Hybrid Open Endovascular Technique for Aortic Thoracoabdominal Pathologies

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Background—Many authors using a hybrid debranching strategy for the treatment of thoracoabdominal pathologies have reported disappointing results and the initial enthusiasm for the technique has given way to criticism and ambiguity. The aim of the present meta-analysis study was to assess the safety and efficacy of the technique in patients with thoracoabdominal aortic aneurysms or other aortic pathologies.

Methods and Results—A multiple electronic search was performed on all articles describing hybrid open endovascular repair. Separate meta-analyses were conducted for technical success, visceral graft patency, spinal cord ischemia symptoms, renal insufficiency, and other complications as well as 30-day/in-hospital mortality. Nineteen publications with a total of 507 patients were analyzed. The pooled estimates for primary technical success and visceral graft patency were 96.2% (95% CI, 93.5%–98.2%) and 96.5% (95% CI, 95.2%–97.8%) respectively. A pooled rate of 7.5% (95% CI, 5.0%–11.0%) for overall spinal cord ischemia symptoms was observed; whereas for irreversible paraplegia the pooled rate was 4.5% (95% CI, 2.5%–7.0%). The pooled estimate for renal failure was 8.8% (95% CI, 3.9%–15.5%). The pooled 30-day/in-hospital mortality rate was 12.8% (95% CI, 8.6%–17.0%). During the mean follow-up period of 34.5 (95% CI, 31.5–37.5) months, a total of 119 endoleaks were identified in 111 patients (22.7%).

Conclusions—The repair of thoracoabdominal pathologies by means of hybrid procedures in patients who are poor surgical candidates is still associated with significant morbidity and mortality rates. Future studies may substantiate whether the technique is amenable to amelioration and improvement. (Circulation. 2011;124:2670-2680.)

Key Words: aorta • aneurysm • thoracoabdominal aneurysm • visceral debranching

A fundamental problem in the conventional open surgical repair of thoracoabdominal aneurysm (TAAA) is the extensive aortic exposure and the prolonged interruption of aortic flow to the visceral branches while excluding the aneurysm itself from circulation. Despite higher standards of perioperative care, refinements in operative techniques and the use of several protective adjuncts, including spinal cord protection, hypothermic cardiopulmonary arrest and selective visceral perfusion, open TAAA repair is still associated with remarkable morbidity and mortality rates. In recent reported studies on open surgical repair of TAAAs, the risk of paraparesis or paraplegia has improved, ranging from 2.7% to 13.2% depending on the extent and the cause of the aneurysm; renal failure requiring dialysis ranges from 4.6% to 5.6%, whereas overall 30-day mortality ranges from 5.0% to 19.0%.1–6

Due to these somewhat discouraging results and the fact that endovascular repair of abdominal aortic aneurysms reduces the perioperative mortality, a hybrid procedure for TAAA management evolved. This was thought to be applicable for older, sicker patients who may not tolerate the extensive open surgical procedures well. Presently, the majority of published reports on hybrid open endovascular repair (HOER) of thoracoabdominal pathologies are retrospective or prospective case series with ambiguous results, because some authors report reassuring and other disappointing results.7,8

We undertook a systematic review to identify all published reports on HOER. With the intention of providing an assessment of the safety and the efficacy of this technique, we combined the eligible studies into an extensive meta-analysis. A further attempt to investigate the variable results between different centers was also performed by assessing the heterogeneity among studies and the potential publication bias.

Methods

Search Strategy

A multiple electronic health database search (including Medline, Embase, Ovid, the Cochrane Database of Systematic Reviews, and...
the Cochrane Database of Abstracts of Reviews of Effectiveness) was performed on all articles published between January 2000 and January 2011 describing HOER. These databases were searched with an unrestricted search strategy, using exploded MeSH (Medical Subject Heading) terms (“thoracic,” “abdominal,” “thoracoabdominal,” “aortic aneurysm,” “endovascular,” “stent-graft,” “endograft,” “visceral bypass graft,” “visceral revascularization,” “visceral debranching,” “hybrid”). In addition, the references of all included articles were examined for further relevant series. All studies were independently assessed by two reviewers (K.M. and S.M.), and the full text of the studies was retrieved.

