

# Hybrid Debranching With Endovascular Repair for Thoracoabdominal Aneurysms: A Comparison With Open Repair

Himanshu J. Patel, MD, Gilbert R. Upchurch, Jr, MD, Jonathan L. Eliason, MD, Enrique Criado, MD, John Rectenwald, MD, David M. Williams, MD, and G. Michael Deeb, MD

Departments of Surgery and Radiology, University of Michigan Cardiovascular Center, Ann Arbor, Michigan

**Background.** Hybrid visceral-renal debranching procedures with endovascular repair have recently been proposed as a less invasive alternative to conventional thoracoabdominal aortic aneurysm (TAAA) surgery. This study provides a concurrent assessment of hybrid and open TAAA repair.

**Methods.** One hundred two consecutive patients (mean age, 63.0 years) underwent open (73) or hybrid (29) Crawford type 1 (19), 2 (50), or 3 (33) TAAA repair from 2000 to 2009. Hybrid debranching procedures were selected for patients considered poor operative risk for standard TAAA repair (27) or for patient preference (2). The TAAAs were fusiform atherosclerotic (68), dissection (30), or pseudoaneurysm (4). Fifty-seven patients (55.9%) had previously undergone aortic repair. Outcomes were analyzed with 100% follow-up (mean, 30.5 months).

**Results.** Operative procedures were urgent or emergent in 16 (15.6%). Early mortality occurred in 13 (12.7%), and was independently predicted by use of hypothermic

circulatory arrest ( $p = 0.005$ ). Early morbidity included permanent paraplegia (12), stroke (1), need for dialysis (22), or tracheostomy (7). Independent correlates of a composite outcome comprised of early mortality and these early morbidities included an urgent-emergent presentation ( $p = 0.002$ ) or open TAAA repair ( $p = 0.021$ ). Kaplan-Meier survival was similar between open and hybrid TAAA groups ( $p = 0.88$ ). Late mortality was independently predicted by the presence of diabetes ( $p = 0.052$ ) or the need for dialysis at the time of TAAA repair ( $p < 0.001$ ).

**Conclusions.** Hybrid debranching procedures may reduce early morbidity and yield similar late survival, even in a group considered high risk for open surgery. These data support the increasing utilization of a hybrid debranching and endovascular approach for patients requiring thoracoabdominal aneurysmectomy.

(Ann Thorac Surg 2010;89:1475–81)

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In an effort to apply endovascular techniques to aortic segments with branch vessels, extra-anatomic bypass with endovascular exclusion, otherwise known as hybrid debranching and thoracic endovascular aneurysm repair (H-TEVAR) has emerged as a therapeutic option for thoracoabdominal aneurysms [1–6]. This approach was first applied to a patient with Marfan syndrome and a chronic dissection with a Crawford type 2 TAAA at the University of Michigan in December of 1999 because of her insistence in avoiding a redo thoracotomy. She had previously sustained a type A dissection, and had undergone both repair of her ascending aorta and then a subsequent short segment replacement of her proximal descending aorta. She was repaired in a staged fashion with bilateral ileo-renal bypasses, coil embolization of her celiac artery, and endovascular exclusion of her entire thoracoabdominal aorta and proximal iliac arteries, with the exception of a short seg-

ment at the origin of the superior mesenteric artery. Her repair remained successful until she expired in 2008 from the rupture of an aneurysmal aortic root into her left atrium. The late success identified in this patient with this technique propelled us to proceed with a consistent application of this approach to patients considered at high risk for conventional open TAAA repair. The purpose of this report is to contrast outcomes of open and hybrid approaches of TAAA repair in the decade since this index case.

## Material and Methods

This study was approved by the Institutional Review Board (IRB) of the University of Michigan Hospitals (IRB #2003-0128, informed consent requirements waived). Data from all patients who underwent operative therapy for extent 1, 2, and 3 thoracoabdominal aortic pathology at the University of Michigan Hospitals from 2000 to 2009

Accepted for publication Jan 29, 2010.

Presented at the Fifty-sixth Annual Meeting of the Southern Thoracic Surgical Association, Marco Island, FL, Nov 4–7, 2009.

Address correspondence to Dr Patel, Section of Cardiac Surgery, CVC Room 5144, 1500 E Medical Center Dr SPC 5864, Ann Arbor, MI 48109-5864; e-mail: [hjpatel@med.umich.edu](mailto:hjpatel@med.umich.edu).

