Is the frozen elephant trunk technique justified for chronic type A aortic dissection in Marfan syndrome?

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Background: Chronic type A aortic dissection (cTAAD) in Marfan syndrome (MFS) is rare. Surgical experience is limited and the role of frozen elephant trunk (FET) technique remains undefined. We seek to evaluate the safety and efficacy of the total arch replacement (TAR) and FET technique for cTAAD in MFS.
Methods: The clinical data of sixty-eight patients with MFS undergoing FET and TAR for cTAAD were analyzed.
Results: Mean age was 35.8±9.7 years and thirty-nine were male (57.4%). Operative mortality was 10.3% (7/68). Stroke occurred in one (1.5%), re-exploration for bleeding in five (7.3%), low cardiac output in four (5.9%), and acute renal failure in two (2.9%). Follow-up was complete in 100% (61/61) at mean 7.3±4.0 years. The false lumen was obliterated in 73.5% across FET and 50.0% in unstented descending aorta (DAo). Distal dilation occurred in twenty patients, six of whom underwent thoracoabdominal aortic replacement, one abdominal aortic replacement and one thoracic endovascular aortic repair (TEVAR). Late death occurred in five. At ten years, 59.8% were free from distal aortic dilation, and the incidences were 23.2% for death, 14.4% for distal reoperation, and 62.4% for reoperation-free survival. Predictors for operative mortality were extra-anatomic bypass [odds ratio (OR), 229.592; P=0.036], preoperative maximal size (DMax) of aortic sinuses (mm) (OR, 1.134; P=0.032) and cardiopulmonary bypass (CPB) time (minute) (OR, 1.061; P=0.041). Risk factors for aortic dilatation included patent false lumen at diaphragmatic hiatus [hazard ratio (HR), 5.374; P=0.008], preoperative DMax (mm) of proximal DAo (HR, 1.068; P=0.001) and renal arteries (HR, 1.102; P=0.005) which also predicted distal reoperation (HR, 1.149; P=0.001). The time from onset to operation (day) (HR, 1.002; P=0.004) and CPB time (minute) (HR, 1.032; P=0.036) predicted late death.
Conclusions: This study shows that the TAR and FET technique is a safe and durable approach to cTAAD in patients with MFS. The operation should be performed as early as possible to optimize clinical outcomes.

Keywords: Aortic dissection; Marfan syndrome (MFS); frozen elephant trunk (FET); outcomes; survival; reoperation

Introduction

Although survivors of acute type A aortic dissection (TAAD) ultimately enter a chronic disease course (1,2), they are still faced with high risk of life-threatening aortic complications, such as aortic rupture, patent false lumen, aneurysmal dilation and malperfusion syndromes, all of which necessitate reoperation (3,4). However, scarce data have been published on the surgical outcomes of chronic type A aortic dissection (cTAAD) repair (5,6). In particular, the role of total arch replacement (TAR) using the frozen elephant trunk (FET) technique remains unclear for

cTAAD repair involving the aortic arch in patients with Marfan syndrome (MFS), who often have a narrowed true lumen compressed by a large patent false lumen (7).

Since 2003, we have been using the TAR and FET technique to repair TAAD for patients with MFS (8). Our experience has proven the benefits of the TAR and FET technique with respect to long-term survival and freedom from reoperation in such patients (7,9-12). In this study, we seek to assess the early and long-term outcomes of the TAR and FET technique for cTAAD in MFS, and to identify the risk factors for death and reoperation in such patients.

Methods

The Ethics Committees of Beijing Anzhen Hospital of Capital Medical University and Fu Wai Hospital of Chinese Academy of Medical Sciences approved this retrospective study.

Patients

Between September 2003 and October 2016, we performed TAR and FET for cTAAD involving the aortic arch or proximal descending aorta (DAo) in sixty-eight consecutive patients with MFS. The diagnosis of MFS was based on the Ghent and/or revised Ghent criteria (13,14). According to the 2014 European Society of Cardiology guidelines, aortic dissection is divided into sub-acute (15–90 days) and chronic (>90 days) (1). Patients with cTAAD who had a history of proximal aortic surgery were excluded from this study (10,15). The diagnosis of cTAAD was confirmed by computed tomographic angiogram (CTA) in all patients. Malperfusion was diagnosed based on clinical symptoms and imaging evidence.

