The elephant trunk is freezing: The Hannover experience

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Background: The ‘‘elephant trunk’’ (ET) technique traditionally has been performed to treat complex aortic diseases involving the aortic arch and the descending aorta. Despite the fact that, in recent years, the ‘‘frozen elephant trunk’’ (FET) technique has been used increasingly for such pathologies, discussion is still ongoing in the surgical community regarding which of the 2 techniques is better. We compared our results using the classic ET versus the FET technique.

Methods: From August 2001 to March 2013, a total of 277 patients underwent total aortic arch replacement and either ET (group A) or FET (group B) implantation. In group A, 97 patients (59 men; age 59.7 ± 12.7 years; 44.3% with aneurysm; 55.6% with dissection [48.45% acute]) underwent an ET procedure; 21.64% were reoperations. In group B, 180 patients underwent an FET procedure (126 men; age 59.8 ± 13.2 years; 34.4% with aneurysm; 63.3% with dissection [35% acute]); 30% were reoperations.

Results: In group A, in-hospital mortality was 24.7%; postoperative stroke rate was 12.4%. During follow-up, 27.8% underwent a second-stage procedure. In group B, in-hospital mortality was 12.2%; postoperative stroke rate was 13.3%. During follow-up, 27.7% patients underwent further interventions in the downstream aorta.

Conclusions: In selected patients with combined aortic arch and descending aortic aneurysms limited to the proximal descending aorta, the FET approach potentially allows for single-stage therapy, whereas a second-stage operation is inevitable with the classic ET approach. Moreover, owing to the availability of prefabricated, easy-to-use, FET, hybrid prostheses that result in significantly better outcomes in patients who have acute aortic dissection, type A, and if necessary, and provide an ideal ‘‘landing zone’’ for future endovascular completion, the classic ET procedure is ‘‘freezing,’’ in the sense that it is being replaced by the FET approach. (J Thorac Cardiovasc Surg 2015;149:1286-93)

See related commentary on pages 1294-5.

Various approaches have been used to treat the combined pathologies of the aortic arch and the descending aorta (aneurysms and dissection). Borst and colleagues[1] introduced the ‘‘elephant trunk’’ (ET) technique at our center, designed to simplify the second-stage operation of the 2-stage procedure.[2-4] Endovascular stent-graft technology was introduced in 1998 by Dake and colleagues,[5] to treat aortic pathology.[6] A combination of the above 2 techniques resulted in the ‘‘frozen elephant trunk’’ (FET) technique,[7] which therefore represents an evolution of the classic ET procedure. The purpose of the current study was to compare our results from use of the classic ET versus the FET procedure.

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METHODS

Patients

The ET technique was first introduced at our center in March 1982, whereas the first FET implantation was performed in August 2001. To compare the results of the 2 procedures, we decided to include the data for both groups, dating from the first FET implantation (2001). The ethics committee of our institution gave approval for this study.

From August 2001 to March 2014, a total of 277 patients underwent total aortic arch replacement with either ET (group A, n = 97) or FET (group B, n = 180) implantation. Prospectively collected patient records were reviewed. Clinical follow-up ended in March 2014 and was 100% complete. Overall, the characteristics of patients in the 2 groups were comparable. However, group A had significantly more patients with acute aortic dissection, type A (AADA) (n = 47 [48.5%] vs n = 63 [35.0%]; $P = .039$); whereas group B had more patients with chronic aortic dissection, typeA (n = 7 [7.2%] vs n = 51 [28.3%]; $P < .0001$). Group A had a higher percentage of patients with Marfan syndrome (n = 3 [5.4%] vs n = 3 [4.8%]; $P = .003$).

We believe that aortic aneurysms, acute aortic dissections, and chronic aortic dissections are 3 separate disease entities, with different sets of risks. Accordingly, we divided both study cohorts into 3 subgroups. Preoperative demographic patient characteristics are reported in Table 1.

Surgical Technique

Classic ET technique. The early version of the ET technique was performed between 2001 and 2006. In this procedure, the ET part of the aortic graft was inserted per Svensson and colleagues' modification[4] of the original technique.[2] The supra-aortic vessels were reimplanted in the aortic arch prosthesis using the classic ‘‘island’’ technique.

