cold saline to the visceral arteries in order to stabilize the intestinal perfusion pressure during clamping. Moreover, to evaluate perfusion of the intestine, a second look operation was routinely performed. No early or late gastrointestinal complications as a consequence of bowel resection or cholecystectomy were seen. This result is based on a reliable graft patency in this cohort of patients, which was 97.3\% after 30 days and 95.3\% after 1 year.

Endoleak remains a significant drawback of hybrid procedures, since it requires reintervention and sometimes even open conversion, which results in higher morbidity and mortality. Endoleaks were observed in 9.1\% of this group of patients. Black et al.\textsuperscript{15} described an endoleak rate of 42\% in a series of 26 patients. Approximately one-third of those were type 1a. Furthermore, some authors have pointed out that proximal endoleak often persists, even after proximal extension, which occurred in one patient of this group as well. A review from Donas et al.\textsuperscript{24} reported a significantly lower rate of initial endoleak (18.9\%) in a series of 58 patients. Bakoyiannis et al.\textsuperscript{25} reported even lower rates of initial endoleaks (16.6\%).

This study is limited by its small number of patients, which does not allow any subgroup comparison. On the other hand, it represents the largest published single-center cohort of patients undergoing a TAAA hybrid repair in the urgent and emergency setting.

In the authors’ opinion the procedure is advantageous because it is readily available and enables an adequate surgical repair with enduring results without the need for thoracotomy and high aortic clamping. Nevertheless the procedure still has a significant mortality and morbidity. Growing experience and technical improvements will help to further reduce mortality, morbidity and the number of reinterventions in the future.

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None.

**CONFLICT OF INTEREST**

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**REFERENCES**

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