Surgical indications and techniques

In MFS patients with cTAAD, we would perform TAR and FET for the following pathologies: (I) an intimal tear located in the transverse arch or DAo; (II) aneurysm of the aortic arch or proximal DAo (>40 mm in diameter); (III) dissection, aneurysm, or occlusion of the brachiocephalic arteries. For cTAADs confined to the ascending aorta (i.e., DeBakey type II), we would choose an ascending aortic replacement if the arch and DAo are intact, or an ascending aortic and hemiarch replacement if the proximal arch is involved.

Our surgical technique of TAR and FET (the Sun operation) has been described in detail previously (7,8,16-18). We routinely use unilateral selective antegrade cerebral perfusion through right axillary cannulation and moderate hypothermic circulatory arrest at 20–25 ℃. The procedure involves deployment of an FET, Cronus® (MicroPort, Shanghai, China) in the DAo, followed by TAR with a 4-branched vascular graft (Maquet Cardiovascular, Rastatt, Germany). To minimize the time of cerebral, myocardial and spinal cord ischemia, distal reperfusion is initiated once the distal anastomosis is completed. The left carotid artery is reconstructed first (after which rewarming is started and the brain is perfused bilaterally), followed by the ascending aorta (to resume myocardial perfusion), then the left subclavian artery, and finally, the innominate artery. In selected patients, the arch branches were reconstructed using a modified en bloc technique (17,18). Near-infrared spectroscopy, bispectral index, and cerebrospinal fluid drainage are used in high-risk patients.

Clinical and imaging follow-up

CTA of the entire aorta was performed at one month (or discharge), six months, one year and annually henceforth to assess the maximal aortic size (DMax) and complications (endoleak, migration, etc.). The aortic diameter (mm) was measured from the outer contours of the aortic wall in the axial plane, and growth rate calculated by dividing the diameter difference between the first and last CTAs. CTA measurements and analyses were performed at four aortic levels: the stented proximal descending aorta (FET), unstented DAo, diaphragmatic hiatus (DH) and renal arteries (RA). The statuses of the false lumen were classified as: completely thrombosed (obliterated) if no flow was present; partially thrombosed if both flow and thrombus were present; and patent if flow was present in the absence of thrombus.

Open or endovascular reintervention on the distal aorta was indicated for patients with a distal DMax of >50 mm. Earlier reintervention is recommended for patients with a positive family history (19,20), or distal new entry (21,22), or new onset of chest or back pain.

Study endpoints

The primary clinical endpoints included operative mortality, late death, dilation and distal aortic reoperations. Late death referred to all-cause mortality during follow-up, excluding operative mortality (defined as deaths within

30 days of surgery or before final hospital discharge, including transfers). Distal aortic reoperation included any open or endovascular reintervention on the distal aorta.

Aortic dilatation was defined as a maximal diameter of >50 mm (45 mm in patients with a family history of aortic surgery or rupture) or an average growth rate of >5 mm/year at any aortic segment as detected by CTA during follow-up.

Statistical analysis

Statistical analysis was performed using SPSS for Windows 22.0 (IBM SPSS, Armonk, NY, USA) and Prism 8.3 for Mac (GraphPad, La Jolla, CA, USA). Data are expressed as the mean ± standard deviation (SD) or number (percentage) and were compared using the Student *t*-test or Mann-Whitney U for continuous variables, and the Pearson χ^2 text or Fisher's exact for categorical variables, as appropriate. Risk factors for operative mortality and complications were identified with logistic regression. Predictors for distal aortic dilatation (binary), reoperation and late death were identified with Cox regression models. Survival and freedom from aortic dilatation and reoperation were estimated using the Kaplan-Meier method, and intergroup comparisons were made with the log-rank test. Competing risks analysis of death and reoperation were based on the decomposition of the hazard function into multiple, additive overlapping phases of hazard, as described by Blackstone *et al.* (23). All tests were 2-sided and a P value of <0.05 was considered statistically significant.

Results

Baseline characteristics

Mean age of patients was 35.8±9.7 (range, 19–57) years and thirty-nine were male (57.4%). TAAD was sub-acute (15–90 days) in thirty-eight (55.9%) and chronic (>90 days) in thirty (44.1%).

The interval from onset of symptoms to diagnosis was 150 days on average (median 6.5 days, range 1 day to 7 years). The mean interval from symptomatic onset to operation was 306 days (median 64 days, range 15 days to 9 years), which was significantly longer in the chronic group compared to the sub-acute group (643±791 *vs.* 39±18 days, P<0.001).

