Frozen elephant trunk with total arch replacement for type A aortic dissections: Does acuity affect operative mortality?

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Objective: We seek to compare the early outcomes of frozen elephant trunk with total aortic arch replacement using a 4-branched graft (the Sun procedure) in patients with acute and chronic type A aortic dissection (TAAD), identify the risk factors for operative mortality, and determine whether the acuity of TAAD significantly affects operative mortality.

Methods: We performed univariate and multivariate analyses of the clinical data from 803 patients with TAAD who underwent the Sun procedure.

Results: The operative mortality was 6.5% (52 of 803). The overall incidence of stroke and spinal cord injury was 2.0% (16 of 803) and 2.4% (19 of 803), respectively. Patients with acute TAAD had a greater incidence of operative death (8.1% vs 4.3%; $P = .031$), stroke (2.2% vs 0.6%; $P = .046$), and respiratory morbidities (20.8% vs 8.6%; $P < .001$). However, acuity was not identified as a risk factor for operative mortality (odds ratio [OR], 1.67; $P = .152$). The risk factors were previous cerebrovascular disease (OR, 7.01; $P = .001$); malperfusion of the brain (OR, 7.10; $P = .002$), kidneys (OR, 12.67; $P = .005$), spinal cord (OR, 22.79; $P = .008$), and viscera (OR 22.98; $P = .002$); concomitant extra-anatomic bypass (OR, 9.50; $P < .001$); and cardiopulmonary bypass time >180 minutes (OR, 1.01; $P < .001$).

Conclusions: In this group of patients with type A dissection, acuity was not a risk factor for operative mortality after the Sun procedure. Patients with previous cerebrovascular disease; malperfusion of the brain, kidneys, spinal cord, and/or viscera; concomitant extra-anatomic bypass; and a longer cardiopulmonary bypass time (>180 minutes) were at greater risk of operative mortality. (J Thorac Cardiovasc Surg 2014;148:963-72)

Stanford type A aortic dissection (TAAD) remains one of the most lethal conditions and is associated with significant morbidity and mortality. The patient is at the greatest risk in the acute phase, within 14 days of the initial event, when

complications resulting from hemorrhage or rupture are most likely.^{1,2} Although the past 2 decades have seen advances in surgical techniques and postoperative care, evidence for improved outcomes has been modest,³ and several contentious issues remain in the surgical treatment of patients with TAAD. The most fundamental issue is the optimal surgical approach, especially the extent of the distal aortic repair.⁴⁻⁶ Some surgeons have advocated a more limited approach, such as ascending aortic or hemiarch repair,⁶ and others have supported the frozen elephant trunk (FET) technique,⁷⁻⁹ which has considerably improved the clinical outcomes of TAADs involving the aortic arch and proximal descending aorta.^{10,11} However, surgical opinion has been divided on the use of this extensive approach for patients with TAAD.^{3,7,8,12,13} The event of acute dissection itself is the dominant risk factor, just as is the need for preoperative resuscitation.^{3,14} This raises another concern that surgical repair in the acute phase is associated with greater operative mortality than in the chronic phase, which was evidenced by the report of Safi and colleagues,¹ which showed an operative mortality of 20% in those with acute and 4% in those with chronic TAAD.

For those reasons, we retrospectively analyzed the early outcomes of FET with total aortic arch replacement using a 4-branched graft (ie, the Sun procedure)¹⁵⁻¹⁸ in 803

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Abbreviations and Acronyms

CPB	= cardiopulmonary bypass
FET	= frozen elephant trunk
OR	= odds ratio
TAAD	= type A aortic dissection

consecutive patients with TAAD treated by our group. We compared the early outcomes between the acute and chronic TAAD groups after the Sun procedure to identify the risk factors for operative mortality in both groups and whether the acuity of aortic dissection significantly affects the operative mortality with this extensive surgical approach for TAADs.

METHODS

The ethics committees of Fu Wai Hospital and Cardiovascular Institute and Beijing Anzhen Hospital, Capital Medical University approved the present retrospective study.