Study Design
HOER for thoracoabdominal pathologies should include, by definition, an open visceral debranching stage as well as an endovascular stage. A visceral debranching procedure can be achieved by various techniques (ie, lazy C graft, VORTEC technique). Thus, reports on celiac trunk, superior mesenteric artery, or renal artery open debranching procedure followed by endovascular exclusion of thoracoabdominal pathologies are included in this review. Studies on arch debranching procedures are excluded.

Studies were included in the present review if:
- Diagnosis of thoracoabdominal pathology had been made by computed tomography scan of the thorax, abdomen, and pelvis.
- Visceral bypass followed by endovascular stent graft implantation was the intended treatment strategy.
- Series included ≥4 patients. The majority of the reports on HOER in the literature were case reports or small case series; reports of >10 patients are rare. Intending to avert bias in these small case series, we excluded from the present analysis studies of <4 patients. The relatively low cutoff point of ≥4 patients was chosen as the threshold criterion on the basis of the paucity of series with a large number of patients and the reflection that experience from a center with ≥4 patients treated with this technique merits consideration. In addition, the heterogeneity among studies did not differ after the exclusion of studies with ≤8 or ≥10 patients.
- Demographic data and comorbidities of the patients were provided.
- At least I of the basic outcome criteria (neurological, renal, or respiratory complications; visceral graft patency; and endopros thesis-related complications) as well as the primary technical success rate and the total mortality rate were stated.
- Follow-up period ≥4 months.

Articles in languages other than English were excluded. An extensive effort was made to minimize the impact of covert duplicate or metachronous republication from the same surgical groups on the patient sample size; in these cases, only the latest report was included. Reports on TAAA repair by surgical or endovascular approaches alone were excluded. Furthermore, several studies included, among other patients, patients with HOER for thoracoabdominal pathologies but did not provide data separately for the thoracoabdominal HOER group; they were therefore not included in the present review.

Patient Characteristics and Data Extraction
The recruited patients were all deemed unsuitable for open surgical repair due to severe medical comorbidities, including chronic obstructive disease, coronary artery disease, congestive heart failure, diabetes mellitus, hypertension, and significant perioperative risk. Morphological parameters of the aneurysm and anatomic variations (marked arterial tortuosity, severe angulation of the aortoiliac system, or involvement of the aortic side branches in the aneurysm) raised technical limitations for endovascular approach. Patients with aortic pathology isolated in or involving the aortic arch were excluded from the present study.

Each study was reviewed by 2 independent observers (K.M. and S.M.), and the following data were extracted: number of patients; sex; mean age; comorbidities; kind of aortic pathology; type of TAAA (according to the Crawford classification, modified by Safi); maximal diameter of the aneurysm; stages of the procedure (and the intraprocedural interval if a staged approach was applied); implanted stent grafts design; primary technical success; mean length of intensive care unit and hospital stay; mean follow-up period; endoprosthesiserelated complications: early or late endoleak, stent migration or fracture, or aneurysm progression; 30-day in-hospital mortality; neurological complications; renal function impairment (<25% increase in serum creatinine or need for dialysis); respiratory complications (prolonged ventilatory support >5 days); cardiac complications; gastrointestinal complications; wound complications; visceral graft patency; bleeding or coagulopathy disorders; and overall follow-up mortality. If discrepant results were obtained, the articles were reanalyzed by the 2 reviewers and consensus was reached.

Statistical Analysis
Standard descriptive statistics (reported as mean with 95% confidence interval [CI]) were used to summarize demographic and baseline data of the recruited patients from all eligible published studies. Furthermore a meta-analysis was carried out on all included studies for technical success, visceral graft patency, spinal cord ischemia (SCI) symptoms, renal insufficiency, and other major complications, as well as 30-day-in-hospital mortality. The pooled proportion was calculated as the back-transformation of the weighted mean of the transformed proportions using the random effects model proposed by DerSimonian-Laird. A statistical test for heterogeneity using the I2 test was performed. The I2 value lies between 0% and 100% and is presented with a 95% CI; I2 value ≥50% is considered to indicate significant heterogeneity. The heterogeneity and robustness of pooled proportions were explored by conducting sensitivity analyses. However, because there are no published randomized clinical trials on HOER and all the reported studies are retrospective or prospective case series, the sensitivity analysis was limited to the exclusion of extreme studies as identified by the construction of funnel plots. Frequency study-specific estimates were pooled and are reported as proportions and 95% CI. The possibility of publication bias was assessed for both aims using the Begg-Mazumdar adjusted rank correlation test. A post hoc meta-regression analysis was performed to explore the heterogeneity observed among studies. The meta-analysis was conducted using StatsDirect statistical software (StatsDirect Ltd, UK) whereas the meta-regression analysis was performed using STATA statistical software (Stata Corp LP).

