Evolution in the management of the total thoracic aorta

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Objectives: Extensive aneurysms of the ascending, arch, and descending thoracic aorta traditionally have been managed with a 2-stage “elephant trunk” procedure. Single-stage transmediastinal repairs have also been used, because in some patients the entire repair is not completed owing to either complications during first-stage repair or magnitude of the second-stage operation. Since 2006, second-stage elephant trunks have been preferentially completed with endovascular stent grafts in anatomically appropriate patients. This study compares outcomes of 2-stage elephant trunk, single-stage, and hybrid endovascular repairs of extensive thoracic aortic aneurysms.

Methods: This is a single-institution retrospective cohort study of 103 patients (1992–2007) with extensive thoracic aortic aneurysms undergoing 2-stage elephant trunk repair with either surgical (OPEN) or endovascular (TEVAR) completion versus single-stage transmediastinal replacement (SS). Outcomes were analyzed with Statistica 8.0 software (Tulsa, Okla).

Results: Of 103 patients, 74 had elephant trunk procedures, 24 TEVAR-eligible and 50 OPEN, and 29 had SS. Completion rates were higher with TEVAR than OPEN (78% vs 47%; $P = .01$). Seven of 18 TEVARs were performed during the index hospitalization. TEVAR patients had shorter second-stage hospital stay (5.5 vs 16.5 days [$P < .01$]), required fewer transfusions ($P < .01$), and had less acute kidney injury ($P = .04$). There were no differences in mortality, paraplegia, or stroke. Six-month Kaplan–Meier survival estimates for OPEN, TEVAR, and SS were 64%, 78%, and 64% ($P = .08$).

Conclusion: More patients complete the second stage when TEVAR is used after elephant trunk repair, with fewer hospital days and transfusions. TEVAR is feasible and safe in the hybrid management of extensive thoracic aortic aneurysms.

Extensive thoracic aortic aneurysms, involving the ascending, arch, and descending thoracic aorta, are surgically challenging owing to both the extent of aortic involvement and the morbidity and mortality associated with repair. In 1983, Borst, Walterbusch, and Schaps¹ introduced the “elephant trunk” technique, in which a segment of graft is left suspended in the descending aorta to facilitate the second-stage graft-to-graft anastomosis, typically performed 6 to 8 weeks after the first stage (Figure 1). While modifications have been applied to this technique, it has become the mainstay in the staged treatment of the total thoracic aorta. However, in up to 50% of patients, the second stage is never completed owing to both the morbidity and mortality of the first operation and to death from aneurysm rupture before the second stage.^{2–4} Svensson and associates³ reported that only 45% of patients underwent second-stage completion

and that the 5-year survival after limited first-stage repair was only 34%. Safi and associates⁵ and Elefteriades⁶ reported that 30% of patients who did not return for their second-stage repair had died and that 30% of these deaths were due to rupture of the untreated descending aneurysms. Accordingly, we⁷ previously have reported our experience with a single-stage transmediastinal replacement of the ascending, arch, and descending thoracic aorta (SS). In this operation, the ascending aorta and proximal arch aorta are repaired as in the standard first-stage elephant trunk operation, but a long segment of distal graft is anastomosed to the descending aorta through a transmediastinal exposure (Figure 1). Although completion rates were 100% with this technique, morbidity and mortality were significant with a 17% incidence of paraplegia and a 14% mortality rate secondary to extended periods of circulatory arrest and cardiopulmonary bypass (CPB).

In January 2005, the Food and Drug Administration approved the first commercially available thoracic endograft (W. L. Gore TAG, Flagstaff, Ariz). By 2006, patients with extensive thoracic aortic aneurysms were preferentially treated with a first-stage elephant trunk operation followed by second-stage thoracic endovascular aortic repair (TEVAR) in anatomically suitable candidates. We hypothesized that this technique would improve completion rates and early outcomes. The purpose of this report is to present our concurrent series of evolving techniques for the treatment of extensive thoracic aortic aneurysms and compare outcomes among these three techniques.

