Combined Aortic Debranching and Thoracic Endovascular Aneurysm Repair (TEVAR) Effective but at a Cost

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Objectives: To compare hybrid repair (HR) (aortic debranching and TEVAR) with conventional open thoracoabdominal and aortic arch repairs (OR), including a cost analysis.

Design: Retrospective cohort.

Setting: University hospital.

Patients: Thirty patients with thoracoabdominal aneurysms were evaluated between November 1, 2005, and December 31, 2006.

Interventions: There were 18 HRs and 12 ORs. Aortic abnormalities included the arch, visceral aorta, and arch/visceral aorta combined. Aortic debranching with TEVAR (HR) was performed at a single setting. Dacron grafts were used for OR, and branch vessels were bypassed. Hospital costs and reimbursements were obtained from the finance department.

Main Outcome Measures: Perioperative morbidity, mortality, and cost.

Results: Patients were significantly older in the HR group (mean [SD], 72 [8.9] vs 58 [17.4] years, \( P = .2 \)). The HR group had significantly less blood loss (mean [SD], 1.7 [2.3] vs 4.8 [3.1] L, \( P = .004 \)), transfusions (5.1 [5.9] vs 14.7 [7.8] units, \( P = .001 \)); renal failure (0% vs 42.0%, \( P = .002 \)), and pulmonary morbidity (17% vs 67%, \( P < .001 \)); shorter intensive care unit stays (5.2 [4.8] vs 16.4 [12.9] days, \( P = .005 \)); and shorter hospital length of stay (mean [SD], 11.6 [6.2] vs 20.8 [10.8] days, \( P = .01 \)). There were no differences in mortality or spinal cord ischemia. There was no difference in mean direct hospital costs (HR:$59 435.70 vs OR: $49 341; \( P = .35 \)). However, the mean cost margin per case was −34% for HR and +6.2% for OR (\( P = .04 \)).

Conclusions: Improved clinical outcomes are seen after HR despite treatment of an older, sicker patient population. However, HR ultimately comes at a significant cost to the hospital, with a 34% loss in revenue per case.

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The mortality of untreated thoracic aortic aneurysms (TAAAs) exceeds 80% at 5 years.\(^1,2\) Operative repair greatly alters the natural history of this disease and is, therefore, indicated for aneurysms larger than 6 cm. This repair, however, has been associated with significant morbidity (65%-80%) and mortality (10%-20%), tolerated only in lieu of the extensive risks associated with conservative management.\(^3,6\)

With the advent of thoracic aortic stent grafting,\(^7\) endovascular repair of TAAAs has become an attractive alternative to open repair (OR). This advancement has been associated with fewer blood transfusions, lower perioperative morbidity and mortality rates, shorter intensive care unit (ICU) and hospital stays, and faster recovery.\(^8,9\) Initially, this technology was restricted in its application owing to anatomical limitations imposed by aortic branching. However, hybrid repair (HR) of complex thoracic and aortic arch aneurysms can overcome this limitation.

Hybrid repair consists of combined aortic branch vessel revascularization followed by thoracic endovascular aortic repair (TEVAR). This treatment modality has been demonstrated to be safe and effective.\(^10,11\) However, reported experiences have been small, and hospital costs of hybrid procedures have yet to be discussed in the literature. The purpose of this study is to review clinical outcomes after conventional OR for thoracic aneurysm and HR with TEVAR, including a cost analysis of these procedures.
DATA COLLECTION

A retrospective medical record review was performed of all patients with aortic pathology involving branch vessels treated at the University of Texas Southwestern Medical Center between November 1, 2005, and December 31, 2006. Patients underwent either aortic debranching followed by TEVAR (HR) or conventional OR. Data from patient medical records were reviewed to create a database for analysis. Demographic data collected for both groups included preexisting comorbidities, previous aortic operations, aneurysm type, and diagnosis-related group. Surgical records were reviewed for revascularization details, graft type used for aneurysm exclusion, intraoperative blood loss, and transfusion requirements. The postoperative course was evaluated for perioperative mortality, complications, number of days of mechanical ventilation, length of stay in the ICU, length of hospital stay, and final disposition (home vs rehabilitation center). Postoperative complications were further divided by organ system: neurologic, cardiac, pulmonary, renal, and wound complications.