Results
The electronic literature search yielded 371 citations, 19 of which fulfilled the inclusion criteria and were reviewed in the present study (Figure 1). A total of 507 patients (63.7% male, mean age 70.1 years; 95% CI, 69.3–70.5 years) were analyzed. Patient demographics, the type of the TAAA, and indication for HOER are detailed in Table 1. Indication for HOER included degenerative aneurysms (65.0%; 95% CI, 60.5%–69.2%), aortic dissections (18.5%; 95% CI, 15.1–22.2%), secondary aneurysms due to connective tissue disorders (Marfan syndrome or Ehlers-Danlos syndrome) (3.4%; 95% CI, 2.1%–5.4%), visceral aortic patch aneurysm (6.4%; 95% CI, 4.5%–8.9%), mycotic aneurysms (0.8%; 95% CI, 0.3%–2.1%), and other aortic pathologies (penetrating ulcers, intramural hematomas) (5.9%; 95% CI, 4.1%–8.4%).

The type of the TAAA was reported for 413 patients: 56 TAAAs were type I (13.6%; 95% CI, 10.5%–17.2%), 113 type II (27.4%; 95% CI, 23.2%–31.9%), 139 type III (33.7%; 95% CI, 29.2%–38.4%), 59 type IV (14.3%; 95% CI, 11.2%–17.9%), and 46 type V (11.1%; 95% CI, 8.4%–14.5%). The mean aneurysm diameter was 69.0 mm (95% CI, 68.4–69.6 mm).

The majority of the reported procedures (275 of 500) were performed in one stage (55%; 95% CI, 50.6%–59.4%), whereas 225 patients (45.0%; 95% CI, 40.6%–49.4%) underwent endovascular stent grafting in a second stage following
debranching procedures. The mean interval between the endovascular stage and the debranching procedure was 28.1 days (95% CI, 23.3–32.9 days).

In 64 patients (12.6%; 95% CI, 9.8%–15.8%), the procedure was urgent due to a symptomatic or ruptured TAAA, and 443 patients (87.4%; 95% CI, 84.2%–90.0%) were treated electively. Mean intensive care unit stay was 5.4 days (95% CI, 5.2–5.6 days), mean hospital stay was 22.6 days (95% CI, 20.4–24.8 days), and the mean follow-up period was 34.5 months (95% CI, 31.5–37.5 months).

A variety of endovascular stent grafts were used: Excluder (W. L. Gore & Associates, Newark, DE), Talent (Medtronic, Inc, Minneapolis, MN), Zenith TX1, TX2 (Cook Inc, Bloomington, IN), TAG (W. L. Gore & Associates, Flagstaff, AZ), Jotec E-vita (Jotec GmbH, Hechingen, Germany), Corvita Endoluminal Graft (CEG), Tubular Aortic Endoprosthesis (Schneider, Minneapolis, MN), Gianturco stainless steel Z (Cook Group, Inc, Bloomington, IN), AneuRx (Medtronic, Santa Rosa, CA), Matsui-Kitamura stent graft (Kitamura Inc, Kanazawa, Japan), Inoue stent graft, Endofit stent grafts (Endomed Inc), and homemade endografts. A combination of stent grafts was also applied in some cases.