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Abbreviations and Acronyms

CI	= confidence interval
CPB	= cardiopulmonary bypass
MPSK	= combined incidence of mortality, paraplegia, stroke, or kidney injury
OPEN	= open second-stage completion of elephant trunk
OR	= odds ratio
RIFLE	= risk, injury, failure, loss, end-stage classification for kidney injury
SS	= single-stage transmediastinal replacement of the total thoracic aorta
TEVAR	= thoracic endovascular aneurysm repair for second-stage completion

PATIENTS AND METHODS**Study Variables and Definitions**

“Acute” presentations involved emergency or urgent operations because of rupture, acute dissection, or symptoms. Extent of repair for the second stage was based on Crawford’s classification. “Completion failure” was defined as death before the second stage, loss to follow-up, or failure to treat the descending thoracic aortic aneurysm, except if the aneurysm was less than 6 cm. Paraplegia included both transient and permanent deficits. Acute kidney injury was defined by RIFLE (*Risk, Injury, Failure, Loss, End-stage renal disease*) injury score “I”: serum creatinine twice the baseline within 7 days postoperatively.⁸ Operative mortality included 30-day and inpatient mortality. Gastrointestinal complications included visceral ischemia, perforated viscus, or intestinal bleeding. This study was approved by the Institutional Review Board of the University of Florida College of Medicine.

Patients

The medical records of 103 consecutive patients with extensive thoracic aortic aneurysms between 1992 and 2007 were retrospectively reviewed. All patients underwent either single-stage transmediastinal replacement (SS) or 2-stage elephant trunk repair, with either surgical (OPEN) or endovascular (TEVAR) second-stage techniques. This represented an off-label use of thoracic aortic endografts. Among the patients who underwent a first-stage elephant trunk operation, all anatomically suitable or “TEVAR-eligible” patients were considered for endovascular repair and placed in the TEVAR group. The rest were placed in the OPEN group.

Statistics

Completion rates and outcomes were analyzed for 3-way comparison by Statistica 8.0 software (Statsoft Inc, Tulsa, Okla). Continuous variables were expressed as means with standard deviation and analyzed by analysis of variance, with the exception of hospital length of stay, time to completion, and follow-up period, which were expressed as medians with interquartile ranges and analyzed by nonparametric analysis (Kruskal–Wallis test). Categorical variables were expressed as proportions and compared by Fisher’s exact significance test.

Kaplan–Meier survival analysis was performed by the Mantel–Cox log-rank test. To compare survival among the three groups, we established a uniform cutoff time point at 6 months based on the group that first reached a standard error greater than 10%. We used the Social Security Death Index to note survivors to date.

Univariate analysis was performed by logistic regression to identify statistically significant predictors of outcomes.

FIGURE 1. Illustration of the basic principle of the elephant trunk procedure using an extension into the proximal descending thoracic aorta to facilitate second-stage repair. Reprinted from Safi HJ, Miller CC 3rd, Estrera AL, Huynh TT, Porat EE, Allen BS, et al. Staged repair of extensive aortic aneurysms: long-term experience with the elephant trunk technique. *Ann Surg* 2004;240:677-84; with permission.

Operative Details

Ascending and aortic arch operations were performed through a median sternotomy. After systemic heparinization, arterial cannulation was performed via the ascending aorta after epiaortic ultrasound (73%) or the femoral artery or, more recently, the right axillary artery,⁹ and dual-stage venous cannulas were placed in the right atrium. A vent was placed in the right

FIGURE 2. Illustration of the single-stage transmediastinal replacement A, An incision is made in the posterior pericardium to expose the descending thoracic aorta. A wire is passed into the arch to guide the graft down through the aorta and complete the distal anastomosis first. B, The ascending and arch aorta are then repaired. Reprinted from *Annals of Thoracic Surgery* 72:1232-8, 2001. Beaver TM, Martin JD. Single-stage transmediastinal replacement of the ascending arch, and descending thoracic aorta; with permission from The Society of Thoracic Surgeons.

