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Arch Debranching versus Elephant Trunk Procedures for Hybrid Repair of Thoracic Aortic Pathologies

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Abstract

Background—We compared outcomes of arch debranching (AD) and elephant trunk (ET) techniques when used with thoracic endovascular aortic repair.

Methods—A review was performed of consecutive patients with proximal thoracic aortic pathologies repaired with a hybrid approach.

Results—Between 2005 and 2009, 58 patients underwent first stage ET (n = 21) or AD (n = 37). Cardiopulmonary bypass was utilized in 100% of ET and 68% of AD procedures ($p < 0.01$). Circulatory arrest was used in 86% of ET and 27% of AD cases ($p < 0.01$). The second stage was completed in 76% of ET and 76% of AD patients. Rates of spinal cord ischemia (ET 0/21, AD 0/37, $p = 1.0$), stroke (ET 2/21, AD 4/37, $p = 1.0$), and 30-day mortality (ET 4/21, AD 6/37, $p = 1.0$) were similar. Each group had one major aortic complication between the two stages. Type Ia endoleak at 1 and 12 months occurred in 13% ET and 4% AD ($p = 0.54$), and 0% and 4% ($p = 1.0$), respectively. Kaplan-Meier estimates of survival at 1 and 12 months were $90.5\% \pm 6.4$ and $73.1\% \pm 10$ in the ET, and $86.5\% \pm 5.6$ and $71.6\% \pm 8.5$ in the AD group, respectively ($p = 0.68$). The risk of a secondary procedure at 1 and 12 months were 76.2 ± 9.3 and $58.7\% \pm 12$ in the ET, and $71.0\% \pm 7.8$ and $52.8\% \pm 10$ in the AD group, respectively ($p = 0.86$).

Conclusions—Arch debranching achieves equivalent results to standard elephant trunk repair but with a decreased need for cardiopulmonary bypass and circulatory arrest.

Keywords

Aortic arch aneurysm; endovascular procedures

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Introduction

Extensive diseases involving the ascending, arch and descending thoracic aortas are challenging to repair. Conventional treatment has involved the elephant trunk (ET) technique, which was originally developed by Borst in 1983 [1] using deep hypothermia and circulatory arrest (DHCA) but was associated with neurologic, cardiac, respiratory and renal complications [2-4]. Thoracic endovascular aortic repair (TEVAR) was first introduced by Dake in 1994 [5]. Initially limited to the descending thoracic aorta, endovascular therapy is now being applied to treat a wide range of pathologies throughout the aorta [6-8]. More recently, the two-stage elephant trunk technique has evolved into a hybrid repair involving either an elephant trunk or arch debranching (AD) procedure with subsequent endovascular completion.

The optimal proximal landing zone for a hybrid repair remains uncertain. The ET technique creates a long, prosthetic landing zone but one that is mobile, unsupported and at risk for infolding and crimping. Further, poor fluoroscopic visibility of the elephant trunk may hinder access into the trunk [9]. AD creates a stable, fixed proximal landing zone in the ascending aortic position. The debranching technique has undergone considerable evolution with regards to the configuration of the bypass grafts, number of vessels to bypass and use of cardiopulmonary bypass (CPB). For both techniques, the timing of the endovascular repair as a single versus staged approach remains controversial.

In this study, we compare the outcomes of a first stage arch debranching versus elephant trunk procedure combined with a delayed second stage endovascular repair.

Patients and Methods

We retrospectively reviewed medical records, imaging studies, and a prospective database of thoracic endovascular procedures performed at a single tertiary-care medical center. Demographics, indications for repair, procedural measures, 30-day or in-hospital mortality, morbidity, secondary procedures and discharge dispositions were examined. The study was approved by the Institutional Review Board with a Waiver of Informed Consent.

Preoperative imaging was based on computed tomographic angiography (CTA) of the head, neck, chest, abdomen and pelvis. The dataset was post-processed using the Aquarius 3D Workstation (TeraRecon, San Mateo, CA) for case planning and device selection. All patients had suitable distal landing zones for endograft implantation.