### Artificial Intelligence

**Technical and Clinical Outcome**

The pooled estimate for primary technical success, defined as aortic debranching followed by successful endograft deployment, was 96.2% (95% CI, 93.5%–98.2%) (Figure 2). In 3 cases, the operation was not completed due to perioperative

**Table 1. Patient Demographics and Baseline Characteristics**

<table>
<thead>
<tr>
<th>Total patients (n)</th>
<th>507</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (% male)</td>
<td>63.7</td>
</tr>
<tr>
<td>Age (years)</td>
<td>70.1</td>
</tr>
<tr>
<td>Comorbidities (%)</td>
<td></td>
</tr>
<tr>
<td>Nicotine consumption</td>
<td>62.9</td>
</tr>
<tr>
<td>DM</td>
<td>21.6</td>
</tr>
<tr>
<td>Hypertension</td>
<td>74.7</td>
</tr>
<tr>
<td>PVD</td>
<td>16.4</td>
</tr>
<tr>
<td>Renal impairment</td>
<td>36.7</td>
</tr>
<tr>
<td>Cerebrospinal disease</td>
<td>23.5</td>
</tr>
<tr>
<td>CHF (NYHA &gt;1)</td>
<td>21.7</td>
</tr>
<tr>
<td>CAD</td>
<td>30.3</td>
</tr>
<tr>
<td>ASA &gt;3</td>
<td>87.0</td>
</tr>
<tr>
<td>COPD</td>
<td>33.3</td>
</tr>
<tr>
<td>History of cardiovascular surgery (thorax, abdomen)</td>
<td>41.3</td>
</tr>
</tbody>
</table>

**Indication for HOER (%)**
- Degenerative aneurysm: 65.0 (306/471) 60.5–69.2
- Dissection: 18.5 (87/471) 15.1–22.2
- Connective tissue disorders: 3.4 (16/471) 2.1–5.4
- VAPa: 6.4 (30/471) 4.5–8.9
- Mycotic aneurysm: 0.8 (4/471) 0.3–2.1
- Other pathologies: 5.9 (29/471) 4.1–8.4

**TAAA mean aneurysm diameter (mm)**
- 69.0 68.4–69.6

**TAAA extend (Crawford classification, modified by Safi) (%)**
- Type I: 13.6 (56/413) 10.5–17.2
- Type II: 27.4 (113/413) 23.2–31.9
- Type III: 33.7 (139/413) 29.2–38.4
- Type IV: 14.3 (59/413) 11.2–17.9
- Type V: 11.1 (46/413) 8.4–14.5

**Procedure mode**
- One-stage procedure: 55.0 (275/500) 50.6–59.4
- Two-stage procedure: 45.0 (225/500) 40.6–49.4

**Interval between stages (days)**
- 28.1 23.3–32.9

**E elective procedure (%)**
- 87.4 (443/507) 84.2–90.0

**Urgent procedure (%)**
- 12.6 (64/507) 9.8–15.8

**Mean ICU stay (days)**
- 5.4 5.2–5.6

**Mean hospital stay (days)**
- 22.6 20.4–24.8

**Follow up (months)**
- 34.5 31.5–37.5

DM indicates diabetes mellitus; PVD, peripheral vascular disease; CHF, congestive heart failure; NYHA, New York Heart Association; CAD, coronary artery disease; ASA, American Society of Anesthesiologists; COPD, chronic obstructive pulmonary disease; HOER, hybrid open endovascular repair; VAPa, visceral aortic patch aneurysm; TAAA, thoracoabdominal aneurysm; and ICU, intensive care unit.
instability, and the debranching procedure was abandoned in 1 case due to a restricted flow rate that was considered insufficient for safe revascularization of the renal and visceral arteries. One patient did not undergo aortic endograft placement because of complications from the debranching procedure. Eight patients succumbed due to procedure-related complications after the first stage. Four more patients with successful visceral rerouting died due to aortic rupture waiting for the endovascular stage and 2 patients refused it.

During the follow-up period, 111 of the 488 patients (22.7%) in whom the procedure was completed presented an endoleak (119 endoleaks in total): 34 type I, 72 type II, and 13 type III endoleaks were identified. Reintervention was required for 27 (22.7%): 12 with type I endoleak, 10 with type II endoleak, and 5 with type III endoleak.

Visceral Graft Patency
Adequate data concerning the revascularized vessels were not available in all eligible studies. However, we estimated a total of 1 204 grafts to visceral or renal vessels performed in 18 studies.7,8,13–24,26–29 On the basis of the morphological configuration of the aneurysm and the sufficiency of the collateral supply via superior mesenteric artery, CA was electively revascularized. Thus, we identified 263 grafts to the CA, 310 to the superior mesenteric artery, and 620 to RAs. Mesenteric and renal debranching procedures were performed in the majority of the cases by either trifurcated or 4-vessel branch grafts. The inflow sites were retrograde the native iliac arteries or the distal aorta or an infrarenal prosthetic graft in patients with prior aortic surgery and antegrade the ascending or supraceliac aorta.