Abbreviations and Acronyms

AADA	= acute aortic dissection, type A
ET	= elephant trunk
FET	= frozen elephant trunk
TEVAR	= thoracic endovascular aortic repair

Prefabricated ET technique. The later version of the technique, known as prefabricated ET, has been used since 2007. In this procedure, a prefabricated branched aortic arch graft is used with an ET part (Siena, Vascutek, Ltd, Renfrewshire, Scotland, United Kingdom).[8-10] The arch part of the graft has 4 branches, 1 for arterial perfusion, and 3 for the anastomoses with the supra-aortic branches. Between the ET and the arch parts of the graft is a sewing collar, designed to simplify the distal anastomosis.

Frozen elephant trunk technique. During the early years of this procedure (2001-2007), the first "prefabricated," custom-made Chavan-Haverich hybrid graft (Curative GmbH, Dresden, Germany) was implanted. We changed to the E-VITA Jotec hybrid graft (JOTEC GmbH, Hechingen, Germany) when it became available. Later, we developed, along with Vascutek (Renfrewshire, Scotland, United Kingdom) the Thoraflex Hybrid multi-branched graft and distal stent.[11]

Technical Evolution of the ET and FET Techniques

We recently published a report of our 30-year experience with the conventional ET technique, as well as of our 10-year experience with the FET technique.[12,13] We identified several parameters that need to be improved, and initiated changes in perioperative management, as follows:

- Reduction of perioperative stroke rate: We use carbon dioxide sufflation in the operative field to reduce the risks of air embolism.
- Myocardial protection: To minimize the myocardial ischemia time, we initiated the "beating heart" aortic arch repair technique.
- Spinal cord protection: To minimize the risks of paraplegia, the lower-body circulatory arrest time is kept to a minimum, and perioperative cerebrospinal fluid drainage is performed in all FET procedures, to keep the spinal pressure below 12 mm Hg. In patients undergoing ET procedures, cerebrospinal fluid drainage is used according to anatomic needs.
- Shortening of the hypothermic circulatory arrest and cardiopulmonary bypass times: We restart the perfusion of the lower part of the body, as well as begin "rewarming," immediately after the distal aortic arch anastomosis.
- Hemostasis: To improve hemostatic control over every anastomotic site, aortic arch repair has been performed exclusively with branched aortic arch grafts since 2007.
- Recurrent nerve palsy: If technically feasible, we perform the distal aortic anastomosis proximal to the left subclavian artery, to minimize surgical dissection and manipulation of the distal aortic arch.

Current Technique for Total Aortic Arch Surgery Using ET and FET

After a standard median sternotomy, cardiopulmonary bypass is initiated with direct cannulation of the aorta and the right atrium. We prefer direct cannulation of the aorta in all cases, including acute and chronic aortic dissections. The left side of the heart is vented through the right superior pulmonary vein. Continuous carbon dioxide insufflation is used in all cases.

Blood cardioplegia is our preferred method of myocardial protection. Cardioplegia is repeated approximately every 30 minutes during the cardiac part of the procedure. Cerebral protection is achieved by moderate hypothermic circulatory arrest at 25°C, along with bilateral selective antegrade cerebral perfusion. During the time the patient is cooled to a nasopharyngeal temperature of 25°C, the aortic root and/or ascending aortic procedure and other concomitant cardiac procedures are performed.

Subsequently, the left ventricle is de-aired, and the heart is perfused in antegrade fashion via an aortic root cannula inserted proximal to the aortic clamp in the ascending aorta or aortic prosthesis. Both the perfusion pressure and flow are continuously monitored. Myocardial perfusion pressure is kept at 70 to 80 mm Hg, corresponding to a myocardial perfusion flow of ≥150 to 200 ml/minute. The left atrium is thoroughly vented. After this step, the aortic arch is replaced on an empty "beating heart."

After reaching the desired temperature, the systemic circulation is arrested and the aorta opened. With the patient in the Trendelenburg position, catheters (Medtronic DPL, Medtronic, Inc, Minneapolis, Minn) are introduced into the left carotid artery and the innominate artery for selective antegrade cerebral perfusion. The left subclavian artery is clamped or occluded with a Fogarty catheter (Baxter Healthcare Corp, Irvine, Calif), thus avoiding the steal phenomenon, as well as preventing blood from flowing into the operative field. Cerebral perfusion is initiated at a rate of 10 ml/kg/minute. The blood temperature of selective antegrade cerebral perfusion is 22°C to 24°C.