Description of the proximal landing zones was based on Criado's definitions (Figure 1) [10, 11]. Spinal cord ischemia (SCI) was defined as any new lower extremity deficit not associated with an intracerebral event. SCI was considered transient (versus permanent) if symptoms were completely resolved at the time of discharge. Stroke was defined as any new global or focal deficit lasting >24 hours with an acute intracranial abnormality on brain imaging.

Our institution did not follow a standardized algorithm for determining whether a patient will undergo arch debranching versus an elephant trunk procedure. The decision to proceed

with either type of surgery reflected a temporal change in our practice pattern rather than an anatomic one; the current practice is to favor the arch debranching technique.

Statistics

Patients were analyzed on an intention-to-treat basis. Categorical variables were analyzed using the Fisher exact test and continuous variables with nonparametric distribution compared using the Mann-Whitney U test. Probabilities of late events were analyzed using Kaplan-Meier estimates and compared with a log-rank test. A two-tailed $p < 0.05$ was considered statistically significant. The Social Security Death Index (<http://ssdi.rootsweb.ancestry.com/>) was used to verify late deaths.

Operative details: Surgical first stage

For the first stage ET procedures, a modified technique was utilized as previously described [12]. Briefly, after cooling to 18°C, a transverse arch aortotomy was performed preserving the great vessels as an aortic island. A Dacron elephant trunk was inserted into the descending thoracic aorta and the arch vessel island was reimplanted on to the side of the graft. The aortotomy was closed, and the graft inverted and anastomosed to the aorta proximal to the arch vessels. The graft was next unfolded, de-aired, and sewn to the ascending aorta.

For arch debranching, the aorta was exposed just above the sinotubular junction and the innominate and left common carotid arteries were mobilized. The left subclavian artery (LSCA) was selectively revascularized if there was a dominant left vertebral artery, but other indications were also considered [13]. In such cases, if the LSCA could be safely exposed, an ascending bypass was performed at the time of the debranching procedure; otherwise a carotid-subclavian bypass was performed at a separate setting but before the endovascular stage. The proximal anastomosis of the debranching graft was created along the right anterolateral aspect of the aorta with a large transversely placed clip at the heel of the anastomosis. Cardiopulmonary bypass with or without circulatory arrest and/or ascending replacement was performed as indicated.

Operative details: Endovascular second stage

The site of insertion of the endograft delivery system was based on the size and quality of the access vessels. Iliac conduits were utilized for small or diseased iliofemoral arteries. Devices were oversized by 10-20% based on a repeat CTA performed after the first stage. A left ventricular guidewire was routinely placed after arch debranching procedures to provide sufficient proximal rail support for the endograft. Blood pressure was lowered selectively using the right atrial inflow occlusion technique [14]. Adjunctive procedures such as coiling and ballooning were performed as indicated. All the cases were performed in an endovascular surgical suite using fixed fluoroscopic equipment (Toshiba Infinix-i, Tustin, CA) for optimal intraoperative imaging.

Management of spinal ischemia

Management of SCI involved blood pressure elevation and spinal drainage. Spinal drains were placed preoperatively if there was planned coverage of greater than 150 mm of the

thoracic aorta or if coverage extended within 5 cm of the celiac artery. Blood pressure was augmented with fluid and vasopressor support to achieve a target pressure of either 160 mmHg systolic or 100 mmHg mean. Spinal drainage was initiated by placing the drain at 10 cm above the level of the right atrium, and adjusted either higher or lower depending on the symptomatic response and amount of drainage. Drainage was limited to <15 ml/hr or <350 ml/day to avoid potential risk of subdural hemorrhage [15, 16]. Spinal drains placed prophylactically were left open for 24 hours, clamped 12 hours and removed. Drains placed for symptomatic patients were kept open for 72 hours, clamped for 24 hours and then removed.