At the mean follow-up of 34.5 months (95% CI, 31.5–37.5), excellent patency was revealed in the revascularized vessels, as the pooled estimate for visceral graft patency rate was 96.5% (95% CI, 95.2%–97.8%) (Figure 3). Of the 37 occluded bypasses, 23 were grafts to a RA (14 asymptomatic, 9 resulted in renal failure requiring dialysis), 8 to SMA (2 asymptomatic and 6 required reintervention), and 2 to CA (1 asymptomatic and 1 required urgent revision). In the study reported by Kabbani et al,26 both renal grafts were fatally thrombosed in a single patient due to severe hypotension. In addition, 1 graft to RA was intentionally occluded to exclude a pseudoaneurysm that developed in a 17-year-old patient after autogenous revascularization.8 In the study published by the VORTEC Group, 4 Viabahn grafts were thrombosed, 2 of which recanalized after thrombolysis.24

Morbidity
Spinal Cord Ischemia
The proportional meta-analysis for overall SCI symptoms showed a pooled proportion of 7.5% (95% CI, 5.0%–11.0%) (Figure 4), whereas the pooled rate for irreversible paraplegia was 4.5% (95% CI, 2.5%–7.0%) (Figure 5). A secondary regression analysis of 20 patients in 18 studies who developed irreversible paraplegia showed a significant correlation between irreversible paraplegia and death (P=0.002).

Renal Insufficiency
A meta-analysis on renal insufficiency requiring hemodialysis showed a pooled rate of 8.8% (95% CI, 3.9%–
15.5%); however, there was great heterogeneity among the 18 eligible studies that provided adequate data\(^7,8,13-25,29\) (I\(^2\) = 76.5%, 95% CI, 61.1%–84%). With respect to not supported renal insufficiency, we extracted available data from 17 studies\(^7,8,13-23,26-29\). The pooled estimate for the not supported renal insufficiency rate, for which a meta-analysis was more accurate, was 5.0% (95% CI, 2.9%–7.7%) (Figure 6).
Prolonged Respiratory Support, Cardiac Complications, and Mesenteric Ischemia

Data concerning prolonged respiratory support (≥5 days) were available in 17 studies.\(^7\)\(^-\)\(^{13}\)\(^-\)\(^{23}\)\(^-\)\(^{26}\)\(^-\)\(^{29}\) The proportional meta-analysis for prolonged respiratory support showed a pooled rate of 8.2% (95% CI, 4.0%–14%). The true rate, however, may differ from the pooled estimate of our meta-analysis due to the significant heterogeneity among the studies (\(I^2=61.1\%, \; 95\% \text{ CI, 24.9\%–75.8}\%\)).
Proportional meta-analysis for cardiac complications was conducted in 17 studies. The pooled estimate for cardiac complication rate was 3.7% (95% CI, 1.7%–6.3%). However, the probability value for the Begg-Mazumdar test was significant ($P=0.020$), indicating the presence of publication bias. This could be associated with the low incidence of cardiac complications after HOER for thoracoabdominal pathologies.

Figure 7. Forest plot of mesenteric ischemia rate.

Figure 8. Forest plot of mortality rate.
Discussion

Because they did not require thoracotomy, hybrid techniques for repair of thoracoabdominal aortic pathologies were initially considered as operations with fewer systematic and cardiac complications. The additional expected benefits of this technique included less postoperative pain, less blood loss and fewer coagulation disorders, a reduced rate of SCI, reduced duration of mesenteric and visceral ischemia, diminished bacteria translocation and sepsis, and reduced renal failure, all resulting in reduced intensive care unit and hospital stays. In the present meta-analysis, we reviewed 507 patients and found the 30-day mortality rate was 12.8% (95% CI, 8.6%–17.0%). Ambiguity characterizes the role of hybrid procedures in TAAA treatment, raising debate about the benefits of the technique. This debate is further enhanced by the heterogeneity of the morbidity and mortality rates among different medical centers. In a series of 107 patients, one of the larger reported in literature, Drinkwater et al described a mortality rate of 14.9%. The most promising outcome was reported by Quinones-Baldrich et al, with a 0.0% mortality rate in a series of 15 patients. The most discouraging results were reported by Da Rocha et al and van de Mortel et al, with death rates of 44.4% and 31.2%, respectively.