The majority of patients (94.1%) sustained an acute onset of pain. Abrupt onset of severe chest pain was seen in 51.5% (35/68), and isolated back or abdominal pain in

14.7% (10/68) during the acute course. Other symptoms included chest tightness accompanied by chest pain in 38.2% (26/68), back pain in 35.3% (24/68), and orthopnea and lower extremity edema in 23.5% (16/68). Twenty patients (29.4%) reported that the pain was "slight" or "transient". In eleven symptomatic patients (16.2%), the dissection was misdiagnosed at first as myocardial infarction, lumbar muscle strain, gastroenteritis, pancreatitis, or pleurisy. In four asymptomatic patients (5.9%), dissection was diagnosed incidentally during medical examination for other reasons.

The distal extent of aortic dissection was to the diaphragmatic hiatus in sixteen (23.5%), to the renal arteries in seven (10.3%) and to the iliac arteries in 45 patients (66.2%). The arch vessels were involved in 68 patients (100%), including left carotid artery in 61 (89.7%) and innominate artery in 66 (97.1%) and left subclavian artery in 60 (88.2%).

Before surgery, the DMax at the levels of the aortic sinuses, arch, proximal descending aorta, diaphragmatic hiatus and renal arteries were 67.8±13.7, 33.5±6.7, 37.5±10.6, 29.4±7.8 and 25.6±6.8 mm, respectively.

Preoperatively, malperfusion syndrome was diagnosed in six patients (two in sub-acute phase), including ischemia of the kidney in four cases, brain in one, and coronary artery in one, and acute heart failure secondary to severe aortic insufficiency in three (*Table 1*).

Operative data

The entry tear was located in the ascending aorta in sixty-six patients (97.1%). An arch entry tear was found in two patients (2.9%).

The times of cardiopulmonary bypass (CPB), cross-clamp and selective unilateral antegrade cerebral perfusion were 185.3±48.5, 104.0±33.6, 23.4±7.9 minutes, respectively. The mean cooling nasopharyngeal temperature was 21.1±3.0 ℃ (range, 15–25 ℃). Bentall procedure with a mechanical valve was performed in sixty-two patients (91.2%) and ascending aortic replacement in six (8.8%). Coronary artery bypass grafting was performed in four (5.9%) and mitral valve surgery in five patients (7.4%).

An extra-anatomic bypass was performed in seven patients (10.3%), six as a bailout, including ascending aortic-to-femoral bypass in six and femoro-femoral bypass in one. All seven patients had a small true lumen and visceral or lower limb ischemia and were found to have a pressure difference of >50 mmHg between the upper and lower

Table 1 Baseline patient characteristics

Variable	Total (n=68)	Subacute (n=38)	Chronic (n=30)	P value
Age, y	35.8±9.7	36.4±10.8	35.1±8.3	0.578
Male gender	39 (57.4%)	24 (63.2%)	15 (50.0%)	0.276
Hypertension	22 (32.4%)	10 (26.3%)	12 (40.0%)	0.231
Family history of aortic dissection	27 (39.7%)	13 (34.2%)	14 (46.7%)	0.297
Time from onset to surgery (day)	305.5±601.7	39.1±17.7	642.9±790.8	<0.001
Median (interquartile range)	63.5 (31.3, 356)	32.5 (25.5, 50)	372.0 (241.5, 732)	
Clinical manifestation				
Abrupt severe chest pain	35 (51.5%)	24 (63.2%)	11 (36.7%)	0.030
Slight chest pain	5 (7.4%)	1 (2.6%)	4 (13.3%)	0.093
Chest tightness	13 (19.1%)	9 (23.7%)	4 (13.3%)	0.281
Back or abdominal pain	10 (14.7%)	3 (7.9%)	7 (23.3%)	0.074
Weakness	1 (1.5%)	1 (2.6%)	0	0.371
Asymptomatic	4 (5.9%)	0	4 (13.3%)	0.020
Preoperative aortic diameter, mm				
Aortic sinus	67.8±13.7	66.6±13.7	69.4±13.8	0.416
Aortic arch	33.5±6.7	33.4±6.6	33.6±6.9	0.936
Proximal descending aorta	37.5±10.6	35.4±9.4	40.1±11.7	0.111
Mid-descending aorta	30.1±7.4	29.2±6.4	31.2±8.5	0.339
Diaphragmatic hiatus	29.4±7.8	29.6±7.9	29.1±8.0	0.802
Renal arteries	25.6±6.8	26.0±7.8	25.0±5.5	0.626
Aortic regurgitation				0.517
Moderate	16 (23.5%)	9 (23.7%)	7 (23.3%)	
Severe	47 (69.1%)	25 (65.8%)	22 (73.3%)	
Malperfusion syndrome*	6 (8.8%)	2 (5.3%)	4 (13.3%)	0.244
Stroke*	1 (1.5%)	0	1 (3.3%)	0.257
Acute myocardial infarction	1 (1.5%)	1 (2.6%)	0	0.371
Acute kidney injury	4 (5.9%)	1 (2.6%)	3 (10.0%)	0.200
Heart failure	3 (4.4%)	1 (2.6%)	2 (6.7%)	0.421
Arch vessel involvement				
Innominate artery	66 (97.1%)	36 (94.7%)	30 (100%)	0.202
Left carotid artery	61 (89.7%)	32 (84.2%)	29 (96.7%)	0.093
Left subclavian artery	60 (88.2%)	34 (89.5%)	26 (86.7%)	0.721