Results

Demographics

Between September 2005 and January 2009, 58 patients underwent staged hybrid repairs. The mean age was 65 ± 14 years and 36 (62%) were men. Twenty-one (36%) patients underwent first stage ET repair and 37 (64%) underwent AD repair. Most of the patients underwent their first stage repairs with a planned second stage endovascular repair performed at a separate operative setting. Degenerative aneurysm was the most common indication in the ET (21, 100%) and AD (34, 92%) groups ($p=0.55$) (Table 1). Baseline characteristics were similar between the ET and AD groups (Table 2).

Operative results: Surgical first stage

The first stage procedure was performed electively in 91% (19/21) of ET and 89% (33/37) of AD patients ($p=1.0$). Both groups required adjunctive procedures during their first stage repairs (Table 3). Notably, 19% of ET patients underwent simultaneous brachiocephalic reconstruction; while in the AD group 46% had replacement of the ascending aorta and 43% of the transverse arch. Compared to ET patients, significantly fewer AD patients required CPB (ET 21/21 vs. AD 25/37 patients, $p<0.01$) and DHCA (ET 18/21 vs. AD 10/37, $p<0.01$). There was no difference in the median time on CPB (ET: 202 min vs. AD: 226 min, $p=0.74$) or DHCA (ET: 43 min vs. AD: 25 min, $p=0.36$) between the groups. The median operative time was significantly shorter in the AD (348 min, range 166-618) compared to the ET group (403 min, range 224-785) ($p=0.047$).

There was no difference in the incidence of intraoperative complications between the ET (5/21, 24%) and AD (3/37, 8%) groups ($p=0.12$). Complications in the ET group included 1 kinked graft, 1 retained foreign body, 1 pulmonary artery injury, 1 groin hematoma and 1 pulmonary parenchymal bleeding. AD complications included 1 branch vessel injury, 1 stroke and 1 acute type A dissection from clamp injury. Incidence of perioperative secondary surgical procedures was similar between the two groups: ET (7/21, 33%) and AD (9/37, 24%) ($p=0.55$). They included 1 aortic banding and 11 non-aortic, non-vascular procedures in the ET group, and 1 graft thrombectomy and 16 non-aortic, non-vascular procedures in the AD group.

Operative results: Endovascular second stage

AD patients had a shorter median time to second stage completion compared to ET patients (29 vs. 54 days, $p=0.16$). There was no difference between the groups in the incidence of aortic complications during the time between the stages ($p=1.0$). One ET patient died from a massive hemothorax and one AD patient developed an acute anastomotic pseudoaneurysm with cardiac tamponade. The rates of second stage completion between the ET (16/21, 76%) and AD (28/37, 76%) were similar (Table 4). Two patients in the AD group had simultaneous TEVAR. Of note, one second stage procedure was completed at an outside hospital and the details were not available for analysis.

Regional anesthesia was preferred whenever possible for TEVAR and utilized for the second stage repairs in ET (4/16, 25%) and AD (10/27, 37%) groups ($p=0.51$). Endovascular procedural measures were similar (Table 5). The use of iliac conduits between the ET (3/16, 19%) and AD (5/27, 19%) groups was identical ($p=1.0$). There was no difference in the rates of adjunctive endovascular procedures between the ET (2/16, 13%) and AD (4/27, 15%) groups ($p=1.0$).

There was almost 3-fold greater incidence of intraoperative complications in the ET (5/16, 31%) second stage procedures as compared to AD (3/27, 11%) ($p=0.13$). ET second stage complications included 3 iliac artery injuries, 2 elephant trunk inversions, 1 arch dissection and 1 cardiac arrest. AD complications included 1 iliac artery injury, 1 severe hypotension, and 1 device malfunction at the proximal attachment site.

Additional surgical or endovascular procedures were required in 25% (4/16) of ET patients and in 26% (7/27) of AD patients after their second stage repairs ($p=1.0$) (Table 6).