In an attempt to explore the diversity of the 30-day mortality rates among the reviewed studies, we conducted a post hoc meta-regression analysis. However, the results of this meta-regression analysis documented that none of the investigated variables was associated with the pooled estimate for 30-day mortality rate. Analysis of the feasibility of the technique revealed that the overall primary technical success exceeded 96%, and midterm visceral graft patency rates were encouraging (96.5%, mean follow-up 34.5 months). So, a question is spontaneously raised. If the technique is feasible and the primary midterm graft patency rate so high, what is the cause of the substantial mortality associated with the debranching technique, and what is the reason for the observed variability among different medical centers?

The first important point that should be underlined is that patients’ age and comorbidities were consistently high among all reviewed studies. In our analysis, an American Society of Anesthesiologists physical status score ≥3, indicating a severe systemic disease, was observed in 87% (95% CI, 84.8%–89.2%) of all treated patients.

A second important point is that this applied technique was limited to a handful of institutions that, however, may have used different options and tools for perioperative management. The decreased morbidity rate in centers with larger number of patients treated with a hybrid technique can be attributed to the increased learning curve of the technique and to the early identification and appropriate management of postoperative complications.

In addition, a critical issue that may justify the high mortality rate of the technique is that this operation remains technically demanding, even though extensive aortic exposure and prolonged interruption of aortic flow to the visceral branches are avoided. From a technical view:

Table 2. Detailed Cause of 30-Day/In-Hospital Death

<table>
<thead>
<tr>
<th>Cause of Death</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rupture before TEVAR</td>
<td>6</td>
<td>10.2</td>
</tr>
<tr>
<td>MOF</td>
<td>10</td>
<td>16.9</td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>6</td>
<td>10.2</td>
</tr>
<tr>
<td>Bowel infarction</td>
<td>10</td>
<td>16.9</td>
</tr>
<tr>
<td>Sepsis</td>
<td>5</td>
<td>8.5</td>
</tr>
<tr>
<td>PE</td>
<td>2</td>
<td>3.4</td>
</tr>
<tr>
<td>Coagulopathy/HIT</td>
<td>2</td>
<td>3.4</td>
</tr>
<tr>
<td>Pancreatitis</td>
<td>3</td>
<td>5.1</td>
</tr>
<tr>
<td>Retroperitoneal bleeding</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>Cardiac complications</td>
<td>3</td>
<td>5.1</td>
</tr>
<tr>
<td>MCA stroke</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>Antegrade aortic dissection</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>GI bleeding</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>Massive embolization</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>Liver failure</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>Subarachnoid hemorrhage</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>Infected ascending graft</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>ND</td>
<td>4</td>
<td>6.8</td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
<td>100</td>
</tr>
</tbody>
</table>

TEVAR indicates thoracic endovascular aortic repair; MOF, multiorgan failure; PE, pulmonary embolism; HIT, heparin-induced thrombocytopenia; MCA, middle cerebral artery; GI, gastrointestinal; and ND, not determined.
The dissection required for this procedure remains extensive for high-risk patients. Undoubtedly, the laparotomy in combination with the surgical maneuvers for the preparation of the aorta and the main vessels result in significant organ and tissue trauma. Retrospective data from a US nationwide study suggested a mortality rate of 13.1% after aortoiliac bypass for chronic mesenteric ischemia and a bowel resection rate of 7.0%. In addition, the 30-day mortality rate after surgical intervention for atherosclerotic renovascular disease is suggested to be 4.6%. Obviously, a combination of these surgical procedures is expected to be associated with an increased surgical risk.

The aorta and the main arteries planned for revascularization are usually of poor quality, with mural thrombus or severe calcification. Clamping and graft anastomosis in diseased atherosclerotic arteries can lead to peripheral micro- or macroembolic complications that cannot be identified intraoperatively. Embolism is associated with sympathetic arterial spasm and, in combination with a reduced arterial flow, predisposes the collateral branches to secondary thrombosis and aggravation of the local ischemia.