Dr Patel discloses a financial relationship with W.L. Gore and Medtronic; Dr Williams with W.L. Gore.

were prospectively collected and retrospectively analyzed. If the patient was prospectively deemed a high-risk candidate for traditional open repair ( $n = 27$ ) or preferred a hybrid approach ( $n = 2$ ), a collaborative multidisciplinary team consisting of thoracic and (or) vascular surgeons and interventional radiologists assessed suitability for H-TEVAR. Patients were identified as high risk for open surgery based on age over 80 years (7), poor functional status (9), presence of severe chronic obstructive pulmonary disease (10), untreated significant coronary artery disease (2), significant renal impairment (3), prior stroke with poor mobility (2), need for operation in the second or more redo setting (2), history of cirrhosis (1), and morbid obesity (1). Ten patients had more than one reason for high-risk status.

The definition of Crawford extents of resection included the following: (1) Extent 1 from the left subclavian artery, including varying segments of visceral abdominal aorta, and above the lower renal artery; (2) extent 2 from the left subclavian artery into most of the infrarenal aorta; (3) extent 3 from the distal half of the descending aorta into the infrarenal aorta. Aneurysms confined to the descending thoracic aorta alone or those including only the entire abdominal aorta (ie, extent 4) were excluded from this analysis to avoid potential confounding factors. This classification scheme was applied consistently to all patients included in this study regardless of open or endovascular approach, and verified retrospectively based upon imaging and operative data.

All open TAAA repairs were performed with extracorporeal perfusion support (mean perfusion times,  $227.4 \pm 80$  minutes). Left heart bypass was utilized in 56 patients. The remaining 17 patients had adjunctive use of deep hypothermic circulatory arrest (HCA), as previously described [7]. Indications for HCA included the presence of aortic pathology precluding use of aortic cross-clamp, or the need to extend the resection into the arch aorta (but distal to the left carotid artery). As the study period evolved, the frequency of HCA use, even in the setting of distal arch involvement, decreased in recognition of a perceived increase in morbidity.

In the H-TEVAR group, 100 extra-anatomic bypasses were created and included bypasses to the celiac artery (28), superior mesenteric artery (27), and renal arteries (45). Extra-anatomic bypasses were based off iliac arteries in 24 patients, off native aorta in 1, or off a concomitantly replaced infrarenal aorta in 4. At the time of abdominal debranching, 8 had also undergone ileofemoral bypass to function as a conduit for endograft placement and facilitate later endovascular repair. Subclavian arterial revascularization was performed prior to endovascular repair in the 2 patients whose aortic anatomy required stent graft coverage of this branch vessel.

For those patients undergoing H-TEVAR, endovascular procedures were performed either concomitantly ( $n = 3$ ) or, preferably, in a delayed fashion ( $n = 26$ , median time interval 23 days) after the debranching procedure. The endovascular portion of the repair was delayed to allow for stabilization of hemodynamics and fluid status, to minimize the potential risk for paraplegia known to

occur with hypotensive episodes. Endograft sizing and technique of placement was performed as previously described [8]. Technical success in H-TEVAR was achieved in all patients (100%). Devices utilized included TAG ( $n = 21$ ; W.L. Gore, Flagstaff, AZ), TX2 ( $n = 4$ ; Cook, Bloomington, IN), Talent ( $n = 1$ ; Medtronic, Minneapolis, MN), and custom fabricated ( $n = 1$ ). In 3 patients, multiple types of endografts were utilized.

Postoperative management for prevention of spinal cord ischemia for both open and endovascular repairs was conducted according to standardized protocols as previously described [7–9]. For the H-TEVAR group, all patients who were hemodynamically stable received spinal drainage only for the endovascular portion of the H-TEVAR procedure.

The primary outcome of this study was all-cause mortality. Data were collected from clinic visit notes, hospital charts, and imaging studies, and mortality was verified by interrogation of the National Death Index. Follow-up was 100% complete as of November 2009 (mean,  $30.5 \pm 26.0$  months).

### Statistical Analysis

Data were analyzed using SPSS (SPSS Inc, Chicago, IL). All data are expressed as mean  $\pm$  standard deviation where applicable. Dichotomous variables were evaluated using  $\chi^2$  analysis; continuous variables using one way analysis of variance. Multivariate models (binary logistic regression) were constructed using a forward conditional process to identify factors that were independently associated with each of the outcomes of interest. The factors utilized in multivariate analysis included using those with a  $p$  value less than or equal to 0.1 significance on univariate analysis. Survival analysis was analyzed by Kaplan-Meier methods, with log-rank testing where applicable. All results with a  $p$  value less than 0.05 were considered statistically significant.