PATIENT SELECTION FOR HYBRID PROCEDURE

A thorough assessment of medical comorbidities and a computed tomographic angiogram (CTA) were performed preoperatively in all patients. Patients who were determined to be high risk for OR but with aneurysm morphologic features unsuitable for endovascular repair were offered HR. Patients were deemed to be high risk for surgical repair when significant medical comorbidities or disease was present, including preexisting renal disease, pulmonary disease, cardiac disease, advanced age, and/or previous aortic surgery. In addition, the severity of patient comorbidities, judged during preoperative history taking and physical examination, was often the deciding factor to pursue HR. Patients offered HR were generally perceived as frail with more severe coexisting diseases. Patients with aortic aneurysm involvement of the branched segments of the thoracic aorta were deemed unsuitable for exclusive endovascular repair. Specifically, 8 patients had landing zones in the aortic arch, which would have compromised blood flow to the left carotid and subclavian arteries. Eleven patients required distal landing zones, which required covering of visceral arterial branches. Of these, 1 patient had a proximal landing zone in the aortic arch and a distal landing zone in the visceral branched aorta.

HYBRID TECHNIQUE

All HRs were performed in a single setting. Aortic debranching and revascularization was performed first. A 10-mm graft (Hemashield; Boston Scientific Corp, Natick, Massachusetts) sewn to the common iliac artery was used for access when a laparotomy was performed (n=11). Generally, all covered vessels were revascularized. Exceptions existed with the left subclavian artery and the inferior mesenteric artery (IMA). At the start of patient selection for HR, reimplantation of the left subclavian artery was left to the clinical judgment of the surgeon. However, the literature has since demonstrated that reimplantation of the left subclavian artery is protective against spinal cord ischemia. This vessel is now routinely revascularized at our institution; the IMA is not routinely revascularized. Branch vessel bypass conduits used included deep veins (n=9), the greater saphenous vein (n=1), and Hemashield grafts (n=6). Branch vessel bypass was immediately followed by endovascular stent graft placement. Gore TAG stent grafts (WL Gore & Associates Inc, Flagstaff, Arizona) were used in most patients (n=13). The remaining patients were treated with a modified Zenith endograft (Cook Inc, Indianapolis, Indiana) (n=4) or a Cook graft combined with AneuRx cuffs (Medtronic, Santa Rosa, California) (n=1). Cerebrospinal drainage was performed selectively in patients with a history of previous aortic aneurysm repair (n=5) to maintain cerebrospinal fluid pressures less than 10 mm Hg. These drains were removed on the third postoperative day.

OPEN SURGICAL REPAIR

Open surgical reconstruction was performed in a standard manner using Dacron grafts. Branch vessels were reimplanted or bypassed with artificial conduit (n=7) or deep veins (n=1). Cerebrospinal drainage is the standard of care in this group (except in Crawford type IV and isolated arch aneurysms). Management of spinal drains was identical to that previously described for patients in the HR cohort.

COST ANALYSIS

Total hospital costs, including indirect and direct costs, were obtained from the finance department. Indirect costs reflect hospital overhead and are present independent of patient volume and individual patient care. These costs are distributed equitably among patients as a percentage of their total bill; thus, patients with higher overall costs absorb more overhead. Direct costs are those attributable to each patient’s individual care, including operative time, transfusions, medications, ICU care, and ward care. Costs for thoracic endografts and standard open grafts were included in this analysis. Endograft implant supplies, including extensions, balloon catheters, guidewires, and sheaths, were included in the HR group. Costs for tubing and perfusionist time were included in the OR group. Hospital reimbursement information from Medicare and other insurance companies (Blue Cross Blue Shield and Medicaid) was obtained from the finance department for all patients. The contribution margin was calculated for each patient and each group (HR vs OR). The contribution margin is the percentage of financial loss/gain based on insurance reimbursement (IR) and direct hospital costs (DC), ie, [(IR−DC)/IR]. This study did not include costs for preoperative testing, surgeons’ fees, or follow-up appointments and testing.

DATA ANALYSIS

Results are reported as the mean ± the standard deviation (SD). Differences between the 2 groups were analyzed using the t-test. P ≤ .05 was considered to be statistically significant.