The aorta is transected, either between the left common carotid artery and the left subclavian artery, or distal to the left subclavian artery. The ET or FET is deployed into the proximal descending aorta. With the FET, we routinely use retrograde placement of a guide wire, via femoral access. In addition, we use an endoscope to control the deployment of the ET or FET from inside, after its placement in the descending aorta.

After the distal anastomosis has been completed, the left subclavian artery is anastomosed to the third branch of the arch graft. The perfusion to the lower part of the body and the subclavian artery is restarted via the 4th branch of the graft. "Rewarming" of the patient is initiated.

The proximal end of the graft is anastomosed, either to the native ascending aorta or the ascending aortic graft. In this way, not only the myocardial ischemia time, but also the rewarming time, and consequently the total operation time, is minimized. The 1st and 2nd branch of the Dacron graft are anastomosed to the innominate and left carotid artery, respectively. Once the cardiopulmonary bypass is discontinued, the 4th branch, used for antegrade perfusion, is ligated and resected.

Statistical Analysis

Data were collected and analyzed retrospectively. GraphPad Prism 6.1 for Windows (GraphPad Software Inc, La Jolla, Calif) and SPSS 22.0 (SPSS, Inc, Chicago, Ill) were used to perform data analysis. Continuous variables were given as mean ± SD. Categoric variables were summarized as total number (n) and percentages. The Fisher exact test was used to analyze differences of dichotomous variables. The unpaired *t* test, or as appropriate, the nonparametric Mann-Whitney *U* test were used for group comparisons of continuous variables. The Kaplan-Meier survival estimate was used to analyze survival. Statistical differences in Kaplan-Meier survival were determined with the log-rank test. Two-tailed P values $< .05$ were considered significant. All short- and long-term comparisons were unadjusted.

RESULTS

The detailed intra- and post-operative data are given in Tables 2 and 3. The results from risk factor analysis and multivariate analysis are presented in Tables 4 and 5. Two intraoperative deaths occurred in group A (2.1%). Both of them were patients who had acute dissection. One patient died as a result of myocardial failure; the other died from distal aortic rupture. In addition, 2 intraoperative deaths occurred in group B (1.1%). Both of these patients had acute aortic dissection. One patient could not be weaned

TABLE 1. Preoperative data

Characteristic	Total			Aneurysm			Acute dissection			Chronic dissection		
	Group A (ET)	Group B (FET)	P	Group A (ET)	Group B (FET)	P	Group A (ET)	Group B (FET)	P	Group A (ET)	Group B (FET)	P
Patients	97	180		43	62		47	67		7	51	
Gender, male	59 (61)	126 (70)	.14	20 (47)	35 (56)	.33	34 (72)	53 (79)	.50	5 (71)	38 (74)	1.00
Age, median (range [y])	62 (51-70)	63 (49-70)	.87	63 (54-73)	68 (62-73)	.19	58 ± 12	57 ± 13	.84	62 ± 8	56 ± 14	.31
Marfan syndrome	13 (13)	16 (9)	.30	**8 (19)**	**1 (1.6)**	**.003**	4 (8.5)	5 (7.4)	1.00	1 (14)	11 (22)	1.00
Previous surgery	20 (21)	54 (30)	.12	11 (26)	14 (23)	.82	3 (6.4)	5 (7.5)	1.00	6 (86)	35 (69)	.66
Aneurysm	43 (44)	62 (34)	.12									
AADA or AADB	47 (48)	67 (37)	.07									
CADA or CADB	7 (7)	51 (28)	**<.001**									

Boldface indicates $P < .005$. Values are n, or n (%), unless otherwise indicated. *ET*, Elephant trunk; *FET*, frozen elephant trunk; *AADA*, acute aortic dissection, type A; *AADB*, acute aortic dissection, type B; *CADA*, chronic aortic dissection, type A; *CADB*, chronic aortic dissection, type B.

from the cardiopulmonary support and died, despite receiving veno-arterial extracorporeal membrane oxygenation support. Another patient died from descending aortic rupture.

Intraoperative data showed some distinct differences between group A and group B. Aortic clamp times were significantly shorter in group B, in which patients underwent fewer concomitant cardiac procedures, and their operations involved greater use of "beating heart technique," in which the heart is perfused with cold blood during aortic arch repair, after the cardiac procedures are finished. Selective antegrade cerebral perfusion times were longer in group B, because with the beating heart technique, reattachment of the aortic arch vessels is usually performed with branched grafts at the end of the operation.