### Results

The mean age of the entire cohort was  $63.0 \pm 12.1$  years (50% male). Demographics and comorbidities for the two groups are listed in Table 1. Essentially, the H-TEVAR group was older, had more extensive comorbidities (including prior abdominal aneurysm repair), and more frequently was treated for a fusiform aneurysm or for a Crawford extent 3 TAAA. The status of operation was elective with similar frequency ( $p = 0.38$ ) in both groups.

### Early Results

Early mortality in the entire cohort was seen in 13 patients. Three (all in the open repair group) occurred either intraoperatively or within the first 12 hours from bleeding complications. The remaining deaths were secondary to intracranial hemorrhage after discharge (1) and multisystem organ failure after massive transfusion (1), visceral ischemia (5), respiratory failure, and sepsis (3). There was a nearly fivefold decrease in early mortality (defined as either in-hospital or within 30 days) in the H-TEVAR group ( $n = 1$ , 3.4% vs open TAAA  $n = 12$ , 16.4%,  $p = 0.1$ ). The death in the H-TEVAR group occurred after the debranching procedure and was sec-

**Table 1. Demographics, Comorbidities, and Procedural Details With Univariate Analysis of the Study Cohort**

Variables	Open Repair (n = 73)	H-TEVAR (n = 29)	p Value
<b>Demographics:</b>			
Age (years)	59.5 ± 11.1	71.7 ± 10.4	<0.001
Male sex	44 (60.3%)	7 (24.1%)	0.002
Maximum aortic dimension (cm)	6.6 ± 1.1	6.3 ± 1.3	0.18
<b>Comorbidities:</b>			
CAD	25 (34.2%)	10 (34.5%)	1.0
History of CHF	4 (5.5%)	1 (3.4%)	1.0
COPD	19 (26.0%)	15 (51.7%)	0.019
Diabetes	4 (5.5%)	6 (20.7%)	0.029
Hypertension	51 (69.9%)	24 (82.8%)	0.22
Preoperative creatinine (mg/dL)	1.1 ± 0.2	1.2 ± 0.4	0.58
Prior AAA Repair	16 (21.9%)	14 (48.3%)	0.015
Prior DTAR	10 (13.7%)	3 (10.3%)	0.75
PVOD	18 (24.7%)	6 (20.7%)	0.8
Prior CVA	5 (6.8%)	4 (13.8%)	0.27
History of tobacco abuse	53 (72.6%)	19 (65.5%)	0.48
<b>Underlying aortic pathology:</b>			
Fusiform aneurysm	42 (57.5%)	26 (89.7%)	0.002
Aortic dissection	28 (38.3%)	2 (6.9%)	0.001
Pseudoaneurysm	3 (4.1%)	1 (3.4%)	1.0
<b>Crawford extent of TAAA:</b>			
Type 1	18 (24.7%)	1 (3.4%)	0.012
Type 2	38 (52.1%)	12 (41.3%)	0.38
Type 3	17 (23.2%)	16 (55.2%)	0.004
<b>Procedural details:</b>			
Elective status	53 (72.6%)	23 (79.3%)	0.38
Aortic rupture	6 (8.2%)	4 (13.8%)	0.46

AAA = abdominal aortic aneurysm; CAD = coronary artery disease; CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; CVA = cerebrovascular accident; DTAR = open descending thoracic aortic repair; H-TEVAR = hybrid debranching and thoracic endovascular repair; PVOD = peripheral vascular occlusive disease; TAAA = thoracoabdominal aortic aneurysm.

ondary to liver failure with occlusion of a native hepatic artery distal to the celiac artery bypass graft. By both univariate and multivariate analysis, the need for HCA was identified as a predictor of early mortality ( $p = 0.005$ , odds ratio [OR] 6.1).

Permanent spinal cord ischemia in the entire cohort was seen in 12 patients (11.7%). The urgency of operation ( $p = 0.092$ ) was the only variable that approached significance on univariate analysis. Temporary paraplegia was identified in 4 patients, and presented in a delayed fashion in all. Two had undergone H-TEVAR and presented with delayed paraplegia after the endovascular portion of the repair. One responded to the maneuvers of increased spinal fluid drainage and systemic blood pressure. The other patient had reinsertion of the lumbar drain with resulting improvement. Unfortunately, she sustained an epidural hematoma after its removal, and despite intervention she remained parietic. In the entire

series, stroke was only seen in one patient (after open TAAA repair) who had Marfan syndrome, prior mechanical Bentall procedure, and sustained intracranial hemorrhage with a therapeutic international normalized ratio level two days after discharge.

The need for dialysis in the entire cohort was identified in 22 patients. Of the 13 who survived the operative procedure, only one continues to require dialysis. By multivariate analysis, the urgency of operation ( $p = 0.039$ , OR 3.5) and the need for adjunctive HCA use ( $p = 0.012$ , OR 4.3) independently predicted the need for dialysis.