*, refers to the number of patients who developed clinically apparent ischemia. Malperfusion of specific organs is counted by the number of cases that actually occurred as confirmed by CT scan.

Table 2 Operative data and early outcomes

Variable	Total (n=68)	Subacute (n=38)	Chronic (n=30)	P value
Operative data				
Cardiopulmonary bypass time, min	185.3±48.5	189.4±49.3	180.1±47.8	0.437
Cross-clamp time, min	104.0±33.6	105.9±37.3	101.5±28.8	0.595
Antegrade cerebral perfusion time, min	23.4±7.9	23.8±8.3	23.0±7.6	0.697
Concomitant procedures				
Composite graft root replacement	62 (91.2%)	34 (89.5%)	28 (93.3%)	0.577
Extra-anatomic bypass	7 (10.3%)	3 (7.9%)	4 (13.3%)	0.464
Ascending aortic replacement	6 (8.8%)	4 (10.5%)	2 (6.7%)	0.577
Coronary artery bypass grafting	4 (5.9%)	3 (7.9%)	1 (3.3%)	0.427
Mitral valve surgery	5 (7.4%)	4 (10.5%)	1 (3.3%)	0.259
FET diameter (mm)	26.0±1.5	25.7±1.4	26.5±1.5	0.020
FET length (mm)	100.3±4.2	100.0±4.6	100.7±3.7	0.522
Operative outcomes				
Mortality	7 (10.3%)	3 (7.9%)	4 (13.3%)	0.464
Morbidity	19 (27.9%)	9 (23.7%)	10 (33.3%)	0.379
Stroke	1 (1.5%)	1 (2.6%)	0	0.371
Low cardiac output	4 (5.9%)	1 (2.6%)	3 (10.0%)	0.200
Acute renal failure	2 (2.9%)	1 (2.6%)	1 (3.3%)	0.865
Re-exploration for bleeding	5 (7.4%)	2 (5.3%)	3 (10.0%)	0.457
FET entering the false lumen	4 (6.6%)	3 (8.6%)	1 (3.8%)	0.461

FET, frozen elephant trunk.

limbs after implantation of the FET. Additional bailout procedures included lower-extremity arterial endovascular stenting and thoracoabdominal aortic replacement (TAAAR) in one patient each (*Table 2*).

Operative mortality and morbidity

The operative mortality rate was 10.3% (7/68). The most common cause of death was multiorgan failure in five patients (7.4%). Among these, three underwent an ascending aortic-to-femoral bypass and one received a femoro-femoral bypass. Left ventricular rupture after mitral valve replacement and distal aortic rupture led to one death each (1.5%).

Operative complications included stroke in one patient (1.5%), acute renal failure in two (2.9%), low cardiac output

in four (5.9%), and re-exploration for bleeding in five patients (7.4%). No spinal cord injury occurred.