In group B, the following types of FET prostheses were implanted: Chavan-Haverich graft (Curative GmbH, Dresden, Germany) (n = 66); E-VITA Jotec open hybrid graft

TABLE 2. Intraoperative data

Characteristic	Total			Aneurysm			Acute dissection			Chronic dissection		
	Group A (ET)	Group B (FET)	P	Group A (ET)	Group B (FET)	P	Group A (ET)	Group B (FET)	P	Group A (ET)	Group B (FET)	P
Patients	97	180		43	62		47	67		7	51	
Operation time (min [range])	344 (279-423)	359 (304-425)	.23	296 (235-393)	325 (280-374)	.16	363 (313-450)	370 (316-436)	.94	484 (326-615)	397 (336-440)	.41
CPB time (min [range])	235 (175-308)	229 (187-280)	.77	185 (148-247)	202 (169-249)	.25	263 (267-315)	253 (208-291)	.17	308 (170-365)	242 (193-282)	.42
Cardiac ischemia time (min [range])	142 (95-190)	126 (94-167)	**.052**	98 (83-147)	108 (77-134)	.69	165 ± 54	140 ± 56	.02	220 (118-228)	131 (97-187)	.064
Distal CA time (min [range])	53 (40-71)	55 (41-75)	.61	42 (30-59)	48 (36-64)	.23	65 (46-81)	53 (41-80)	.15	65 (48-88)	58 (53-80)	.95
SACP time (min [range])	51 (39-74)	72 (55-100)	**<.0001**	42 (30-55)	64 (49-92)	**<.0001**	64 (47-97)	84 (56-113)	.039	54 (42-74)	73 (61-94)	.13
Beating Heart	2 (2.1)	29 (16)	**.0002**	1	14	**.004**	1	10	.025	0	6	1.00
Concomitant procedures	68 (70)	97 (54)	**.010**	27 (63)	29 (47)	.12	35 (74)	45 (67)	.053	6 (86)	23 (45)	.10
Bentall	32	33		12	6		16	14		4	13	
Valve-sparing root	27	44		7	10		18	30		2	4	
CABG	21	30		10	13		9	9		2	8	
MVR	1	3		1	1		0	1		0	1	
AVR	4	1		4	1		0	0		0	0	
Blood products												
Packed red blood cells (U [range])	8 (6-12)	6 (4-10)	**.0042**	6 (4-10)	6 (4-7)	.15	9 (6-16)	6 (4-10)	**.0027**	17 (9-28)	9 (5-12)	**.016**
Platelets (U [range])	2 (2-4)	3 (2-4)	**.51**	2 (2-3)	2 (2-3)	.12	3 (2-5)	3 (2-4)	**.51**	2 (2-4)	2 (2-3)	.49
Fresh frozen plasma (U [range])	8 (6-12)	6 (5-8)	**.0003**	6 (6-8)	6 (4-6)	.27	9 (6-13)	6 (5-8)	**<.0001**	16 (10-22)	6 (6-11)	**.0004**

Boldface indicate $P < .005$. Values are n, or n (%), unless otherwise indicated. *ET*, Elephant trunk; *FET*, frozen elephant trunk; *CPB*, cardiopulmonary bypass; *CA*, coronary artery; *SACP*, selective antegrade cerebral perfusion; *CABG*, coronary artery bypass graft; *MVR*, mitral valve replacement; *AVR*, aortic valve replacement; *U*, units.