Patients

From April 2003 to September 2012, our group performed the Sun procedure for 803 patients with TAAD. Their mean age was 46.1 ± 10.8 years (range, 17-78), and 640 (79.7%) were male. Based on the interval between symptom onset and surgery,² acute TAAD (≤ 14 days) was diagnosed in 456 patients and chronic TAAD (> 14 days) in 347. In those with acute TAAD, the interval was 5.0 ± 3.8 days (median, 4; range, 5 hours to 14 days). Also, within the first 10 hours after dissection onset, 30 of the 456 patients (6.6%) presented and 6 (1.3%) underwent surgery. The median interval from symptom onset to surgery in those with chronic TAAD was 37 days (mean, 189; range, 14.2 days to 10 years). A preoperative diagnosis of TAAD was confirmed by transthoracic echocardiography or computed tomographic angiography in all patients.

A total of 101 cases (12.6%) of clinically apparent malperfusion occurred in 88 patients (10.9%), with 56 (12.3%) and 32 (9.2%) in the acute and chronic groups, respectively. Lower limb malperfusion was most common (6.0%, 48 of 803), followed by cerebral (2.6%, 21 of 803), coronary (1.7%, 14 of 803), renal (0.9%, 7 of 803), and visceral ischemia (0.9%, 7 of 803; Table 1).

Selection Criteria

In patients with TAAD, the Sun procedure was indicated in any of the following pathologic conditions: (1) primary entry located in the arch or descending aorta; (2) severe arch vessel pathologic features, including dissection, occlusion, stenosis, or aneurysm changes; (3) intimal intussusception in the arch; (4) concomitant Marfan syndrome; and (5) dissection in a dilated arch > 4 cm in diameter and extending beyond the descending aorta.¹⁹ For patients with none of these conditions, a different approach would be proposed, such as ascending aortic or hemiarch repair or total arch repair without FET.²⁰ For patients with TAAD who had the pathologic indications but developed malperfusion preoperatively, this procedure would still be performed, as long as no end-organ failure had occurred, such as coma, paraplegia, hemiplegia, intestinal necrosis, or hepatic failure. Senior age was not a contraindication.

Surgical Techniques

The Sun procedure refers to total aortic arch replacement using a 4-branched vascular graft combined with implantation of a specially designed FET into the descending aorta.¹⁵⁻¹⁸ The surgical technique has

been previously described in detail.¹⁵⁻²³ In brief, it is performed with right axillary artery cannulation for cardiopulmonary bypass (CPB) and selective antegrade cerebral perfusion, under moderate hypothermic circulatory arrest at 25°C. The procedure involves implantation of an FET (Cronus; MicroPort Medical Co, Ltd, Shanghai, China) in the descending aorta, followed by total arch replacement with a 4-branched vascular graft. A special sequence is used for aortic reconstruction (ie, proximal descending aorta, then left carotid artery, then ascending aorta, then left subclavian artery, and, finally, innominate artery). Early rewarming and reperfusion is performed after the distal anastomosis to minimize the cerebral and coronary ischemia. Associated operations, such as aortic root replacement or coronary artery bypass grafting, are performed during the cooling phase, if indicated.

Definition of Outcomes and Risk Factors

The endpoint was operative mortality, including all deaths, regardless of cause, occurring during the same hospitalization in which the operation was performed, even if after 30 days; and after discharge from the hospital but within 30 postoperative days. Stroke was defined as any confirmed neurologic deficit of abrupt onset caused by a disturbance in blood supply to the brain lasting > 24 hours. Coronary artery disease was documented by preoperative computed tomographic angiography or from a history of myocardial infarction or coronary angiographic findings, or percutaneous coronary interventions. Renal failure was defined as an increase in serum creatinine of 1 mg/dL greater than baseline or a new requirement for renal dialysis. Malperfusion syndrome was defined as end-organ ischemia caused by branch vessel involvement and resulting in clinical symptoms and functional impairment.

Statistical Analysis

The data were analyzed using the Statistical Package for Social Sciences for Windows, version 13.0 (SPSS Inc, Chicago, Ill). Data are expressed as the mean $\pm$ standard deviation or percentages and were compared using the Student *t* test, Pearson chi-square test, or Fisher exact test, as appropriate. Univariate analysis was used to evaluate variables that could affect operative mortality in both groups. Variables with $P < .05$ on univariate analysis were assessed with multivariate analysis using a forward stepwise binary logistic regression model. All statistical tests were 2-sided.