Blood loss and fluid shifts are often substantial and, in combination with repetitive transitional changes in blood pressure, can result in renal failure and organ ischemia. In fact, in our analysis, the overall renal function impairment requiring hemodialysis was extremely high, at a rate of 8.8% (95% CI, 3.9%–15.5%). Bowel ischemia due to inadequate circulation or blood changes is also a significant cause of an uneventful outcome. In our analysis, 5.2% (95% CI, 2.9%–8.1%) of patients experienced complications with a bowel necrosis, and bowel infarction and multiple organ failure were the most common causes of 30-day in-hospital death.

It would be expected that, in hybrid procedures, the avoidance of aortic cross-clamping would significantly reduce the rate of ischemic neurological events. In our analysis, 7.0% of patients presented with spinal cord ischemia symptoms and 1.7% with a cerebral stroke. Neurological events were significant and may actually be worsened in the need for reoperation.

Additional aspects of the hybrid technique are under discussion. The staged hybrid procedure seems to be associated with a decreased rate of renal insufficiency but with an increased possibility of aneurysm rupture.20,23 The longer the waiting period, the greater the risk of rupture. In our analysis, according to available data from 507 patients, 45% of the patients were operated on in a two-stage procedure. The interval between the 2 stages varied from a few days to 4 months (mean 28.1 days [95% CI, 23.3–32.9]), and there were patients who refused to undergo the endovascular stage and patients who were missed. At the SAVS Annual Meeting in October 2007, Lin et al32 presented the clinical records of 38 patients who underwent hybrid repair of pararenal aortic aneurysm or TAAA. Lin et al described a higher incidence of renal insufficiency (87% versus 45%) and need for hemodialysis (25% versus 9%) in patients undergoing a simultaneous hybrid repair versus a staged, hybrid approach. In the same presentation, two patients were reported to have died before undergoing the staged endograft exclusion procedure, presumably due to aneurysm rupture.

Because less than 40% of patients with large untreated TAAAs survive beyond 3 years,33,34 an interventional treatment option is mandatory for these patients. Today there is debate as to which is the optimal treatment for these patients: hybrid technique, totally open repair, or totally endovascular using fenestrated and branched stent grafts? Although a comparison with other techniques is not the purpose of this study, it should be noticed that fenestrated and branched stent grafts have emerged as a demanding alternative for the treatment of thoracoabdominal pathologies with encouraging results.35,36 Haulon et al36 reported a 9% in-hospital mortality rate among 33 patients unfit for open surgical repair treated with this technique and a transient spinal cord ischemia in 12% (permanent paraplegia in 3%). Intermediate-term patient survival and mortality with this technique seem hopeful; however, mortality and spinal cord ischemia risks are still considerable.35,36 A review of the most recent referral center reports of surgically treated patients (Table 3), incorporating in clinical practice the beneficial effects of several adjunctive and protective measures, demonstrates improved results compared with previously reported studies.1–6 The 30-day mortality rate ranges from 5.0% to 19.0%, the rate of SCI ranges from 2.7% to 13.2%, and renal failure requiring dialysis approaches a rate of 4.6–5.6%. In a recent publication of 286 patients, Coselli et al2 documented a 5.0% 30-day mortality rate with a 3.8% occurrence of SCI and a 5.6% rate of renal failure requiring dialysis. In 2008, Etz et al5 described an occurrence of 2.7% SCI based on an analysis of

### Table 3. Studies of Standard Open Surgical Repair Incorporating Use of Hypothermia, Spinal Cord Protection, and Selective Visceral Perfusion

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Patients (n)</th>
<th>Mean Age (Years)</th>
<th>Gender (% Male)</th>
<th>30-Day Mortality (%)</th>
<th>SCI (%)</th>
<th>Renal Failure Requiring Dialysis (%)</th>
<th>1-Year Mortality (%)</th>
</tr>
</thead>
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<td>Rigberg et al1</td>
<td>2006</td>
<td>1010</td>
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<td>Coselli et al2</td>
<td>2007</td>
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<td>3.8</td>
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<td>Schepens et al3</td>
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<td>65.6</td>
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<td>11.4</td>
<td>NR</td>
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<td>Conrad et al4</td>
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<td>455</td>
<td>71.1</td>
<td>48.1</td>
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<td>13.2</td>
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<td>Etz et al5</td>
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<td>858</td>
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<td>2.7</td>
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<td>Greenberg et al6</td>
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<td>8.3</td>
<td>7.5</td>
<td>NR</td>
<td>15.9</td>
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SCI indicates spinal cord ischemia; ND, not determined; and NR, not reported.
858 patients, the lowest rate reported to date in the literature. Although surgical treatment continues to be associated with a significant risk of paraplegia, paraparesis, renal failure, and death, the judicious and critical use of several adjunctive and protective measures has made open surgical repair of TAAAs safer and more effective. A comparison among open repair, hybrid technique, and totally endovascular approach, however, remains an important point of consideration and debate.