TABLE 3. Postoperative data

	Total			Aneurysm			Acute dissection			Chronic dissection		
	Group A (ET)	Group B (FET)	*P*	Group A (ET)	Group B (FET)	*P*	Group A (ET)	Group B (FET)	*P*	Group A (ET)	Group B (FET)	*P*
Patients	97	180		43	62		47	67		7	51	
Ventilation (d [range])	0.91 (0.58-2.7)	1.2 (0.58-4.4)	.13	0.63 (0.50-1.0)	0.87 (0.51-3.2)	.055	2.1 (0.84-5.8)	2.0 (0.70-5.6)	.79	0.76 (0.40-0.96)	1.2 (0.54-4.6)	.29
Hospital stay (d [range])	12 (7.5-20)	15 (9.0-23)	**.037**	12 (9.0-18)	15 (9.0-22)	.31	14 (5.0-22)	13 (8.0-21)	1.00	11 (8.0-12)	17 (12-30)	**.0049**
Rethoracotomy for bleeding	23 (24)	30 (17)	.20	6 (14)	8 (13)	1.00	15 (32)	12 (18)	.12	2 (29)	10 (20)	.62
Stroke	12 (12)	24 (13)	1.00	2 (5)	6 (10)	.47	10 (21)	11 (16)	.62	0 (0)	6 (12)	1.00
Prolonged ventilation	27 (28)	44 (24)	.57	4 (9)	8 (13)	.76	13 (28)	10 (15)	.10	1 (14)	14 (28)	.66
Paraparesis	5 (5)	9 (5)	1.00	0	2 (3)	.51	5 (11)	6 (9)	.76	0 (0)	1 (2)	1.00
Recurrent nerve palsy	15 (16)	36 (20)	.42	8 (19)	10 (16)	.80	5 (11)	13 (19)	.30	1 (14)	9 (18)	1.00
Renal failure; dialysis	12 (12)	25 (14)	.85	2 (5)	7 (11)	.30	10 (21)	9 (13)	.31	0 (0)	9 (18)	.58
30-d mortality	24 (25)	22 (12)	**.011**	4 (9)	9 (15)	.55	19 (40)	10 (15)	**.004**	1 (14)	4 (8)	.42

Boldface indicate $P < .005$. Values are n, or n (%), unless otherwise indicated. *ET*, Elephant trunk; *FET*, frozen elephant trunk.

(JOTEC GmbH, Hechingen, Germany; n = 31); Vascutek Thoraflex Hybrid (Vascutek, n = 83). Group B patients needed fewer packed red blood cells, as well as fresh frozen plasma transfusions. Concomitant cardiac procedures were more frequently performed in group A. Especially in the early years, FET was less often combined with cardiac procedures. Early mortality was significantly lower in group B, particularly because of a high mortality rate in patients who had acute dissection and underwent an ET procedure.

The risk factor analysis of the complete patient cohort is presented in Table 4. Multivariate analysis using a stepwise regression model (Table 5) revealed the following typical independent risk factors for early mortality: age, concomitant coronary artery bypass graft surgery, rethoracotomy for bleeding, postoperative dialysis, postoperative stroke, and AADA. The use of an FET prosthesis independently reduced the risk for mortality.

Follow-up

Follow-up was 100% complete. During follow-up, no patient required a reoperation for the aortic arch. The detailed follow-up data are shown in Table 6. Kaplan-Meier curves for survival and aortic reoperation are shown in Figure 1. Survival differed significantly between groups because of a higher early mortality in group A, especially in patients who had acute dissection (Figure 1, *C*). Follow-up survival was not significantly different between groups in patients with aneurysm.

Overall, no significant difference was found in the reoperation rate between groups. However, the results showed a trend toward fewer downstream procedures in patients who underwent an FET procedure after acute dissection (8% vs 17%; $P = .232$). Independent risk factors for reoperation of the downstream aorta were: acute dissection and Marfan syndrome (Table 5).

DISCUSSION

Combined disease of the aortic arch and the proximal descending aorta remains a surgical challenge. The ET technique was initially introduced to simplify the second-stage operation of the classic 2-stage procedure. The main advantage is that during the second-stage operation, the surgeon needs to anastomose only the descending aortic graft with the previously placed ET, instead of the distal aortic arch, simplifying the procedure considerably.

The main disadvantage is the need for 2 operations, with the associated risk of mortality and morbidity. In addition, death may occur in the interval between the 2 operations, owing to the rupture of the untreated segment of the aorta. In recent years, endovascular stent-graft techniques have been introduced.[5] However, a totally endovascular treatment of aortic arch pathology is still technically difficult because of the presence of supra-aortic vessels.

A combination of the classic ET technique and the endovascular stent technology resulted in the FET technique.[7] Ideally, the distal landing site of the stent graft should be at the nondiseased portion of the descending aorta, for a "single-stage" procedure. Both of these techniques were initially performed in patients with complex thoracic aortic aneurysms. In aortic aneurysms, a second-stage operation is inevitable with classic ET, whereas a single-stage operation can potentially be achieved with FET. However, for a true single-stage operation with FET, the disease has to be