superior pulmonary vein on fibrillation. Retrograde cardioplegia was administered in the coronary sinus and antegrade cardioplegia in the coronary ostia. CPB was established and circulatory arrest was initiated at 18°C on electroencephalogram silence. For extended aortic arch reconstructions, retrograde or antegrade cerebral perfusion was used on a case-by-case basis.¹⁰

SS was performed as previously described (Figure 2).⁷ Intercostal arteries were excluded with this technique. First-stage elephant trunk procedures were performed with modifications by Kusuvara, Shiraishi, and Iwakura.¹¹ A transverse arch aortotomy was made, preserving an aortic island containing the great vessels, and an elephant trunk Dacron tube graft was placed in the descending thoracic aorta (<10 cm). A portion of the graft was resected to reimplant the aortic great vessels in a single anastomosis. The transverse arch aortotomy was then closed around the graft. At this time, the graft was inverted and sewn to the aortic wall proximal to the arch vessels, sealing the aorta around the graft. The graft was then unfolded, deaired, and the aortic cannula was placed in the graft. The proximal graft was then anastomosed to the ascending aorta. The patient was rewarmed and weaned from CPB.

For the second-stage OPEN procedure, the descending thoracic aneurysm was approached through a left thoracotomy or thoracoabdominal incision. Distal aortic perfusion strategies were used to reduce neurologic complications.¹² Formerly, left atrial–femoral artery partial bypass was used, but now femoral artery–femoral vein bypass is preferentially used with mesenteric perfusion. We routinely place cerebrospinal fluid drainage catheters in the operating room for both OPEN and endovascular second-stage repair (TEVAR) for prevention of spinal cord ischemia.¹³

Patients in the second-stage TEVAR group underwent computed tomographic imaging with 3-dimensional reconstruction to verify adequate proximal and distal landing zones for stent-graft deployment and to determine the appropriate sized endograft, typically 20% greater diameter. Using up to 10 cm of elephant trunk graft typically provides a sufficient proximal landing zone. During the procedure, guidewires were fluoroscopically guided into the elephant trunk. After systemic heparinization, an introducer sheath was advanced, and the stent grafts were deployed. The proximal and distal attachment sites and intervening junctions were ballooned to secure the seal. Completion angiography was performed in all cases.

RESULTS

Between 1992 and 2007, 95 of 103 patients with extensive thoracic aortic aneurysms underwent either an elephant trunk operation with 43 intended surgical (OPEN) completions or 23 intended endovascular (TEVAR) completions

or 29 single-stage transmediastinal replacements (SS). Eight patients (7 OPEN, 1 TEVAR) are currently being followed up inasmuch as their descending thoracic aortic aneurysms did not meet size criterion (6 cm) for repair, and these patients were excluded from completion rate calculation.

Demographics

Each group of patients represented different time periods in the management of the total thoracic aorta. Accordingly, some baseline characteristics were different among the three groups: there were significantly more patients with aortic dissections in the OPEN group and more patients with both chronic lung disease and renal insufficiency in the TEVAR group (Table 1).

Operative Characteristics

Forty-four percent of patients underwent a concomitant aortic valve or root repair (Table 2). We have increasingly used a valve-sparing procedure with external Dacron graft support as previously described.¹⁴ Approximately one third of patients underwent concomitant coronary artery bypass grafting. Circulatory arrest time and retrograde cerebral perfusion time were significantly longer in the SS group compared with both the OPEN and TEVAR groups.

Of the 38 patients who underwent second-stage repair (20 OPEN and 18 TEVAR), 19 had purely descending thoracic aortic aneurysms, and 19 thoracoabdominal aortic aneurysms, 10 of which were extent II (Table 3). During the second-stage procedure, mean operating room time with TEVAR completion was shorter than with OPEN completion (161 vs 308 minutes; $P = .0001$).