In order to identify predictive variables for morbidity and early mortality, a composite outcome consisting of early mortality, permanent spinal cord ischemia, stroke, or the need for dialysis or tracheostomy was constructed. Binary logistic regression revealed that hybrid debranching TAAA repair was protective ( $p = 0.021$ , OR 0.25), and an urgent or emergent status portended a poor outcome ( $p = 0.004$ , OR 6.1). Finally, an analysis including rates of morbidity stratified by type of repair is shown in Table 2.

### Late Results

The overall crude mortality rate for the entire cohort at last follow-up was 26.5%, and was similar between groups ( $p = 0.81$ ). Actuarial survival at 5 and 8 years was  $75.8 \pm 4.6\%$  and  $43.3 \pm 15.3\%$ , respectively. A Kaplan-Meier analysis contrasting survival between groups is shown in Figure 1. Despite significant differences in both age and comorbidities, the mean survival was similar for both groups ( $p = 0.88$ ). Multivariate analysis revealed that the presence of diabetes ( $p = 0.052$ , OR 4.5) and the need for dialysis ( $p < 0.001$ , OR 8.6) both independently predicted late mortality. Kaplan-Meier curves were constructed to analyze the time dependency of both these variables on late survival, and are shown in Figure 2.

For the H-TEVAR group overall graft patency was 95% and included all celiac and superior mesenteric arterial bypasses at the time of last follow-up. However, of the 45 renal artery bypasses, 5 were occluded (11.1%) in 4 patients, all in the perioperative period. No significant clinical sequelae resulted from renal artery bypass thrombosis in 2 of these 4 patients. The third patient, who

**Table 2. Early Outcomes After TAAA Repair and Univariate Analysis**

Variables	Open Repair (n = 73)	H-TEVAR (n = 29)	p Value
<b>Early outcomes:</b>			
Median postoperative length of stay (days)	14	19	0.21
Early mortality	12 (16.4%)	1 (3.4%)	0.1
Permanent paraplegia	11 (15.1%)	1 (3.4%)	0.17
Stroke	1 (1.4%)	0 (0%)	1.0
Need for dialysis	17 (23.3%)	5 (17.2%)	0.6
Need for tracheostomy	6 (8.2%)	1 (3.4%)	0.67
Poor composite outcome	28 (38.3%)	5 (17.2%)	0.04

H-TEVAR = hybrid debranching and thoracic endovascular repair; TAAA = thoracoabdominal aortic aneurysm.

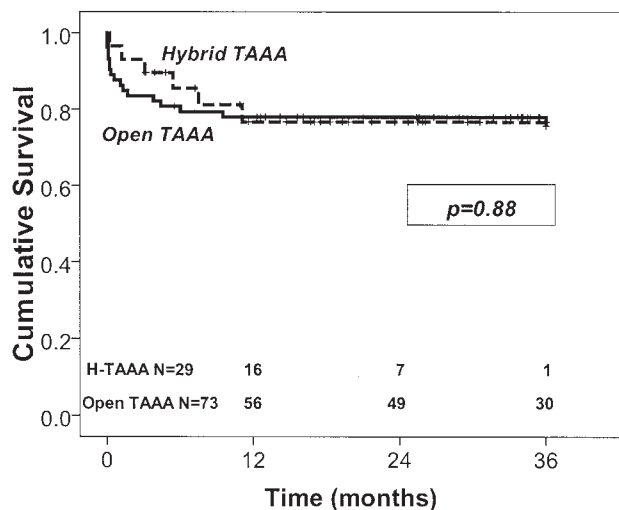


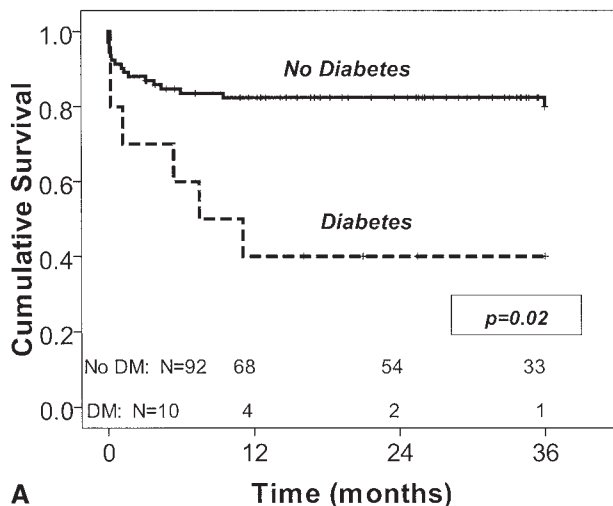
Fig 1. Kaplan-Meier survival analysis comparing conventional open thoracoabdominal aneurysm repair (TAAA) to hybrid debranching repair. This actuarial analysis demonstrates that after either open or hybrid debranching thoracoabdominal aortic repair, there is no significant difference in Kaplan-Meier survival (mean survival open repair, 75 months versus hybrid debranching and thoracic endovascular repair, 81.1 months;  $p = 0.88$ ).