Long-term outcomes

Clinical and radiological follow-up was complete in 100% (61/61) for a mean duration of 7.3±4.0 (median, 7.2; range, 0.3–14.8) years, extending to 5 years in 87% and beyond 10 years in 76%.
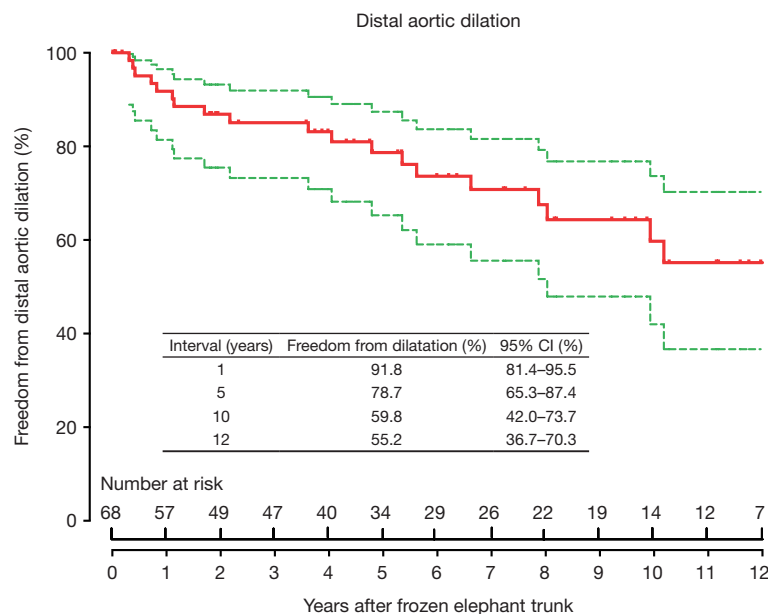
Thrombosis of false lumen

Before discharge, complete thrombosis (obliteration) of the false lumen occurred at the proximal end of the FET in 96.7% of patients (58/60) and type I endoleak was detected in two patients. At the distal end of FET, unstented mid-DAo and diaphragmatic hiatus, the false lumen

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Table 3 Status of false lumen thrombosis in sub-acute and chronic groups

Aortic segment	Subacute (%)			Chronic (%)			P value
	Complete	Partial	Patent	Complete	Partial	Patent	
Proximal end of FET	94.1	2.9	2.9	100.0	0	0	0.453
Distal end of FET	73.5	20.6	5.9	88.5	11.5	0	0.264
Unstented descending aorta	50.0	20.6	29.4	46.2	23.1	30.8	0.953
Diaphragmatic hiatus	35.3	20.6	44.1	26.9	19.2	53.8	0.730
FET, frozen elephant trunk.							

Figure 1 Freedom from distal aortic dilation.

was obliterated in 80.0%, 48.3% and 31.7%; partially thrombosed in 16.7%, 21.7%, and 20.0%; and patent in 3.3%, 30.0%, and 48.3%, respectively (*Table 3*).

Distal aortic dilatation

The mean DMax at the levels of the FET, unstented mid-DAo, diaphragmatic hiatus and renal arteries were 39.8, 34.8, 35.2 and 31.0 mm on the latest computed tomographic (CT) scan, as compared to 37.5, 30.1, 29.4 and 25.6 mm before surgery, respectively.

Distal aortic dilation occurred in twenty patients, including twelve in the sub-acute group (34.3%) and eight in the chronic group (30.8%; P=0.772). Among these, six were managed with open TAAAR, one with abdominal

aortic replacement, one with thoracic endovascular aortic repair (TEVAR), three died of distal aortic rupture, eight were awaiting surgical repair and one with a distal DMax of <45 mm was closely followed up.

The freedom from distal aortic dilatation was 91.8% (95% confidence interval, CI, 81.4–95.5%), 78.7% (95% CI, 65.3–87.4%) and 59.8% (95% CI, 42.0–73.7%) at 1, 5 and 10 years, respectively (*Figure 1*).

Late reintervention

Reintervention on the dilated distal aorta included open TAAAR in six patients, abdominal aortic replacement in one patient, and TEVAR in one patient with a giant false lumen (*Table 4*).

Table 4 Late outcomes

Variable	Total (n=61)	Subacute (n=35)	Chronic (n=26)	P value
Late death	5 (8.2%)	1 (2.9%)	4 (15.4%)	0.078
Distal aortic rupture	3 (4.9%)	1 (2.9%)	2 (7.7%)	0.388
Congestive heart failure and arrhythmia	1 (1.6%)	0	1 (3.8%)	0.242
Non-cardiac cause	1 (1.6%)	0	1 (3.8%)	0.242
Late adverse events				
Type Ia endoleak	2 (3.3%)	2 (5.7%)	0	0.215
Leakage of coronary button	2 (3.3%)	1 (2.9%)	1 (3.8%)	0.830
Dilatation of distal aorta	20 (32.8%)	12 (34.3%)	8 (30.8%)	0.772
Distal reintervention	8 (13.1%)	5 (14.3%)	3 (11.5%)	0.753
Thoracoabdominal aortic replacement	7 (11.5%)	5 (14.3%)	2 (7.7%)	0.424
Thoracic endovascular aortic repair	1 (1.6%)	0	1 (3.8%)	0.242
Maximal aortic diameter, mm				
Proximal descending aorta	39.8±14.3	38.7±12.3	41.1±16.4	0.562
Mid-descending aorta	34.8±11.5	34.8±11.6	34.7±12.1	0.976
Diaphragmatic hiatus	35.2±11.5	36.7±12.4	33.4±10.3	0.312
Renal arteries	31.0±10.4	31.6±11.3	30.2±9.4	0.632

Discharge CTA showed that the distal end of FET entered the false lumen in four patients. The distal aorta remained undilated in one and eventually became dilated in three, which were managed with TAAAR.