Outcomes

For the entire series of 103 patients, the overall 30-day and/or inpatient mortality rate was 18% (18/103) (Table 4).

TABLE 1. Demographic variables of patients with extensive thoracic aortic aneurysms

Characteristics	Total	OPEN	TEVAR	SS	P value
No.	103	50	24	29	
Age (y)	65 (± 13)	64 (± 11)	65 (± 14)	66 (± 14)	.85
Sex					.82
Men	46 (45%)	22 (44%)	12 (50%)	12 (41%)	
Women	57 (55%)	28 (56%)	12 (50%)	17 (60%)	
Acute presentation	21 (20%)	12 (24%)	3 (13%)	6 (21%)	.52
Aortic dissection	33 (32%)	23 (46%)	6 (25%)	4 (14%)	.008
Acute	2 (2%)	1 (2%)	0 (0%)	1 (3%)	.67
Chronic	31 (30%)	22 (44%)	6 (25%)	3 (10%)	.005
Marfan syndrome	5 (5%)	2 (4%)	1 (4%)	2 (7%)	.84
Previous sternotomy	33 (32%)	19 (38%)	8 (33%)	5 (17%)	.16
Prior aortic procedure	37 (36%)	19 (38%)	10 (42%)	8 (28%)	.53
Hypertension	85 (83%)	42 (84%)	20 (83%)	23 (79%)	.87
Smoking	55 (53%)	28 (56%)	13 (54%)	14 (48%)	.80
Diabetes	8 (8%)	2 (4%)	4 (17%)	2 (7%)	.16
CAD	54 (52%)	23 (46%)	14 (58%)	17 (59%)	.45
CLD	37 (36%)	18 (36%)	13 (54%)	6 (21%)	.04
CRI	11 (11%)	4 (8%)	6 (25%)	1 (3%)	.03

OPEN, Open second-stage completion of elephant trunk; TEVAR, thoracic endovascular aneurysm repair for second-stage completion; SS, single-stage transmediastinal replacement of the total thoracic aorta; CAD, coronary artery disease; CLD, chronic lung disease; CRI, chronic renal insufficiency.

Fifty-four percent (56/103) were discharged home, and 28% (29/103) of patients were discharged to a rehabilitation facility.

Of the 74 first-stage elephant trunk operations, 38% were not followed by the second-stage repair (Table 5) because of loss to follow-up (24%), first-stage death (8%), interim death (4%), and too high risk for a second operation (1 patient, 1%).

Four patients received a “prophylactic” elephant trunk in the event of a future descending thoracic aortic repair. One was a 24-year-old patient with Marfan syndrome and no descending aneurysm. Another had a ruptured ascending aneurysm and no descending component. Two other patients had

descending aortas with maximum diameters of 2.0 cm and 3.5 cm.

The highest completion rate was with the single-stage (SS) approach (100%), whereas among patients undergoing elephant trunk repair, TEVAR completion (78.3%) was significantly higher than OPEN completion (46.5%) ($P = .01$) (Table 4). Seven of 18 TEVARs were performed during the index hospitalization but as separate procedures. In the patients undergoing elephant trunk repair, median second-stage hospital stay was shorter with TEVAR (5.5 vs 16.5 days; $P < .01$). TEVAR patients required fewer intraoperative blood transfusions, both overall and in the second stage

TABLE 2. Operative variables for elephant trunk (OPEN and TEVAR) and single-stage repairs of extensive aneurysms