thrombosed both renal grafts, was the only mortality after H-TEVAR (occurring after the debranching portion), and had exceedingly poor quality vessels for bypass. This same patient had occlusion of the native hepatic artery distal to his celiac arterial bypass and died from liver failure after the debranching procedure. In retrospect, he was not considered an appropriate candidate for intervention and should not have been offered operative treatment. The final patient required temporary dialysis; his renal function returned within 2 weeks after H-TEVAR in the setting of a chronic dissection with rupture and aortobronchial fistula.

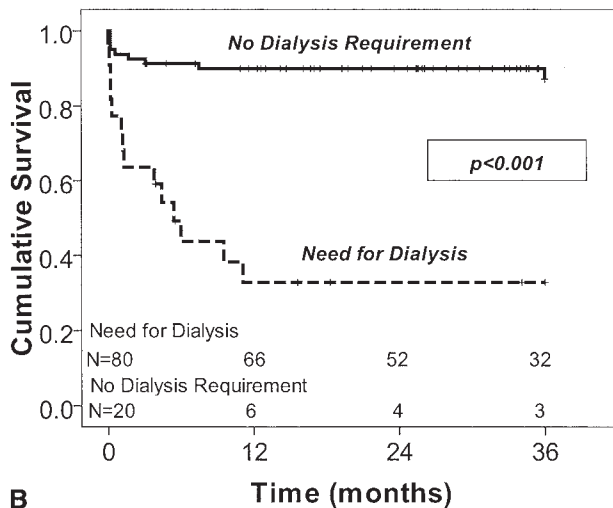
Finally, in the H-TEVAR group 10 patients (34.5%) had endoleaks after surgery. These included 9 patients with type 2 endoleaks, and 1 with a type 2 endoleak. The only patient with a type 3 endoleak expired during of an unclear (nonaortic related) etiology in the fourth postoperative month prior to reintervention. Of the 9 patients with type 2 endoleaks, 7 patients were observed for persistent endoleaks from intercostal or bronchial vessels with stable or decreasing sac sizes. One patient with a type 2 endoleak from the inferior mesenteric artery after an extent 3 TAAA repair required reintervention 2 months postoperatively for an increasing sac size. Another had an endoleak from a celiac artery that was incompletely ligated at the time of debranching and required coil embolization of this target vessel. Interestingly, the patient who underwent the index debranching procedure in 2000 had satisfactory sac thrombosis until 2005, when she presented with a new type 2 endoleak. Despite a persistent endoleak, her sac size remained stable until she expired from a ruptured sinus of Valsalva aneurysm in 2008. An analysis of freedom from treatment failure revealed similar results between groups at 4 years (Fig 3).

Comment

Although endovascular solutions have been rapidly adopted in the treatment of infrarenal and isolated descending thoracic aortic aneurysms, application of this technology has been considerably slower in the patient population with thoracoabdominal aortic pathology due to the presence of visceral and renal branches in the treatment zones [1-6, 8-11]. Despite the selective utilization of a total endovascular solution to thoracoabdominal aneurysms, the broad application of this technique has



A



B

Fig 2. (A) Impact of diabetes on late survival. Diabetes was identified as an important independent predictor of late mortality ( $p = 0.052$ , odds ratio 4.5). This actuarial analysis demonstrates the significant time-dependent effects of diabetes on late survival, with 3-year survival in diabetic patients at 40% versus 80% for nondiabetics. (B) Impact of postoperative need for dialysis on late survival. The postoperative need for dialysis was an independent risk factor for late mortality on multivariate analysis ( $p < 0.001$ , odds ratio 8.6). This Kaplan-Meier analysis identifies decreased late survival in patients who underwent thoracoabdominal aortic aneurysm repair and had a postoperative dialysis ( $p < 0.001$ ). The 3-year survival is 87.1% for those without a postoperative need for dialysis versus 32.8% for those requiring postoperative dialysis ( $p < 0.001$ ).