RESULTS

PATIENT DEMOGRAPHICS

Thirty patients underwent treatment for thoracic aneurysms involving branch vessels of the aortic arch and visceral aorta at our institution between November 1, 2005, and December 31, 2006. Eighteen patients underwent HR with debranching of the aortic arch (n=8) or visceral aorta (n=11), immediately followed by TEVAR. One patient had debranching of the aortic arch and the visceral aorta for combined arch and TAAA aneurysms. Twelve patients underwent conventional OR with bypass or reimplantation of branch vessels of the aortic arch (n=5) or visceral aorta (n=10). Three patients required bypass or reimplan-
The involvement of branch vessels of the aortic arch and the visceral aorta for complete TAAA repair. Five patients in the OR cohort were placed on cardiopulmonary bypass (CPB) during repair of the aortic arch. No patients in the HR cohort required CPB. There were no statistically significant differences in the location of pathology or branch vessel involvement between the 2 groups.

Patient demographic characteristics are given in Table 1. Patients were significantly older in the HR cohort (P = .02). Medical comorbidities were present in all 30 patients undergoing HR and conventional OR. Multiple significant comorbidities were present in most patients in the HR and OR groups (89% and 75%, respectively; P = .29). Although there was no statistically significant difference in the number of comorbidities present between the HR and OR groups, there was a trend toward higher preexisting disease in the HR group (4.21 [1.72] vs 3.24 [2.22], P = .22). There was also a higher prevalence of coronary artery disease in the HR cohort that was significant (P = .04).

### Aneurysm Pathology and Repair

There was no difference in aneurysm size between the HR and OR groups (P = .76). Five patients in the HR subset (28%) had previous aortic surgery, which included infrarenal abdominal aortic aneurysm repair (n = 2), aortobifemoral bypass (n = 1), TAAA repair (n = 1), and TAAA repair with aortic arch replacement (n = 1). Three patients in the OR cohort (25%) had a history of aortic repair consisting of infrarenal aortic aneurysm repair (n = 2) and aortic arch replacement for acute dissection (n = 1). Five patients in each group required spinal drainage (HR: 28%; OR: 42%).

In the HR cohort, 8 patients (44%) had aneurysmal involvement of the aortic arch that required arch debranching procedures to obtain adequate proximal landing zones for endograft placement. Carotid-carotid artery bypass was performed in 6 patients (33%) and carotid-subclavian artery bypass was performed in 6 patients (33%). In 1 patient, prohibitive risk imposed by the patient's morbid obesity prevented us from reimplanting the left subclavian artery. Eleven patients (61%) had involvement of the visceral aorta that required visceral debranching procedures to obtain adequate distal landing zones. Retrograde bypass from the distal aorta or iliac artery was used for celiac artery bypass in 9 patients (50%), superior mesenteric artery bypass in 9 patients (50%), and renal artery bypass in 8 patients (44%). One patient received a retrograde bypass of the IMA because this vessel was largely patent on preoperative imaging and it demonstrated poor intraoperative back bleeding. One patient had an aortic arch and a TAAA requiring arch and visceral revascularization to obtain adequate proximal and distal landing zones. This patient received carotid, celiac, and superior mesenteric artery bypasses. The OR cohort required arterial reimplantation (n = 6) or bypass (n = 8) of the innominate artery in 4 (33%) patients, carotid artery in 5 (42%), subclavian artery in 5 (42%), celiac artery in 6 (50%), superior mesenteric artery in 7 (58%), and renal arteries in 8 (67%) (Table 2).

### Patient Outcome Data

There were 2 deaths in the OR group (17%) and 1 in the HR cohort (6%). The mortality difference was not significant (P = .34). However, compared with the OR group, HR patients had significantly less blood loss intraoperatively (1.7 [2.3] vs 4.8 [3.1] L; P = .004), fewer ICU days (5.2 [4.8] vs 16.4 [12.9]; P = .005), and shorter hospital stays (11.6 [6.2] vs 20.8 [10.8] days; P = .01). At discharge, 50% of the HR group and 30% of the OR cohort were discharged home. The remaining patients (HR: 50% vs OR: 70%; P = .38) required transfer to a rehabilitation center.
Patients undergoing HR experienced a lower overall complication rate (Table 3). Although 44% of patients undergoing HR had 1 or more significant postoperative complications, 100% of the OR patients developed at least 1 significant morbidity attributable to surgery ($P = .001$). Three patients in the HR group and 1 in the OR cohort experienced neurologic complications. One HR patient experienced a postoperative transient ischemic attack and 2 others a stroke. Two of these 3 patients had a personal history of stroke. The only reported case of spinal cord ischemia was in the OR group. Pulmonary complications, including pneumonia and failure to wean from mechanical ventilation, were higher in the OR group ($P < .001$). There was no significant difference in the rate of cardiac complications, including myocardial infarction, troponin leak, arrhythmia, and congestive heart failure ($P = .45$). In addition, the incidence of postoperative renal failure was significantly lower in the HR group ($P = .002$). Renal failure was defined as a creatinine rise to greater than 1.8 from a previously normal baseline. Of the 3 patients with postoperative renal failure in the OR group, 3 required conventional hemodialysis and 1 required continuous venovenous hemodialysis. Three type II endoleaks were found on 1-month surveillance computed tomographic scans, but none have required intervention to date.