Variable	Total	OPEN	TEVAR	SS	P value
No.	103	50	24	29	
Valve/root procedure	45 (44%)	25 (50%)	13 (54%)	7 (24%)	.04
AV repair	21 (20%)	13 (26%)	5 (21%)	3 (10%)	.29
Root	9 (9%)	5 (10%)	3 (13%)	1 (3%)	.40
Valve sparing	6 (6%)	2 (4%)	2 (8%)	2 (7%)	.64
AV replacement	9 (9%)	5 (10%)	3 (13%)	1 (3%)	.39
CABG	35 (34%)	15 (30%)	7 (29%)	13 (45%)	.36
Operative time (min)		509 (± 205)	537 (± 150)	419 (± 144)	.02
Stage I		385 (± 135)	411 (± 134)		.44
Stage II		308 (± 106)	161 (± 78)		.0001
Perfusion–ischemic times (min)					
Circulatory arrest time		48 (± 14)	44 (± 12)	97 (± 106)	.0006
RCP time		34 (± 17)	31 (± 16)	57 (± 24)	.0001
Total CPB time		184 (± 58)	214 (± 72)	209 (± 82)	.13
Cardiac ischemic time		107 (± 41)	104 (± 68)	117 (± 53)	.57

OPEN, Open second-stage completion of elephant trunk; TEVAR, thoracic endovascular aneurysm repair for second-stage completion; SS, single-stage transmediastinal replacement of the total thoracic aorta; AV, aortic valve; CABG, coronary artery bypass grafting; RCP, retrograde cerebral perfusion; CPB, cardiopulmonary bypass.

($P < .01$). TEVAR patients also had a lower incidence of acute kidney injury: 28%, 13%, and 41% for OPEN, TEVAR, and SS. There were no significant differences among the three groups in rates of 30-day/inpatient mortality, paraplegia, or stroke. Median follow-up was 52, 17, and 71 months for OPEN, TEVAR, and SS. Kaplan–Meier estimates of survival at 6 months were 64%, 78%, and 64%, respectively, for the OPEN, TEVAR, and SS groups ($P = .08$). Reoperation for bleeding was not significantly different: 8%, 8%, and 10% for OPEN, TEVAR, and SS ($P = .65$).

Univariate Analysis

First-stage outcomes were analyzed in all 103 patients, including those having single-stage repair, to find univariate predictors of outcomes for ascending and arch replacements. Univariate predictors for first-stage mortality were stroke (odds ratio [OR] 7.8, 95% confidence intervals [CI] 1.4–43.6), acute kidney injury (OR 13.4, 95% CI 3.7–47.8), dialysis (OR 9.3, 95% CI 2.3–38.5), age (OR 1.3, 95% CI 1.1–1.4), CPB time (OR 1.3, 95% CI 1.1–1.6), and number of intraoperative blood transfusions (OR 1.3, 95% CI 1.1–1.6). The only predictor for first-stage acute kidney injury was operative time (OR 1.2, 95% CI 1.0–1.5); and the only predictor for first-stage paraplegia was prior abdominal aortic aneurysm repair (OR 7.6, 95% CI 1.2–50.1). Univariate predictors for the combined mortality/major morbidity end point MPSK (defined as Mortality, Paraplegia, Stroke, and acute Kidney injury) were operative time (OR 1.3, 95% CI 1.03–1.5), CPB time (OR 1.3, 95% CI 1.04–1.5), and intraoperative transfusions (OR 1.3, 95% CI 1.1–1.6).

Univariate predictors for the 38 patients who underwent the second-stage procedures were as follows: (1) acute kidney injury: surgical technique (OR 4.9 for SS vs TEVAR, 95% CI 1.2–20.4), operative time (OR 1.7, 95% CI 1.3–2.3), and intraoperative transfusions (OR 2, 95% CI 1.5–2.5); (2) spinal cord ischemia: extent II thoracoabdominal aortic aneurysm (OR 11.6, 95% CI 1–129) and operative time (OR 1.6, 95% CI 1.2–2.1); and (3) MPSK: operative time (OR 1.4, 95% CI 1.04–2.0), crossclamp time (OR 1.6, 95% CI 1.04–2.5), and intraoperative transfusions (OR 1.5, 95% CI 1.1–2.1).