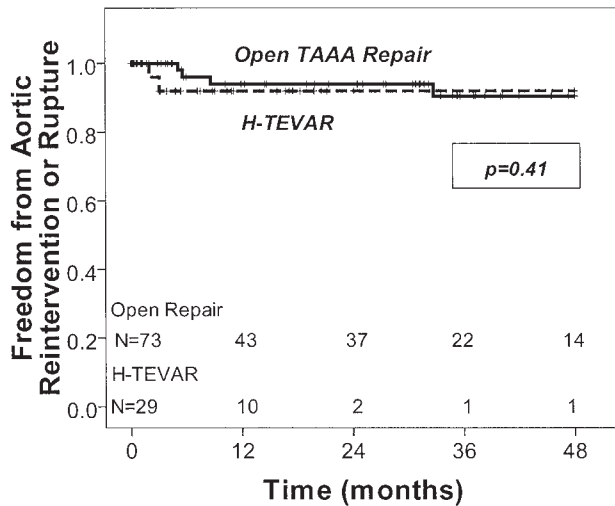


Fig 3. Freedom from need for aortic reintervention or aortic rupture. By Kaplan-Meier analysis, the mean freedom from treatment failure (defined as need for reintervention or rupture) for the entire cohort was  $91.6 \pm 5.9$  months (data not shown). When the analysis was stratified by type of repair there was no difference between groups. The 4-year freedom from treatment failure was  $90.5 \pm 4.7\%$  for the open thoracoabdominal aortic aneurysm repair group versus  $92.0 \pm 5.4\%$  for the hybrid debranching group ( $p = 0.41$ ).

been limited by logistic and regulatory issues [11]. In addition, the acquisition of custom-designed branched endografts often requires 6 to 12 weeks, making their use in urgent or emergent settings impractical. The alternatives remain either medical therapy with its known dismal prognosis, or open thoracoabdominal aneurysmectomy [12]. Previous studies have suggested that at select centers of excellence, the results with open repair have been acceptable and durable [13–16]. Nationwide samples, however, suggest that mortality rates after repair of intact TAAAs exceed 20% [17]. In recent years, however, hybrid debranching with endovascular aortic repair has rapidly been adopted as a less invasive approach, particularly in those high-risk patients who may not tolerate a conventional thoracoabdominal incision, aortic cross-clamping, and (or) extracorporeal perfusion [1–6].

While single-institution series with this approach have been reported, there is only one comparative analysis of intermediate term outcomes after H-TEVAR and open TAAA repair in the literature [1–6]. That study suggested that H-TEVAR is associated with a higher risk for early morbidity when compared with open TAAA repair, and was obtained at the cost of a higher risk for reoperation after H-TEVAR [3]. When their analysis was confined to the lower risk patient population a similar result was obtained. In a comparison of open repair to a totally endovascular approach, Greenberg and colleagues [11] suggested that no benefit in early mortality or paraplegia existed after endovascular repair. Their study was significantly confounded by the inclusion of isolated descending aortic aneurysms or the less extensive type 4 TAAA, comprising 41.3% and 18.4% of the cohort, respectively.

Further examination of their data revealed that for extent 1, 2, and 3 TAAA, the mortality and paraplegia rates were 7.5% and 10%, respectively, for endovascular repair in contrast to 11% and 15% for open repair ( $p =$  not significant). We undertook this analysis to elucidate the role of H-TEVAR, particularly in the high-risk patient.

Our study suggested that the use of H-TEVAR may reduce the early morbidity and mortality seen with conventional open TAAA repair. The results with the debranching procedure presented here are different when compared with other published series, but compare favorably with both our results and others describing open repair [1–6, 11, 13–17]. Although our overall rates of mortality and paraplegia are higher than some reports, they are comparable with published results from other high volume institutions and national statistics. One potential explanation for the mortality rate seen in this series is the prevalent use of hypothermic circulatory arrest (non-HCA mortality 8.2% vs HCA 35.3%, univariate  $p = 0.008$ ), when compared with other series. The HCA was indeed found to be an independent risk factor for early death in this study, and is consistent with that described by others [18, 19]. We now avoid the use of HCA when extending the aortic resection below the diaphragm. The rates of paraplegia after H-TEVAR in our study are also lower than published reports [1–6]. This may partly be related to our standard policy of staging the debranching portion several weeks prior to the endovascular portion.