Postoperative outcomes

In-hospital/30-day mortalities for the first stage (ET: 2/21, 9.5% vs. AD: 5/37, 13.5%, $p=1.0$) and second stage (ET: 2/16, 12.5% vs. AD: 1/27, 3.7%, $p=0.55$) were statistically similar. Kaplan-Meier estimates of survival at 1 and 12 months were $90.5\% \pm 6.4$ and $73.1\% \pm 10$ in the ET group, and $86.5\% \pm 5.6$ and $71.6\% \pm 8.5$ in the AD group, respectively ($p=0.68$) (Figure 2). There was no difference in the incidence of in-hospital/30-day first ($p=1.0$) or second ($p=0.28$) stage major postoperative complications (Table 7), and more specifically, in the incidence of reoperation for bleeding after the first stage procedures (ET: 0/21, 0% vs. AD: 3/38, 8%, $p=0.55$). Type I endoleaks at one (ET: 2/16, 12.5% vs. AD: 1/27, 3.7%, $p=0.54$) and 12 months (ET: 0/16, 0% and AD: 1/27, 3.7%, $p=1.0$) were infrequent in both groups, respectively. Kaplan-Meier estimates of the risk of a secondary procedure at 1 and 12 months were $76.2\% \pm 9.3$ and $58.7\% \pm 12$ in the ET group, and $71.0\% \pm 7.8$ and $52.8\% \pm 10$ in the AD group, respectively ($p=0.86$) (Figure 3).

Stroke after the first stage ET (2/21, 9.5%, one anterior circulation and one multifocal, bilateral cerebral and cerebellar ischemic infarcts) and AD (3/37, 8.1%, one anterior circulation, one anterior and posterior circulation and one not classified) were similar ($p=1.0$), as they were after the second stage (ET: 0/16, 0% vs. AD: 1/27, 3.7%, $p=1.0$). The 2 ET patients with strokes had additional procedures performed at the time of the elephant trunk construction. However, neither patient had significant atheromatous disease. Of the 3

AD patients who had strokes, one had atheromatous disease of the arch and two had concomitant surgical procedures. The single AD patient who had a stroke following TEVAR had a history of a prior stroke and a hypotensive episode during the endovascular repair. There was no permanent spinal cord ischemia in either the AD or ET groups.

There was no difference between the ET and AD groups in the first (ET 18 vs. AD 14 days, $p=0.06$) or second stage (ET 8 vs. AD 6 days, $p=0.11$) median lengths of stay (LOS). However, the median combined LOS of the subset of each group completing both stages was significantly shorter in the AD group (18.5 days, mean 22 ± 16) compared to the ET (27.5 days, mean 34 ± 22) group ($p=0.01$).

Comment

Although other studies of hybrid arch repairs have included both elephant trunk and arch debranching procedures as first stage techniques, they have generally not compared the two techniques. Our study showed that arch debranching as compared to elephant trunk procedures had equivalent early mortality and morbidity (aortic complications, stroke, SCI) yet required less frequent use of cardiopulmonary bypass and circulatory arrest.

Historically, 30-day mortality following first stage ET repair has ranged between 2 and 12%, and open second stage mortality between 4% and 9.7% [17-21]. In a study of 22 patients with ET repairs followed by endovascular completion, Greenberg et al. reported no early mortality following the first stage repair and 5% in-hospital mortality following second stage completion [9]. These results were echoed by Hughes et al. in their report of 28 hybrid repairs including both first stage ET and AD procedures that reported no 30-day/in-hospital mortality [22]. However, some smaller studies have reported a combined mortality of 12.5 to 15.4% after arch debranching with endovascular completion [23, 24]. In the current study, the combined mortality of the ET and AD groups was 17%. A potential contributing factor for the disparity between these results and those of earlier studies may be related to the complexity of the case mix as measured by a large proportion of patients in this study requiring major adjunctive procedures at the time of their first stage repairs.

Antegrade introduction of the stent graft at the time of the first stage procedure as a combined single stage repair has been advocated by some operators [25]. When this is used with the ET technique, it has been referred to as the “frozen elephant trunk” [26]. In this approach, the endograft is advanced under direct vision through the elephant trunk and deployed. This has been also used with arch debranching by introduction of the endograft through a separate sidearm conduit near the base of the debranching graft [27].