TABLE 4. Risk factor analysis

Factor	n	P 30-d mortality	P Aortic reoperation
Preoperative			
Age (y)	277	.88	.43
Gender (male)	185	.76	.90
Emergency	116	**.001**	**<.001**
Previous surgery	74	.94	.276
Acute aortic dissection (type A or type B)	114	**.002**	**<.001**
Chronic dissection (type A or type B)	58	**.044**	**.006**
Aneurysm	105	.14	**.010**
Marfan syndrome	30	.90	**<.001**
Intraoperative			
FET	180	.12	.53
Bentall	65	**.088**	.40
Valve-sparing root surgery	71	.86	**.045**
CABG	51	**.018**	.85
Operation time (min)		**.003**	.10
CPB time (min)		**<.001**	.85
Cardiac ischemia time (min)		**.017**	.079
HCA time (min)		.332	.87
SACP time (min)		.825	.066
Red blood cells (units)		**<.001**	.68
Postoperative			
Ventilation time (d)		**<.001**	.24
Reoperation for bleeding	53	**<.001**	.93
Respiratory insufficiency	71	.13	.79
Dialysis	37	**<.001**	.79
Paraplegia and/or paraparesis	14	.38	.43
Stroke	36	**<.001**	**.033**

Boldface indicate $P < .005$. *FET*, Frozen elephant trunk; *CABG*, coronary artery bypass graft; *CPB*, cardiopulmonary bypass; *HCA*, hypothermic circulatory arrest; *SACP*, selective antegrade cerebral perfusion.

TABLE 5. Multivariate analysis

Factor	P	Odds ratio	95% CI
30-d mortality			
Age (y)	.002	1.06	1.02-1.10
Acute aortic dissection (type A and type B)	.039	2.41	1.21-6.24
FET	.029	0.40	0.17-0.91
CABG	.026	2.98	1.14-7.77
Rethoracotomy for bleeding	<.001	5.29	2.12-13.19
Dialysis	.002	4.89	1.83-13.05
Stroke	.023	3.22	1.17-8.86
Aortic reoperation			
Acute aortic dissection (type A and type B)	<.001	0.17	0.076-0.37
Marfan syndrome	<.001	4.88	2.03-11.72

CI, Confidence interval; *FET*, frozen elephant trunk; *CABG*, coronary artery bypass graft.

limited to the level of the distal ‘‘landing zone’’ of the FET in the descending aorta. Depending on the distance of the landing zone from the left subclavian artery, the length of the FET is chosen.

If patients are not selected carefully, or the disease progresses into the downstream aorta, a second-stage procedure may be imperative, even with FET.[13] However, any type of thoracic aortic aneurysm that would require a surgical 2-step approach with classic ET may qualify for the FET technique. But whether to perform a primary distal seal or a secondary retrograde thoracic endovascular aortic repair (TEVAR) for completion remains a strategic choice of how best to reduce the potential risk of symptomatic spinal cord injury. The FET technique can be used for both secondary open and endovascular repair, as it not only offers a better landing zone for endovascular completion, compared with the ET technique, but also makes an open surgical completion possible should the need arise. The modern nitinol stents used in the FET procedure make clamping possible, and the stent graft resumes its natural configuration after declamping, owing to the inherent memory effect of the alloy.

Overall, the outcomes between the 2 groups are comparable. The ET group had more patients with AADA, and fewer patients with chronic aortic dissection, type A. This difference might be a result of the fact that, over the years, with improvements in operative techniques, as well as organ protection, the range of indications for total aortic arch replacement with both the ET and FET techniques has been expanded to include aortic dissections, both acute and chronic.

We believe that these 3 disease entities are totally different, and as such, should be treated differently. Acute aortic dissection, type A, is a surgical emergency. The main goal of emergency surgery is to prevent the rupture of the ascending aorta from causing pericardial tamponade. Therefore, many surgeons advocate performing an ascending aortic replacement only, with or without replacement of the proximal arch, in addition, if necessary, to the aortic root repair.[14] However, in such cases, the dissection in the aortic arch and descending aorta remains ‘‘untreated,’’ with the risk of subsequent dilatation and even rupture. To prevent this risk, Ando and colleagues[15] as well as Kazui and colleagues,[16] recommended a more aggressive strategy, with total aortic arch replacement, to improve late surgical outcome.