Limitations of this study include its sample size and retrospective nonrandomized design over a long time interval, including a “learning curve” for endovascular repair. As a result, there were undoubtedly some patients (not included in this analysis) who were not offered H-TEVAR either because they were not considered suitable for the debranching portion of the procedure or because of our reluctance in extending this option early on in the study period when limited data existed regarding its efficacy. Another limitation of this study relates to the baseline differences between groups, including both demographic differences as well as differences in underlying pathology and extent of TAAA. The hybrid repair group was older and had a higher frequency of extent 3 (versus extent 1) TAAA, fusiform pathology (versus dissection), chronic obstructive pulmonary disease, and diabetes. Despite these differences, multivariate analysis identified open repair as a significant independent predictor of early adverse events, and actuarial analysis did not show any late survival advantage for open repair.

We continue to believe that open TAAA repair represents the gold standard therapy for suitable operative candidates. Although our study suggests that late survival as well as freedom from treatment failure is similar between groups, the long-term patency of debranching bypass grafts with orientation in a retrograde manner remains unknown. Midterm visceral and renal bypass patency in the setting of TAAA has varied between 86% and 100% [5]. Indeed, this factor as well as the potential for graft-enteric erosion or endoleak may limit the durability and late efficacy of this procedure.

In summary, this comparative analysis suggests that hybrid debranching and endovascular repair of extensive thoracoabdominal aneurysms represents a suitable therapeutic option to reduce the morbidity of TAAA repair, particularly in those typically considered high risk for standard open repair. These results support the growing use of hybrid debranching procedures in the treatment of TAAA. Prior to broad application in all, longer term studies are needed to further characterize late efficacy of this procedure, understanding the potential limits of visceral and renal bypass graft patency.

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## DISCUSSION

**DR MARC R. MOON** (St. Louis, MO): Dr Patel, in our experience, anybody who can tolerate one of these procedures, if it is not in a redo setting, can probably tolerate a thoracoabdominal aneurysm. It is a fairly big operation. The one difference, obviously, is it does not require cardiopulmonary bypass under most circumstances. We found it to be very beneficial, though, in the reoperative setting; for example, a patient who gets a visceral aneurysm patch where you can put a stent graft in as opposed to doing a redo thoracoabdominal aneurysm. Over the last 10 years we have been very pleased that this technology is available, and that we can now perform it without having to jump through a bunch of hoops with the stent-graft companies like we had to 10 years ago to get grafts for these indications.

You mentioned hypothermic circulatory arrest being associated with a much higher mortality rate. Have you given up on hypothermic circulatory arrest now then?

**DR PATEL:** A large proportion of the mortality seen with open repair was early on in the series when we frequently used hypothermic circulatory arrest, particularly for the more extensive aneurysms. However, in recognizing our results over the last several years, we have attempted to avoid it. In fact, if a

patient presents with an asymptomatic aneurysm but has arch pathology precluding the use of cross clamp, we will try to use a two-stage approach with initial arch repair and creation of an elephant trunk followed subsequently by thoracoabdominal aneurysmectomy with the use of left heart bypass.

**DR MOON:** And when you do the hybrid procedure, do you try to do that in one-stage or two stages? We oftentimes like to do the revascularization and then bring them back a couple of days later for the stent graft. Obviously, if it is a rupture situation that is not practical but on an elective situation it seems to work well.

**DR PATEL:** Our belief is that a significant reason for paraplegia seen after thoracoabdominal aortic aneurysm repair may relate to the fluctuations in the hemodynamics postoperatively. One of the reasons we believe that the risk for paraplegia after endovascular repair may be lower is because of the stable hemodynamics following an endovascular procedure. In extending this rationale to the hybrid procedure, if a patient presents with nonemergent indication for intervention, we choose to separate the time between debranching and subsequent endovascular

repair by as much as a few weeks, to allow for recovery after the debranching procedure.

**DR MOON:** And you also mentioned that you have performed this operation for Crawford extent I aneurysms. Why would you need to do this procedure with a Crawford I aneurysm?

**DR PATEL:** In this study, we consistently applied a classification scheme whereby a Crawford extent 1 thoracoabdominal aneurysm required pathology not just purely of the entire descending thoracic aorta but that the repair had to occur below the diaphragm into the visceral segment. In that setting we have not been very aggressive in coiling celiac arteries alone to extend the distal landing zone into the visceral segment beyond the descending thoracic aorta. An extent 2 aneurysm included repairs down into the infrarenal segment, and then an extent 3 was a more classic distal half of the thorax into the infrarenal segment. So we specifically exclude those patients in whom you could have just done an isolated descending aortic repair, which can be done without associated debranching procedures.