We have generally not favored the antegrade approach for multiple reasons. First, most thoracic endografts are not bidirectional. The construction of the proximal end differs from its distal end and the effectiveness of the proximal fixation mechanism when used in the distal position remains untested. Second, most delivery systems deploy the endograft in the tip-to-hub manner. When deployed in the antegrade manner, the proximal end either cannot be easily visualized or the foreshortening that can occur as the endograft accommodates the curvature of the arch cannot be easily predicted. Third, safe tracking of the delivery system around the arch requires a through-and-through transfemoral fixation of the guidewire.

Fourth, nitinol-based endografts may not expand fully under hypothermia. And lastly, imaging can be hampered by metallic retractors, use of a portable C-arm and lack of blood flow in cases of circulatory arrest. These limitations preclude use of this single-stage technique except in anatomies which does not involve the distal half of the descending thoracic aorta.

A two-stage approach may be disadvantageous in cases of compromised access or severe aortic tortuosity, where an iliac conduit or other adjunctive techniques may be required. Specific to the AD technique, even if the ascending aorta may not be aneurysmal, it should be replaced with a prosthetic graft if its diameter is greater than 36 mm and/or it is unusually short. This diameter represents the upper limit of treatable aortic size with a 15% minimum oversizing using non-bare stented endografts currently available in the US. Prosthetic replacement is likely superior to banding from standpoint of long-term durability and risk of aortic wall necrosis. Additionally, following arch debranching, the endograft delivery system may have to cross the aortic valve. Although transvalvular placement of a large sheath is relatively safe for native and some bioprosthetic valves, it would be contraindicated for a mechanical valve, and so in this situation a single-stage antegrade deployment may be superior.

There are several limitations associated with this study. Though the data was abstracted and analyzed from a prospectively maintained database, it remains a retrospective study with an intrinsic selection bias. Furthermore, despite comparison with a wide variety of clinical and outcome measures, we were unable to identify which was the superior procedure in the short term. It may be that any superiority of one technique over the other may be manifest in the long-term, which remain to be examined.

In conclusion, the approach to the repair of complex arch pathologies is in evolution. A hybrid approach conceptually decreases the magnitude of a single operation into small ones and takes advantage of the minimally-invasive benefits of catheter-based techniques. The results of this study show that the outcomes of the first stage procedure to create a suitable proximal landing zone in preparation for the second stage endovascular repair appear to be generally equivalent between standard elephant trunk and arch debranching techniques, with arch debranching having the benefits of shorter cardiopulmonary bypass and circulatory arrest times, and shorter combined length of stay.

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Abbreviations and Acronyms

AD	arch debranching
ASA	American Society of Anesthesiologists
CABG	coronary artery bypass graft
CAD	coronary artery disease
CPB	cardiopulmonary bypass
CRI	chronic renal insufficiency
CTA	computed tomography angiography
DHCA	deep hypothermic circulatory arrest
ET	elephant trunk
HTN	hypertension
LCCA	left common carotid artery
LSCA	left subclavian artery
SCI	spinal cord ischemia
TAAA	thoracoabdominal aortic aneurysm
TEVAR	thoracic endovascular aortic repair
TIA	transient ischemic attack

Figure 1.

Anatomical map of the aortic arch divided into four landing zones for the proximal end of an endograft.

Figure 2.
Kaplan-Meier survival curves for ET and AD patients.

Figure 3.

Kaplan-Meier curves estimating freedom from secondary procedures for ET and AD patients.

Table 1

Indications for treatment by pathology.

Indication	ET (n=21)	AD (n=37)	<i>p</i>
Aneurysm			
Aortic root aneurysm	2	1	0.55
Ascending aortic aneurysm	19	15	<0.01
Arch aortic aneurysm	19	24	0.06
Descending thoracic aortic aneurysm	17	32	0.71
TAAA	4	5	0.71
Dissection			
Chronic type A	0	2	0.53
Chronic type B	4	9	0.75
Acute type A	0	2	0.53
Not otherwise specified	2	1	0.55

Table 2

Demographics and ASA score.