The DMax of distal aorta at the time of distal reintervention was 58.0±17.1 mm (range, 42–90 cm). After reintervention, eight patients were alive at mean follow-up of 4.0±2.7 years (range, 0.1–8.1 years).

The freedom from distal reoperation was 96.6% (95% CI, 87.1–99.1%), 90.2% (95% CI, 77.7–95.9%) and 82.0% (95% CI, 66.7–90.8%) at 1, 5 and 10 years, respectively (*Figure 2*).

Two patients undergoing Bentall procedure were found to have coronary button leak, which was successfully managed with open repair. The two patients with type Ia endoleak elected to have conservative management and are being closely monitored.

Late survival
Late death occurred in five patients. Three died of distal aortic rupture, one due to chronic heart failure and arrhythmia and one for non-cardiac causes.

Survival was 86.8% (95% CI, 76.1–92.9%), 86.8% (95% CI, 76.1–92.9%), and 76.0% (95% CI, 59.0–86.7%) at 1, 5 and 10 years, respectively (*Figure 3*), which did not differ significantly between patients in the sub-acute and chronic groups (P=0.107) (*Figure 4*).

In competing outcomes analysis, the incidences were 13.2% and 23.2% for death, 9.2% and 14.4% for reoperation, and 77.6% and 62.4% were alive without distal reoperation, at 8 and 10 years, respectively (*Figure 5*).

Risk factors for death, aortic dilation and distal reoperation

Logistic regression identified that the risk factors for operative mortality were extra-anatomic bypass [odds ratio (OR), 229.592; 95% confidence interval (CI), 1.429–36,880.03; P=0.036]; preoperative DMax of the aortic sinuses (OR 1.134; 95% CI 1.011–1.271; P=0.032) and time of CPB (in minutes) (OR, 1.061; 95% CI, 1.003–1.123; P=0.041).

In Cox regression, predictors for distal aortic dilatation were the preoperative maximal aortic diameter (in mm)
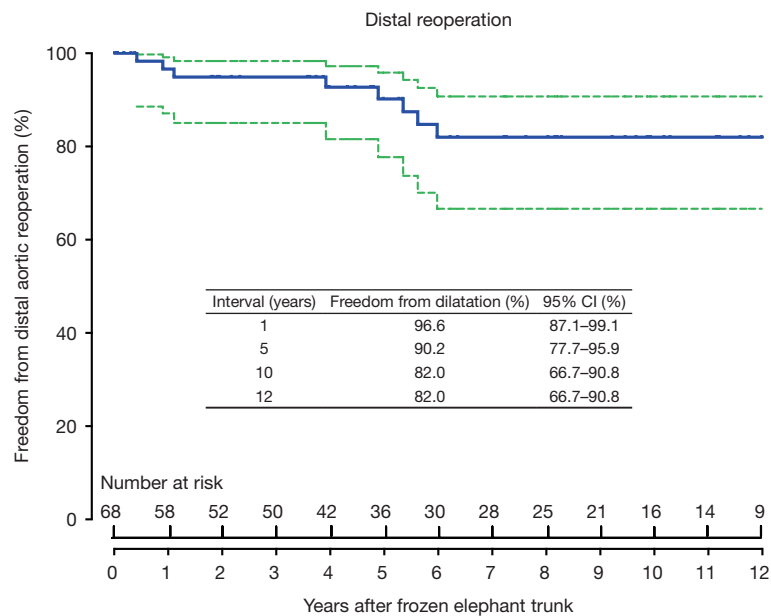
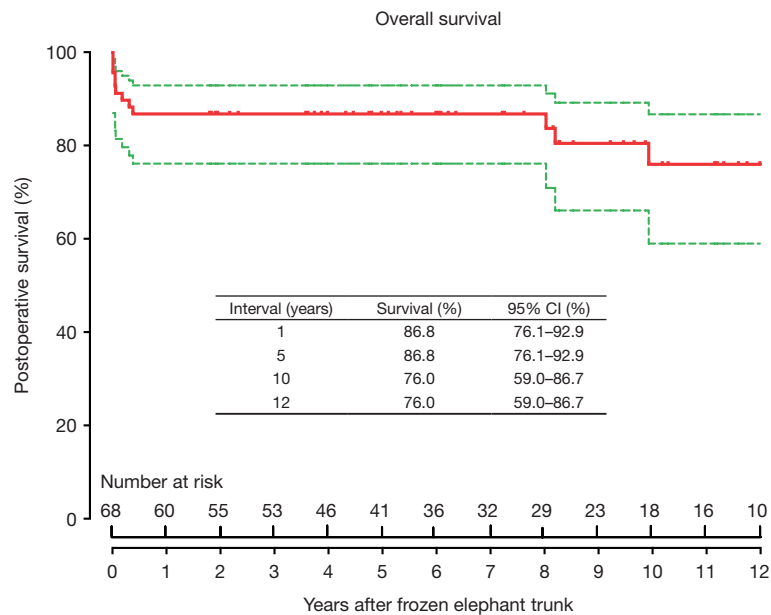**Figure 2** Freedom from distal aortic reoperation.