**DR HAZIM J. SAFI (Houston, TX):** There is a notion that TEVAR [thoracic endovascular aortic repair] is simpler, and that the incidence of neurological deficits is lower than open repair. In centers with adequately trained personnel, the incidence of neurological deficit in cases of the entire descending thoracic aorta is less than 1%, and in the thoracoabdominal extent 1, it is less than 1%. Now, regarding the hybrid procedure about which I have done much reading, in Greek “hybrid” means monster, so it is a monster operation. You get the worst of both worlds. You try to do bypasses in the iliac arteries to the renals with the aneurysm right in your face; it is horrible. My main statement is that I don’t think the TEVAR is less risky than the open.

**DR MOON:** Dr Safi, what about in the redo setting, in patients presenting with a visceral patch aneurysm, what is your impression under that circumstance? Visceral patch aneurysms can be very tricky to treat with an open procedure.

**DR SAFI:** My associate, Dr Tony Estrera, and I approach patch aneurysm in patients with Marfan, connective tissue disorder, or the young folks with a dissection using what Tony calls the STAG procedure. This is a side arm graft, which is commercially available. We individually bypass to the celiac with both renal arteries. When we looked at patients with atheromatous and medial degenerative conditions, the incidence of patch aneurysm in our hands is less than 2% over a 10 to 15 year period.

**DR THORALF SUNDT (Rochester, MN):** Can I make a quick comment and then ask a question. First, I just have to represent the circulatory arrest side. I can tell you that we have finally gotten our vascular surgeons to buy into it. It is our preferred approach and we have great results with circulatory arrest. So not everyone has abandoned that field.

And a question about paraplegia. This is a distressingly high rate of paraplegia in your controls. The principal thrust of your paper is the results of the hybrid endovascular, but, I am concerned about the controls. Maybe I missed it, but do you use permissive hypertension postoperatively? Your incidence of paraplegia is threefold higher than the next speaker that is going to get up and present a paper. So I just wonder if you could comment on that.

**DR PATEL:** We could not find any correlates in our analysis with the occurrence of paraplegia. We do use all the standard

maneuvers, including distal perfusion techniques, lumbar drainage, intercostal artery reattachment where appropriate, and then also permissive hypertension postoperatively, and the results are what they are. The incidence of paraplegia for thoracoabdominal aneurysm repair seen within this series is within the range reported in the literature. There are a few sites that report lower rates. We must be certain, however, that when we look at the studies reported in the literature, we are certain that the outcomes described discuss operative procedures involving the thoracoabdominal aorta alone, and not those studies that frequently lump pure descending aortic repair with TAAA [thoracoabdominal aortic aneurysm] repair. We agree that repair of just the descending aorta alone has a significantly lower paraplegia rate than those reported in our current study.

**DR MOON:** I assume these were not all immediate paralysis; so, what percentage of these were delayed paralysis? Dr Sundt and I wrote a paper addressing that subject a few years back; a complication that is particularly depressing.

**DR PATEL:** Four patients actually had the occurrence of delayed paraplegia, which responded with either reinstatement of lumbar drainage or more aggressive measures to increase the blood pressure. But the majority were early paraplegia presenting at the time when the patients awoke.

**DR JOHN S. IKONOMIDIS (Charleston, SC):** What are your preferences for devices in these cases?

**DR PATEL:** We have actually used a variety of devices. Understanding the duration of the study period, the majority of the devices that were utilized in the study have been the Gore devices [W.L. Gore, Flagstaff, AZ]. But we really tailor it according to the pathology that we see. For example, in certain situations we may be more inclined to use the Cook device [TX2; Cook, Bloomington, IN] because of its active fixation and perhaps a bit more of a controlled release. We have been a little reluctant to utilize the Talent graft [Medtronic, Minneapolis, MN] because of the short segments that it is really only able to treat, being only available in the 11 cm size. We have utilized it in the setting where the neck may be significantly dilated or smaller, as it does have the largest or the smallest diameter grafts that are available on the market. So, all the thoracic devices, as well as some abdominal endografts, were used in the series presented here.

**DR OURANIA PREVENTZA (Houston, TX):** Very interesting and good paper. Your patency rate was high, approximately 80%, and you based the inflow on the iliac arteries. I was wondering if you have any specific recommendations postoperative for these patients. Do you give any anticoagulation regimen; Plavix [Bristol-Myers Squibb/Sanofi Pharmaceuticals Partnership, NY, NY] versus Coumadin [DuPont, Wilmington, DE] or both?

**DR PATEL:** We maintain them on antiplatelet agents, usually just an aspirin, unless the target bypassed vessel was of poor quality in which case they are occasionally prescribed clopidogrel as well at the discretion of the surgeon. We strongly believe that the limitations of this procedure include the late risk for endoleak, as well as the unknown long-term durability of these retrograde bypasses, and the potential for graft enteric erosion. This is why we have typically reserved this for the high-risk patient throughout the study period.