Group	ET (n=21)	AD (n=37)	<i>p</i>
Gender, Male (%)	13 (62)	23 (62)	1.0
Age (years)	68±11	63±15	0.24
Comorbidities, n (%)			
HTN	19 (91)	31 (84)	0.70
Smoking	15 (71)	27 (73)	1.0
CAD	11 (52)	23 (62)	0.58
Hyperlipidemia	8 (38)	16 (43)	0.79
CRI	3 (14)	5 (14)	1.0
Stroke/TIA	2 (10)	5 (14)	11.0.0
Diabetes	2 (10)	8 (22)	0.30
ASA score, n (%)			
III	3 (14)	8 (22)	0.73
IV	18 (86)	23 (62)	0.08

Table 3

First stage operative details and concomitant surgeries.

	ET (n=21)	AD (n=37)
Cardiopulmonary bypass, n (%)	21 (100)	25 (68)
Circulatory arrest, n (%)	18 (86)	10 (27)
Concomitant surgeries, n (%)		
Valve repair	6 (29)	11 (30)
Root replacement	3 (14)	3 (8)
Ascending replacement	-	17 (46)
Arch replacement	-	16 (43)
CABG	5 (24)	11 (30)
Brachiocephalic reconstruction	4 (19)	-

Table 4

Second stage endovascular repair.

Group	2 nd stage completion rate	Reasons for non-completion (n)
ET	16/21 (76%)	Death from bleed (1) Death from sepsis (1) Repair not yet scheduled (3)
AD	28 ^a /37 (76%)	Death from stroke (4) Death from multisystem organ failure (1) Repair not yet scheduled (4)

^aOne completed at an outside hospital and details not available for analysis.

Table 5

Second stage operative details.

Group	ET	AD	<i>p</i>
Fluoroscopy (minutes), median (range)	29 (18-67)	24 (13-49)	0.12
Contrast (ml), median (range)	135 (80-250)	140 (65-250)	0.61
Operative time (minutes), median (range)	144 (62-299)	118 (74-308)	0.95
Endografts used per case, median (range)	3 (2-4)	2 (1-6)	0.47

Table 6

Secondary procedures after TEVAR.

Group	Additional surgeries (n)
ET-TEVAR	Endograft extension for type I endoleak (1)
	Exploratory laparotomy for cholecystectomy and small bowel resection (1)
	Proximal bare stenting for endograft infolding (1)
	Skin grafting (1)
AD-TEVAR	Distal aortic aneurysm repair (3)
	Endograft extension (2)
	Aortic root pseudoaneurysm repair (1)
	Percutaneous gastrostomy tube/gastrojejunostomy tube (3)
	Iliac aneurysm repair (1)
	LSCA coil embolization (1)
	Tracheostomy (2)
	Wound debridement (1)
	Cystoscopy and clot evacuation (1)
	Exploratory laparotomy for cholecystectomy and abscess drainage(1)
	Mesenteric bypass (1)
	Craniotomy (1)

Table 7

Early post-operative complications.

Group	1 st stage complications	2 nd stage complications
ET	Atrial fibrillation, bacteremia, gastrointestinal bleed, mediastinal abscess, myocardial infarction, respiratory failure, SCI, stroke	Atrial fibrillation, bacteremia, cardiac arrest, cholecystitis, respiratory failure, small bowel infarction, SCI, wound infection
AD	Atrial fibrillation, cardiac tamponade, deep venous thrombosis, graft thrombosis, heart block, intraabdominal abscess, mediastinal bleeding, pneumonia, renal failure, respiratory failure, seizure stroke, vocal cord injury	Aortic root pseudoaneurysm, atrial fibrillation, deep venous thrombosis, laryngeal nerve injury, SCI, stroke