RESULTS**Operative Data**

The location of an intimal tear was confirmed during surgery (Table 2). An intimal tear in the aortic arch was found only in the patients with acute TAAD ($n = 92$, 20.2%). The patients with chronic TAAD had more tears in the descending aorta (106 of 347, 30.5%) than did those with acute TAAD (101 of 456, 22.1%; $P = .007$) and had more unidentifiable tears (43 of 347, 12.4%) than did those with acute TAAD (17 of 456, 3.7%; $P > .001$). Aortic root or valve procedures were performed in 221 patients (48.5%) with acute and 163 patients (47.0%) with chronic TAAD, including aortic valve repair in 63 (13.8%) and 22 (6.3%; $P = .001$) and the Bentall operation in 130 (28.5%) and 119 (34.3%), respectively. A total of 109 concomitant operations were done in 102 patients (12.7%), including coronary artery bypass grafting in 43 (9.4%) and 24 (6.9%), extra-anatomic bypass in 11 (2.5%) and 16 (4.6%), and mitral valve surgery in 2 (0.4%) and 13 (3.7%) patients in the acute and chronic groups, respectively. The CPB, crossclamp, and selective

TABLE 1. Preoperative clinical profiles

Variable	Acute (n = 456)	Chronic (n = 347)	P value
Age (y)	46.2 ± 10.5	45.9 ± 11.2	.063
Age group (y)			.750
<40	126 (27.6)	100 (28.8)	.711
40-49	156 (34.2)	112 (32.3)	.565
50-59	127 (27.9)	92 (26.5)	.673
≥60	47 (10.3)	43 (12.4)	.554
Sex			.026
Male	376 (82.5)	264 (76.1)	
Female	80 (17.5)	83 (23.9)	
Comorbidities			
Hypertension	333 (73.0)	228 (65.7)	.025
Marfan syndrome	34 (7.5)	52 (15.0)	.001
Diabetes mellitus	14 (3.1)	10 (2.9)	.877
Coronary artery disease	18 (3.9)	31 (8.9)	.003
Cerebrovascular disease	12 (2.6)	11 (3.2)	.650
Chronic kidney disease	10 (2.2)	10 (2.9)	.535
Congestive heart failure	1 (0.2)	2 (0.6)	.812
Malperfusion syndrome*	56 (12.3)	32 (9.2)	.169
Cerebral malperfusion	13 (2.8)	8 (2.3)	.631
Coronary malperfusion	9 (2.0)	5 (1.4)	.568
Renal malperfusion	7 (1.5)	0 (0)	.053
Spinal cord malperfusion	3 (0.6)	1 (0.3)	.817
Visceral malperfusion	6 (1.3)	1 (0.3)	.243
Lower limb malperfusion	27 (5.9)	21 (6.0)	.938
≥2 Organs	8 (1.8)	4 (1.2)	.486
Acute heart failure	7 (1.5)	0 (0)	.053
Cardiac tamponade	15 (3.3)	1 (0.3)	.003

Data presented as mean ± standard deviation or n (%). *Number of patients in whom clinically apparent malperfusion occurred; malperfusion of ≥2 organs expressed by the number of cases that actually occurred.

cerebral perfusion times in the acute group were remarkably longer than the those in the chronic group (199 ± 50 vs 184 ± 52 minutes, $P < .001$; 112 ± 47 vs 98 ± 29 minutes, $P < .001$; and 25 ± 8 vs 24 ± 8 minutes, $P = .038$, respectively). Prolonged aortic crossclamp (>100 minutes) and CPB (>180 minutes) times occurred predominantly in the acute group ($P < .001$).

Operative Mortality and Morbidity

The overall operative mortality was 6.5% (52 of 803), including 15 deaths (4.3%) in the chronic and 37 (8.1%) in the acute group, respectively ($P = .031$). The leading cause of death was multiorgan failure, identified in 24 of the 52 patients (46.2%); of the 24 deaths, 16 were in the acute TAAD group (3.5% of 456). Stroke and low cardiac output syndrome led to 9 (2.0%) and 7 (1.5%) deaths in the acute group compared with 1 (0.3%) and 3 (0.9%) deaths in the chronic group. Three patients (0.4%) died of acute renal failure. Other causes of death included respiratory failure, cardiac arrest, mediastinal infection, abdominal aortic rupture, and coagulopathy (n = 1 for each; Table 3).