DISCUSSION

Repair of extensive thoracic aortic aneurysms poses a significant surgical challenge, and alternative treatment options are now available with endovascular techniques. Both single-stage and 2-stage techniques have been described in the literature, and novel hybrid techniques have been recently introduced.

Proponents of a 2-stage technique believe that the morbidity and mortality of replacing the entire thoracic aorta in one stage are too high—17% in one report³ and 24% in our own experience.⁷ Mortality rates of 8% for each stage have been reported with the 2-stage approach.^{2,4} Borst's elephant trunk

TABLE 3. Operative variables for second-stage OPEN versus TEVAR

Variable	Total (n = 38)	OPEN (n = 20)	TEVAR (n = 18)	P value
Extent of repair				
Descending only	19 (50%)	5 (25%)	14 (79%)	.003
TAAA extent I	8 (21%)	6 (30%)	2 (11%)	.24
TAAA extent II	10 (26%)	8 (40%)	2 (11%)	.07
TAAA extent III	1 (2.6%)	1 (5%)	0	1.00
TAAA extent IV	0	0	0	
CSF drainage in OR	27 (71%)	20 (100%)	7 (39%)	~0
CSF drainage in ICU	1 (3%)	0	1 (6%)	.47
Intercostal artery reattachment		13 (65%)		
Operative time (min)		308 (±106)	161 (±78)	.0001

OPEN, Open second-stage completion of elephant trunk; TEVAR, thoracic endovascular aneurysm repair for second-stage completion; TAAA, thoracoabdominal aortic aneurysm; CSF, cerebrospinal fluid; OR, operating room; ICU, intensive care unit.

technique obviates potentially hazardous dissection of the aortic arch, with its associated risk of significant bleeding or injury to the vagus and left recurrent laryngeal nerves. Limiting the elephant trunk extension to no more than 10 to 15 cm is believed to reduce the risk of paraplegia.³

Kouchoukos and associates¹⁵ have used a bilateral anterior thoracotomy incision in a single-stage approach with arch-first anastomosis to decrease circulatory arrest times. Early mortality rate was 7.2% with 5-year survival of 71% and no perioperative strokes. The benefits of a single-stage replacement are that patients undergo treatment of the entire thoracic aorta in one operation and avoid the risk of interval rupture between stages. One limitation in both our own single-stage series and also Kouchoukos' series is that the aneurysm can extend no further than the diaphragm. Furthermore, our transmediastinal approach did not employ the arch-first technique, which resulted in extended circulatory arrest times and may have led to increased morbidity.¹⁶

Recently, hybrid endovascular approaches have been used to treat extensive thoracic aortic aneurysms. Szeto and associates¹⁷ reported using brachiocephalic bypass with stent grafting of the arch for large aortic arch aneurysms. The “frozen elephant trunk,” which involves placement of a stent in the descending aorta during arch replacement, was reported by Baraki and coworkers¹⁸ with an early mortality rate of 12.5% and stroke rate of 12.8%.

TEVAR completion of elephant trunks has been reported by multiple centers, sometimes at the initial arch operation.¹⁹ Greenberg and colleagues²⁰ reported a 30-day mortality of 4.5% in their series of 22 patients. The less-invasive endovascular therapy increases the likelihood of completing the second stage—a primary concern with staged approaches. Safi and associates² showed that patients may die of rupture even within 6 weeks after first-stage repair and accordingly shortened prior recommendations of second-stage repair to 4 weeks.