Figure 3 Overall survival.

of the proximal DAo (hazard ratio, HR, 1.068; 95% CI, 1.026–1.112; P=0.001) and at the renal arteries (HR, 1.102; 95% CI, 1.030–1.178; P=0.005), and patent false lumen at the diaphragmatic hiatus (HR, 5.374; 95% CI, 1.537–18.788; P=0.008).

The maximal aortic size at the renal arteries (mm) was

predictive of late reoperation (HR, 1.149; 95% CI, 1.059–1.247; P=0.001).

The risk factors for late death were the duration from symptom onset to operation (in days) (HR, 1.002; 95% CI, 1.001–1.003; P=0.004), and the time of CPB (in minutes) (HR, 1.032; 95% CI, 1.002–1.063; P=0.036) (*Table 5*).

Figure 4 Survival in patients with subacute and chronic type A aortic dissection (TAAD).
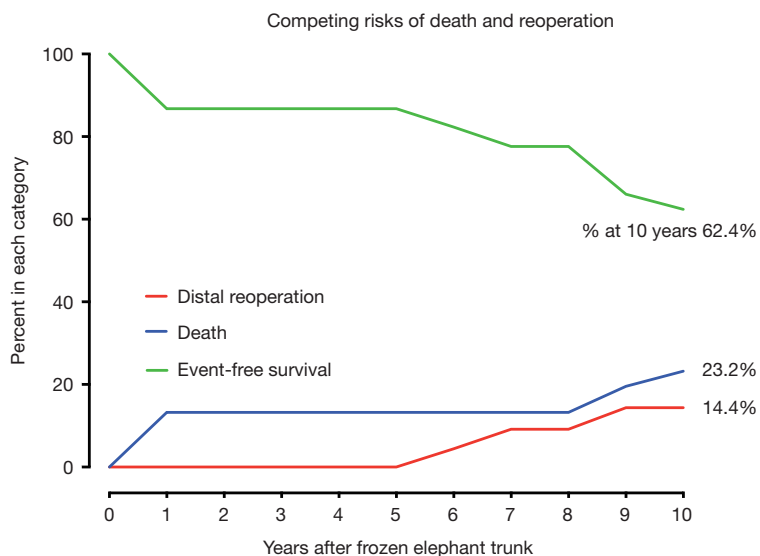

Figure 5 Competing risks of death and distal reoperation.

Discussion

While the majority of patients with TAAD are treated surgically upon presentation (24), only a small proportion of such patients experience delayed diagnosis and treatment. Therefore, cTAADs remain a rare and highly elusive entity, and, consequently, clinical experience is limited (2), especially in patients with connective tissue disorders.

In this series, 94.1% of patients were undiagnosed and untreated during the acute phase and survived despite the lack of therapy. Possible reasons include lack of or atypical symptoms, limited extent of dissection, and initial admission at a local nontertiary hospital without an aortic team (25). TAAD was an occasional finding in 5.9% and the pain was either "slight" or "transient" in 29.4% of patients, which suggests that patients with MFS may be more likely to

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Table 5 Risk factors for adverse events