COST ANALYSIS

Cost data were available for all of the patients (Table 4). The mean total hospital cost for patients undergoing HR was $81,907. The mean direct hospital cost for the HR group was $59,458. These amounts were more than the mean total and direct costs for OR, which were $76,012 and $49,341, respectively, although differences were not significant ($P = .09$ and .35, respectively). Hybrid repairs were consistently reimbursed less, although this was not significant in itself (HR: $54,169$ vs OR: $71,097$, $P = .42$). The mean contribution margin per case was significantly lower in the HR group vs the OR group ($–34\%$ vs $6.2\%$; $P = .03$). Furthermore, when all cases were analyzed in total, the contribution margin was $–23\%$ for HRs and $31\%$ for all ORs.

Several studies have now shown combined aortic branch vessel revascularization followed by TEVAR to be an effective and feasible means of repairing thoracic aneurysms.\textsuperscript{10-13} However, the current reports are small and inadequately powered to reliably detect differences in patient outcomes. The largest series range from 15 to 31 patients and are summarized in Table 5. The small patient volumes are likely a direct result of the low prevalence of thoracoabdominal pathology, thereby prohibiting an individual center from achieving extraordinary case numbers. Nevertheless, all the reports have consistently demonstrated low perioperative morbidity and mortality, including a low incidence of spinal cord ischemia. Although the present study is also limited by a small number of patients, these data further support the safety and efficacy of this treatment modality. With low perioperative mortality, and no incidences of spinal cord ischemia in the HR cohort, these data are consistent with previous reports.

Herein, we compared patients undergoing HR with patients undergoing OR during the same time frame within our institution. Patients chosen for HR were deemed to be high risk for OR. The HR group was older and had a higher incidence of preoperative cardiac disease. Furthermore, although the absolute number of comorbidities appears matched between the HR and OR groups, it was the clinically perceived severity of comorbidities that often validated the decision to pursue HR. These patients were perceived as frail with more severe disease, including chronic obstructive pulmonary disease that required supplemental oxygen, congestive heart failure with lower ejection fractions, and more severe cardiac disease.

The aforementioned differences between the HR and OR groups would presumably predispose HR patients to increased perioperative morbidity and mortality. Instead, perioperative mortality rates were not statistically significantly different between the 2 groups, and mor-

![Table 3. Operative Outcome Measures](chart)

![Table 4. Cost Analysis](chart)

$^a$The overall contribution margin is the percentage of financial loss/gain based on insurance reimbursement and direct hospital costs.

$^b$P < .05 was considered statistically significant.
bidity rates were lower in the HR cohort. In fact, there was only a 5.5% mortality rate in the HR group, whereas the OR group had a mortality rate of 16.6%, consistent with the 10% to 20% mortality previously reported with open TAAA. 16-20 Although 44% of patients undergoing HR had 1 or more significant postoperative complications, 100% of the OR patients developed at least 1 significant morbidity attributable to surgery. The HR cohort also had fewer pulmonary and renal complications and a similar rate of cardiac complications, despite a higher prevalence of preexisting cardiac disease in this group. Furthermore, these patients also experienced fewer days receiving mechanical ventilation, fewer days in the ICU, and shorter overall hospital stays.