TABLE 4. Comparison of completion rates and outcome data for OPEN versus TEVAR versus SS

	Overall	OPEN	TEVAR	SS	P value
No.	103	50	24	29	
Follow-up (mo)	44 (22–74)	52 (38–79)	17 (12–28)	71 (34–86)	.001
Completion*	67/95 (71%)	20/43 (47%)	18/23 (78%)	29/29 (100%)	.02†
Completion time (d)	112 (58–276)	114 (74–190)	84 (16–441)	—	.52
Median LOS (d)	19 (13–31)	21 (13–33)	19 (14–27)	16 (9–29)	.08
Stage I	13 (9–20)	12.5 (9–20)	15.5 (8–24)		.19
Stage II	11 (6–20)	17 (12–25)	6 (4–10)		.0001
Operative mortality	18 (18%)	7 (14%)	4 (17%)	7 (24%)	.53
Stage I	7 (9%)	5 (10%)	2 (8%)		1.00
Stage II	4 (11%)	2 (10%)	2 (11%)		1.00
Paraplegia	10 (10%)	3 (6%)	2 (8%)	5 (17%)	.23
Stage I	1 (1%)	0	1 (4%)		.32
Stage II	4 (11%)	3 (15%)	1 (6%)		.60
Stroke	8 (8%)	5 (10%)	1 (4%)	2 (6%)	.89
Stage I	4 (5%)	3 (6%)	1 (4%)		1.00
Stage II	2 (5%)	2 (10%)	0		.49
AKI	29 (28%)	14 (28%)	3 (13%)	12 (41%)	.04
Stage I	12 (16%)	9 (18%)	3 (13%)		.74
Stage II	5 (13%)	5 (25%)	0		.048
MPSK	44 (43%)	19 (38%)	7 (29%)	18 (62%)	.04
Stage I	33 (45%)	11 (22%)	4 (17%)		.76
Stage II	11 (29%)	8 (40%)	3 (17%)		.16
Tracheostomy	14 (14%)	6 (12%)	1 (4%)	7 (24%)	.10
Stage I	6 (8%)	5 (10%)	1 (4%)		.66
Stage II	1 (3%)	1 (5%)	0		1.00
Arrhythmias	38 (37%)	22 (44%)	11 (46%)	5 (17%)	.03
Stage I	32 (43%)	21 (42%)	11 (46%)		.81
Stage II	2 (5%)	2 (10%)	0		.49
Sternotomy/mediastinitis	4 (4%)	3 (6%)	1 (4%)	0	.46
Reoperation for bleeding	9 (9%)	4 (8%)	2 (8%)	3 (10%)	.91
Stage I	4 (5%)	3 (6%)	1 (4%)		1.00
Stage II	2 (5%)	1 (5%)	1 (6%)		1.00
Perioperative MI	1 (1%)	0	1 (4%)	0	.23
Stage I	1 (1%)	0	1 (4%)		.32
Stage II	0	0	0		
Pneumonia	19 (18%)	8 (16%)	1 (4%)	10 (34%)	.02
Stage I	7 (9%)	6 (12%)	1 (4%)		.42
Stage II	2 (5%)	2 (10%)	0		.49
GI complications	12 (10%)	3 (6%)	5 (21%)	4 (14%)	.15
Stage I	5 (7%)	1 (2%)	4 (17%)		.04
Stage II	5 (13%)	2 (10%)	3 (17%)		.64
Multisystem failure	6 (6%)	2 (4%)	0	4 (14%)	.09
Stage I	2 (3%)	2 (4%)	0		1.00
Stage II	0	0	0		
Intraop PRBC (U)	6.2 (±5.2)	7.2 (±6.1)	3.8 (±3.1)	6.2 (±4.1)	.03
Stage I	4.1 (±3.9)	4.7 (±4.2)	3.0 (±3.1)		.09
Stage II	3.9 (±4.9)	6.5 (±5.4)	1.0 (±1.6)		.0002

OPEN, Open second-stage completion of elephant trunk; TEVAR, thoracic endovascular aneurysm repair for second-stage completion; SS, single-stage transmediastinal replacement of the total thoracic aorta; LOS, length of stay; AKI, acute kidney injury; MPSK, incidence of operative Mortality; Paraplegia, Stroke, or acute Kidney injury; MI, myocardial infarction; GI, gastrointestinal; PRBC, packed red blood cells. *Completion rates were calculated after exclusion of 7 patients from the OPEN group and 1 patient from the TEVAR group who are actively being monitored. †P value relates to pairwise comparison between OPEN and TEVAR group.