However, total aortic arch replacement in the setting of acute aortic dissection is a technical challenge. Until the FET technique became available, total aortic arch replacement with the classic ET technique was performed only as a last-resort operation in patients with ‘‘re-entries’’ in the distal aortic arch or the proximal descending aorta. The classic ET technique cannot expand the compromised true lumen in the descending aorta, and therefore cannot treat malperfusion of the visceral organs. In this regard,

TABLE 6. Aortic reoperations

	Total			Aneurysm			Acute dissection			Chronic dissection		
	ET	**FET**	***P***	**ET**	**FET**	***P***	**ET**	**FET**	***P***	**ET**	**FET**	***P***
Patients	97	180		43	62		47	67		7	51	
Second procedure downstream aorta	23 (24)	47 (26)	.772	14 (33)	20 (32)	.827	8 (17)	5 (8)	.232	1 (14)	22 (43)	.235
Open surgical	**18 (19)**	**25 (14)**		9 (21)	8 (13)		8 (17)	3 (5)		1 (14)	14 (28)	
Thoracoabdominal	**7**	**12**		5	3		1	0		1 (14)	8 (16)	
Descending aorta	**6**	**3**		4	1		2	0		0	2 (4)	
Abdominal/iliac	**5**	**10**		0	4		6	3		0	4 (8)	
Endovascular	**5 (5)**	**22 (12)**		5 (12)	12 (19)		0	2 (3)		0	8 (16)	

Boldface indicate $P < .005$. Values are n, or n (%), unless otherwise indicated. *ET*, Elephant trunk; *FET*, frozen elephant trunk.

patients in this situation were the most ill, as reflected by the very high in-hospital mortality of 40.4%.

Our results show that we were able to significantly improve survival in our patients who underwent an FET versus a classic ET procedure. The in-hospital mortality was reduced to15.9% ($P = .005$) with the FET technique. The reduction can be explained by the fact that a conventional ET procedure cannot completely stabilize the dissecting membrane or seal the false lumen. Moreover, hemostasis may be difficult to achieve intraoperatively, owing to back-bleeding from the false lumen, which was evident from the need for more blood transfusions.

Therefore, if a total aortic arch replacement has to be performed in the setting of AADA, several groups, including ours, have proposed using an FET implantation to stabilize the dissecting membrane in the proximal descending aorta, expand the true lumen, and seal the false lumen, preventing its dilatation.[17] This approach has the potential to help not only in intraoperative hemostasis, but also in reducing subsequent downstream problems that often determine the long-term results. Therefore, in acute and chronic aortic dissections, a length of approximately 10 cm for the FET (beyond the left subclavian artery) seems to be enough, as its primary purpose is to stabilize the dissected membrane and favor true lumen expansion downstream. In addition, this approach may reduce the risk of spinal cord injury.

Initially, FET implantations were performed as last-resort operations in patients with acute DeBakey type I disease with ruptured distal arch or proximal descending aorta. Later, after more experience had been gained and better results achieved, the indications were expanded to include patients with DeBakey type I disease, even without rupture, especially younger patients.

In patients who have aortic dissection, a critically important step is to carefully analyze the preoperative CT scans to note the presence of any re-entries in the downstream aorta

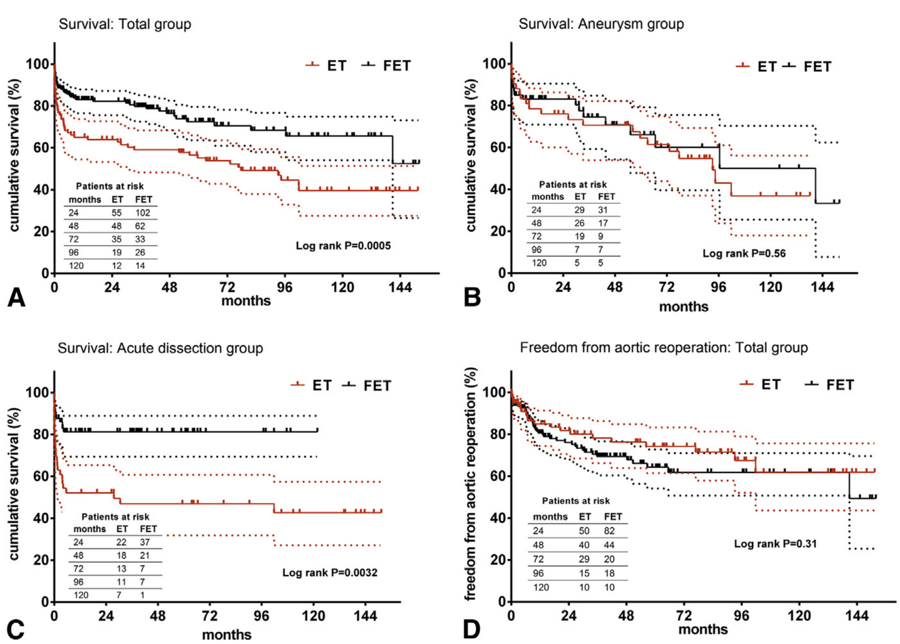

FIGURE 1. Kaplan-Meier curves for the (A) complete patient cohort; (B) patients who have aneurysm; (C) patients who have acute dissection; (D) freedom from aortic reoperations, complete patient cohort. *ET*, Elephant trunk; *FET*, frozen elephant trunk.