Conclusions

The repair of thoracoabdominal pathologies by means of hybrid procedures in patients who are poor surgical candidates is associated with significant morbidity and mortality rates. Some centers continue to follow this strategy and have demonstrated very good results. However, there is reasonable hesitation to embrace the method and for it to be widely applied, because of the uncertainty of its potential benefits. The safety, effectiveness, and long-term performance cannot yet be established, and, as a result, lifelong regular follow-up must be undertaken to assess the ongoing performance of the grafts. Future studies may substantiate whether the technique is amenable to amelioration and improvement.

Disclosures

None.

References

CLINICAL PERSPECTIVE

Treatment of thoracoabdominal pathologies still remains challenging. Despite higher standards of perioperative care, refinements in operative techniques and the use of several protective adjuncts, including spinal cord protection, hypothermic cardiopulmonary arrest, and selective visceral perfusion, open thoracoabdominal aneurysm repair is still associated with considerable morbidity and mortality rates. An alternative treatment option, especially for patients considered unfit for open conventional repair, can be provided following the hybrid approach. However, ambiguity still characterizes the role of hybrid procedures in thoracoabdominal pathologies treatment, raising a debate for the benefits and risks of the technique. With the intention of summarizing the published experience on this technique and providing an assessment of its safety and efficacy, we undertook a systematic review to identify all published studies and combined the eligible ones in an extensive meta-analysis. This is the most comprehensive meta-analysis to date, including 507 cases with hybrid repair of thoracoabdominal pathologies and providing reliable data concerning the feasibility, the technical success, and the morbidity and mortality rates of this technique.
Hybrid Open Endovascular Technique for Aortic Thoracoabdominal Pathologies
Konstantinos G. Moulakakis, Spyridon N. Mylonas, Efthimios D. Avgerinos, John D. Kakisis, Jan Brunkwall and Christos D. Liapis

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Supplemental Table 1: Results of meta-regression analysis by outcomes and moderator variables (t, p value)

<table>
<thead>
<tr>
<th>MODERATORS</th>
<th>OUTCOMES</th>
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<tr>
<td></td>
<td>Technical success</td>
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<tr>
<td>Mean age</td>
<td>2.65 (0.02)</td>
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<tr>
<td>NC</td>
<td>0.79 (0.45)</td>
</tr>
<tr>
<td>DM</td>
<td>1.39 (0.20)</td>
</tr>
<tr>
<td>HN</td>
<td>0.36 (0.73)</td>
</tr>
<tr>
<td>Renal insufficiency</td>
<td>-0.63 (0.55)</td>
</tr>
<tr>
<td>Cerebrospinal disorders</td>
<td>0.23 (0.83)</td>
</tr>
<tr>
<td>CHF (NYHA&gt;1)</td>
<td>1.66 (0.14)</td>
</tr>
<tr>
<td>CAD</td>
<td>-0.77 (0.46)</td>
</tr>
<tr>
<td>ASA=3 or more</td>
<td>-0.76 (0.50)</td>
</tr>
<tr>
<td>COPD</td>
<td>-0.29 (0.78)</td>
</tr>
<tr>
<td>Previous cardiovascular surgery</td>
<td>-0.72 (0.485)</td>
</tr>
</tbody>
</table>
ABBREVIATIONS

NC: Nicotine Consumption
DM: Diabetes Melitus
HN: Hypertension
CHF (NYHA>1): Congestive Heart Failure class 1 according to NYHA classification
CAD: Coronary Artery Disease
ASA=3 or more: class 3 or higher according to the American Society of Anesthesiologists (ASA) Physical Status classification system
COPD: Chronic Obstructive Pulmonary Disease
SCI: Spinal Cord Ischemia