Thrombus can form around or even within the folded the elephant trunk.²¹ Dislodgment of “peri–elephant trunk thrombus” by guidewires during endovascular therapy can result in thromboembolic consequences, as in 2 of our pa-

tients. One had mesenteric emboli, and the other had peripheral thromboembolism with foot necrosis. The risk of perigraft thrombus may be reduced by earlier second-stage repair, as advocated by Safi and colleagues.² In fact, we

TABLE 5. Completion failures among elephant trunk patients

	Total (n = 74)	OPEN (n = 50)	TEVAR (n = 24)
Total first-stage only	36 (48.6%)	30 (60%)	6 (25%)
Active follow-up	8 (10.8%)	7 (14%)	1 (4.2%)
Completion failures*	28 (37.8%)	23 (46%)	5 (20.8%)
*Reasons for completion failure			
No follow-up	18 (24.3%)	17 (34%)	1 (4.2%)
First-stage death	6 (8.1%)	4 (8%)	2 (8.3%)
Interim death	3 (4.1%)	1 (2%)	2 (8.3%)
Too high risk	1 (1.4%)	1 (2%)	0

performed 7 of 18 TEVARs during the index hospitalization. Other technical modifications that have evolved over time include marking the distal aspect of the endograft with radiopaque surgical clips and snaring a guidewire introduced through the right brachial artery to assist in the catheterization of the elephant trunk.^{20,22}

Patients assigned to the TEVAR group may have inherently been at lower risk, by way of being “anatomically eligible” for TEVAR and having less complex aneurysms that did not involve the visceral vessels. Four of our TEVAR patients had thoracoabdominal aortic aneurysms (2 extent I and 2 extent II aneurysms). One patient with extent I thoracoabdominal aortic aneurysm underwent TEVAR to cover the entire descending thoracic aorta, leaving a small segment of aneurysm in the supraceliac aorta; follow-up computed tomography at 1 month showed a stable descending aorta diameter. Another patient with extent II thoracoabdominal aortic aneurysm was treated similarly, leaving a smaller 4.3-cm aneurysm from the supraceliac aorta to down below the renals. The other patient with extent I thoracoabdominal aortic aneurysm had an external Dacron wrap of the supraceliac aorta to create a suitable landing zone. We²³ have used this technique in patients with large-neck aneurysms and with endoleaks after TEVAR. The final patient with extent II thoracoabdominal aortic aneurysm had a suitable landing zone only in the infrarenal aorta and aneurysmal involvement of all visceral vessels. She underwent a mesenteric/renal revascularization from the right common iliac artery using a bifurcated Dacron graft and was subsequently covered with stent grafts down to the bifurcation. Lee and colleagues²⁴ published early results of similar staged hybrid repairs of thoracoabdominal aortic aneurysm involving visceral and/or renal vessels in 17 patients. These patients had extensive comorbidities precluding an open approach, and operative mortality was significant at 24%.

There are several limitations of the current study. It is a retrospective study with an inherent selection bias. There is also potential for bias owing to interactions between our outcomes and time period. We analyzed our data for interactions between mortality, stroke, or MPSK and time period but found no significant interactions (data not shown). Also, given the relatively recent implementation of TEVAR,

follow-up for this group was shorter. Long-term follow-up will be required to monitor for endoleaks and the stability of the surgical graft–endograft junction. Nonetheless, TEVAR is less invasive and short-term results are acceptable.

CONCLUSION

In conclusion, this study reports a concurrent series of three techniques that have evolved over 15 years in a single institution for the treatment of extensive thoracic aortic aneurysms. In anatomically suitable candidates, TEVAR has become our preferred approach in the management of complex thoracic aortic aneurysms.

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