Endpoint/Risk factor	Odds or hazard ratio	95% CI	P value
Operative mortality			
Extra-anatomic bypass	229.592	1.429–36,880.026	0.036
Preoperative DMax of aortic sinus (mm)	1.134	1.011–1.271	0.032
Cardiopulmonary bypass time (min)	1.061	1.003–1.123	0.041
Operative complications			
Extra-anatomic bypass	24.776	2.336–262.789	0.008
Cardiopulmonary bypass time (min)	1.016	1.001–1.030	0.032
Iliac artery extension	4.934	0.849–28.677	0.075
Proximal descending intimal tear	6.129	0.812–46.279	0.079
Distal aortic dilatation			
Preoperative DMax of proximal DAo (mm)	1.068	1.026–1.112	0.001
Preoperative DMax at renal arteries (mm)	1.102	1.030–1.178	0.005
Patent false lumen at diaphragm hiatus	5.374	1.537–18.788	0.008
Distal aortic reoperation			
Preoperative DMax at renal arteries (mm)	1.149	1.059–1.247	0.001
Late death			
Time from onset to surgery (day)	1.002	1.001–1.003	0.004
Cardiopulmonary bypass time (min)	1.032	1.002–1.063	0.036

CI, confidence interval; DAo, descending aorta; DMax, maximal aortic size.

present with less severe or no pain (26).

Morphologically, chronic aortic dissections are characterized by dilation of the aorta, continued false lumen patency, thickening and immobility of the intimal flap, increased fibrosis in the media and deceleration of remodeling over time (2). Clinical experience with cTAAD is limited to a few studies (3-5) and current guidelines recommend surgery for patients with cTAAD when the ascending aortic diameter exceeds 55 mm (1). However, the optimal surgical procedure for cTAADs involving the distal arch or DAo and the timing of repair remain unclear in patients with MFS (27).

The thickened and stiffened dissection flap, and the small true lumen compressed by the false lumen in cTAAD increased the technical complexity and mortality risk of surgical repair (12). In this context, the FET technique is particularly well-suited for covering the proximal entry tear and alleviating or delaying distal aortic dilation (28,29). In this series, operative mortality was 10.3%, stroke rate

1.5%, and no spinal cord injury occurred; at 10 years, 60% were free from distal aortic dilation, while the cumulative incidences were 23.2% for death, 14.4% for distal reoperation, and 62.4% were alive without reoperation. These favorable results demonstrate the safety and efficacy of the FET technique for cTAAD in MFS, providing evidence for use of this extensive approach in such patients.

Nevertheless, an extra-anatomic bypass was found to increase the mortality risk drastically (OR, 229.6), leading to four among seven operative deaths in this series. Preoperative CT scan showed a narrowed true lumen compressed by an enlarged false lumen in all these patients, who also had a dilated thoracoabdominal aorta and sustained lower extremity or visceral ischemia. As a result, extra-anatomic bypass, endovascular stenting or TAAAR was necessitated as a bailout procedure, which markedly increased the risk for mortality and morbidity. This implies that the FET may be not as efficacious in expanding the true lumen in the chronic phase as in the acute phase, when

the intimal flap is more mobile and flexible (21). Therefore, the distal aorta of patients with a small true lumen should be carefully evaluated preoperatively and preemptive extra-anatomic bypass and endovascular stenting of distal aorta be considered beforehand to minimize the surgical risks (7,30).

The natural history of cTAAD is dependent on several factors, such as patient age, the baseline aortic size, extent of dissection, false lumen patency, presence of a persistent communication, growth rate and control of hypertension (3,31). In patients with connective tissue disorders, degeneration of the medial layer weakens the aortic wall and predisposes the aorta to dilatation, dissection and rupture. In this study, although overall survival did not differ significantly between patients operated on during the subacute (15–90 days) and chronic phases (after 90 days), the time from onset of symptoms to surgery was identified as a risk factor of late death. Given the limited efficacy of FET for true lumen expansion as shown in this cohort and the cumulative risk of adverse aortic events over time in young patients (3), we recommend that cTAAD should be repaired using the TAR and FET technique as early as possible, even at smaller aortic sizes in patients with MFS.

The study is limited by its retrospective nature, small sample size and the lack of a control group. With a larger number of patients, the difference in overall survival may become significant between the subacute and chronic groups. The extended period before surgery represents a selection bias occurring before referral to our team, whereby the less severe and complicated cases were more likely to have been managed by other hospitals, while the more severe and complicated cases to be referred and to reach our institution.

Conclusions

The TAR and FET technique is a safe and efficacious approach to cTAAD in patients with MFS, which achieved favorable early and late survival, and freedom from reoperation and dilatation. Given that the preoperative aortic size and duration from onset to surgery are predictive of early and long-term adverse events, earlier repair of cTAAD using the FET and TAR is recommended for such patients, even at smaller aortic sizes.

Acknowledgments

Footnote

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