The lower rate of pulmonary morbidity and fewer days receiving mechanical ventilation in the HR group can likely be explained by several factors. First, most of these patients had much less extensive incisions than the OR group, the latter of which often required thoracotomy or large thoracoabdominal incisions, with disruption of the diaphragm and the need for tube thoracostomy drainage postoperatively. In addition, patients in the OR group had more blood loss and a higher need for blood transfusion or volume replacement. This may lead to acute lung injury and cardiogenic and noncardiac pulmonary edema manifested by pulmonary failure and the inability to be weaned from mechanical ventilation. 14,15 Furthermore, avoidance of prolonged aortic cross-clamping and CPB likely lowered the incidence of systemic inflammatory response syndrome (SIRS) in the HR group compared with those in the OR cohort, in which prolonged cross-clamp times and CPB were more common. 16-18 Cardiopulmonary bypass was, in fact, necessary in 42% of those undergoing OR and has been directly associated with postoperative SIRS, which may manifest as respiratory failure, cardiac dysfunction, and renal insufficiency. 17,18 Less blood loss, lower cross-clamp times, avoidance of CPB, and a lower incidence of SIRS likely explain the lower rate of renal failure and the relative decrease in expected cardiac morbidity seen in the HR group. 16-20

The decrease in ICU and overall hospital time is likely to be a direct result of the overall lower rate of the aforementioned complications in HR patients. The HR group also demonstrated a trend toward decreased need for rehabilitation after hospital discharge, although this was not statistically significant. The need for rehabilitation in this group was likely due to the advanced age and frailty of those who underwent this repair, which resulted in overall deconditioning.

The improved results and patient outcomes mentioned herein, however, come at a significant cost to the hospital system. The contribution margin for HRs is −34% per case. Otherwise stated, the hospital receives a total payment that is 34% less than the direct hospital costs for the procedure. Furthermore, these figures do not account for indirect costs, and, therefore, the hospital is actually taking a greater financial loss per case than is actually calculated. In contrast to the loss in income seen with HR, we experience a modest positive per-case contribution margin (6.2%) when performing conventional OR for TAAA repair. Thus, there exists a 40% mean income loss per case when HR is performed instead of conventional OR.

A trend toward higher procedure costs and lower insurance reimbursements for HR cases explains the loss of revenue seen with the HR. These factors appear to be attributable to the cost of the endograft. Although endograft costs can be expected to decrease across time as technology expands, device companies should be encouraged to collate their endograft costs, charging on a per-case basis as opposed to charging for individual endograft components. The significant financial loss to the hospital is seen when second and third devices are used during HR. The complex nature of these aneurysms makes them difficult to treat with a single endograft. Furthermore, the trend of increasing Medicare cutbacks demands that physicians become more assertive, insisting that adequate reimbursements are made for procedures that clinically benefit our patients. Physicians should be encouraged to report prohibitive failures of proper reimbursement.

Overall, hybrid arch and TAAA repairs result in improved clinical outcomes compared with conventional OR despite treating an older and sicker patient population. However, the deleterious effects of improper reim-

Table 5. Comparison of Current Hybrid Repair Trials

<table>
<thead>
<tr>
<th></th>
<th>Black et al, 12 2006 (n=26)</th>
<th>Saleh and Inglese, 11 2006 (n=15)</th>
<th>Zhou et al, 13 2006 (n=31)</th>
<th>Present Study (n=18)</th>
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<tr>
<td>Age, mean, y</td>
<td>74</td>
<td>74</td>
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<td>72</td>
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<tr>
<td>Length of stay, mean, d</td>
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<td>NA</td>
<td>NA</td>
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<tr>
<td>Mortality, %</td>
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<td>3</td>
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<tr>
<td>Postoperative complications, %</td>
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<td>44</td>
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<tr>
<td>Spinal cord ischemia</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cardiogenic support</td>
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<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Pulmonary edema</td>
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<td>0</td>
<td>17</td>
</tr>
<tr>
<td>Renal failure requiring support</td>
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<td>0</td>
<td>6.4</td>
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</tbody>
</table>

Abbreviation: NA, not available.
bursure are negatively affecting the hospital budget. As the benefits of endovascular interventions are continually proved in the clinical setting, efforts must now be made to encourage proper reimbursement.

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Author Contributions: Drs Murphy and Arko had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Murphy, DiMaio, and Arko. Acquisition of data: Murphy, Beck, Clagett, DiMaio, Jessen, and Arko. Analysis and interpretation of data: Murphy, Beck, DiMaio, and Arko. Drafting of the manuscript: Murphy, Beck, and Arko. Critical revision of the manuscript for important intellectual content: Murphy, Beck, Clagett, DiMaio, Jessen, and Arko. Study supervision: Arko.

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REFERENCES