(distal to the probable landing zone of the FET). This check helps to minimize the risk of malperfusion caused by occlusion of the false lumen after deployment of the FET, especially if any downstream organs are perfused over the false lumen. Ideally, an angiography evaluation would be done after completion of the procedure, to confirm the absence of malperfusion. Alternatively, at least a postoperative abdominal ultrasonography should be performed.

In spite of the findings reported here, performing a total aortic arch replacement with the FET, in acute dissection patients, involving the arch and the descending aorta (DeBakey type I), is still controversial. We recently published our 10-year results with the FET procedure in acute aortic dissection, which were acceptable.[12] The FET prevented the dilatation of the proximal descending aorta, stabilized the dissecting membrane, and favored true lumen expansion in the distal nonstented segments.

In patients who have AADA with connective tissue disease, even though the stent-graft favors false lumen thrombosis and obliteration, more than the free-floating Dacron prosthesis of the classic ET, concerns remain regarding the dilatation of the native aorta at the landing-zone, especially in cases of ''oversizing.'' Nevertheless, as opposed to TEVAR, the FET approach avoids stent-graft migration and proximal endoleak, owing to the suture of the stent-graft to the proximal descending aorta. Our experience has shown that avoiding oversizing of the FET in these patients is critically important. However, treatment of a larger number of patients who have connective tissue disorders is needed to confirm this point.

In our series, very few patients with chronic aortic dissections were treated with the classic ET procedure as a means to determining which of these 2 methods is more effective. Even so, we have now moved to the FET procedure to treat these patients, given our experience with FET in patients who have AADA.

In patients who have complicated type B aortic dissections, TEVAR is the first choice for treatment. However, the issue of retrograde type A aortic dissection remains unresolved, and patients undergoing TEVAR for acute type B aortic dissection are at increased risk. Consequently, the FET technique represents an alternative when no ''landing zone'' is present for TEVAR, as in cases in which the aortic arch is dilated and/or the arch angulation is steep. In the present study, 4 such patients underwent FET implantation, with good results.

As discussed, the implantation techniques, as well as the grafts used for both the ET and FET approach, have undergone several modifications over the years. Our center was the first to introduce these techniques, which accounts for the higher complication rates, a result of the learning curve in gaining experience in performing a procedure. To reduce the perioperative risks of total aortic arch replacement with both the ET and FET approach, we have modified our operative techniques; namely: use of carbon dioxide, perioperative cerebrospinal fluid drainage, restarting of perfusion of the myocardium as early as possible, and replacement of the aortic arch on continuous perfused myocardium (''beating heart''). However, this beating heart technique results in longer selective antegrade cerebral perfusion times, as the separate reattachment of the supra-aortic vessels with branched grafts is performed at the end of the procedure.

After undergoing FET implantation, patients naturally warrant a similar follow-up protocol as do patients who undergo TEVAR. As with primary TEVAR, after FET implantation, patients may need a planned or unplanned secondary intervention, open or endovascular. Therefore, we advise that the follow-up protocol be strictly maintained for these patients.

Limitations

The main limitation of this retrospective study is the long time period involved (approximately 13 years) and the many modifications that have taken place in the operative techniques and types of hybrid grafts used during that interval. In addition, the observational nature of the study makes the subgroup comparison difficult. Thus, caution must be used in interpretation of the data.

CONCLUSIONS

In selected patients with aortic aneurysms, the FET technique potentially allows for a single-stage therapy, whereas in the classic ET approach, a second-stage operation is inevitable. In acute DeBakey type I aortic dissections, the FET technique may stabilize the dissecting membrane and favors true lumen expansion. Compared with the classic ET procedure, the FET technique favors false lumen thrombosis and obliteration in both acute and chronic DeBakey type I aortic dissections. If necessary, the FET offers an ideal landing zone for endovascular completion. As for the statement in the title, from our experience, we believe that the classic ET procedure is indeed ''freezing,'' in the sense that it being replaced by the FET approach.

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