TABLE 2. Operative data

Variable	Acute (n = 456)	Chronic (n = 347)	P value
Intraoperative findings			
Location of intimal tear			<.001
Ascending aorta	202 (44.3)	152 (43.8)	.889
Transverse arch	92 (20.2)	0 (0)	<.001
Descending aorta	101 (22.1)	106 (30.5)	.007
Multiple locations	44 (9.6)	46 (13.3)	.108
Unidentified	17 (3.7)	43 (12.4)	<.001
Procedural times			
Cardiopulmonary bypass time (min)	199 ± 50	184 ± 52	<.001
>180 min	274 (60.1)	165 (47.6)	<.001
Crossclamp time (min)	112 ± 47	98 ± 29	<.001
>100 min	250 (54.8)	136 (39.2)	<.001
Selective cerebral perfusion time (min)	25 ± 8	24 ± 8	.038
>25 min	157 (34.4)	108 (31.1)	.115
Aortic valve or root procedures	221 (48.5)	163 (47.0)	.782
Aortic valve repair	63 (13.8)	22 (6.3)	.001
Repair of sinus of Valsalva	19 (4.2)	6 (1.7)	.049
David procedure	1 (0.2)	0 (0)	.999
Aortic valve replacement	5 (1.1)	5 (1.4)	.909
Bentall procedure	130 (28.5)	119 (34.3)	.079
Cabrol procedure	1 (0.2)	5 (1.4)	.115
Wheat procedure	2 (0.4)	6 (1.7)	.143
Concomitant procedures*	53 (11.6)	49 (14.1)	.292
Coronary artery bypass grafting	43 (9.4)	24 (6.9)	.202
Extra-anatomic bypass	11 (2.4)	16 (4.6)	.087
Ascending aortic-to-femoral	6 (1.3)	9 (2.6)	.185
Ascending aortic-to-axillary	1 (0.2)	0 (0.0)	.999
Ascending-to-abdominal aortic	1 (0.2)	2 (0.6)	.812
Femoral-to-femoral	3 (0.7)	4 (1.2)	.716
Axillary-to-femoral	0 (0)	1 (0.3)	.432
Mitral valve operation	2 (0.4)	13 (3.7)	.001
Replacement	2 (0.4)	10 (2.9)	.005
Repair	0 (0)	3 (0.9)	.160

Selective cerebral perfusion time refers to the interval from initiation of hypothermic circulatory arrest to completion of left carotid anastomosis, which is longer than the time for deep hypothermic circulatory arrest, when lower body perfusion is arrested to implant the frozen elephant trunk and suture the proximal descending anastomosis.

*Number of patients in whom concomitant procedures were performed; specific procedures are expressed by the number of cases.

Patients with malperfusion had an overall mortality of 19.3% (17 of 88), predominantly in the acute group (25.0%, 14 of 56 vs 9.4%, 3 of 32; $P < .001$). The major reasons were multiorgan failure in 8, stroke in 4, low cardiac output syndrome in 2, and acute renal failure in 2. Malperfusion of ≥2 organs occurred in 8 (1.8%) and 4 (1.2%) patients in the acute and TAAD groups, respectively, with 5 deaths (62.5%) exclusively in the acute group (Table 4).

The operative mortality rate did not differ significantly, either among 4 age groups in the acute ($P = .185$) and chronic ($P = .927$) groups or between the acute and chronic groups in the 4 age groups ($P > .05$). Patients with acute TAAD who were ≥60 had a mortality of 12.8% (6 of 47),

TABLE 3. Operative mortality and morbidity

Variable	Acute (n = 456)	Chronic (n = 347)	P value
Mortality	37 (8.1)	15 (4.3)	.031
Multiorgan failure	16 (3.5)	8 (2.3)	.321
Stroke	9 (2.0)	1 (0.3)	.070
Low cardiac output syndrome	7 (1.5)	3 (0.9)	.598
Acute renal failure	2 (0.4)	1 (0.3)	1.000
Abdominal aortic rupture	0 (0)	1 (0.3)	.432
Cardiac arrest	0 (0)	1 (0.3)	.432
Respiratory failure	1 (0.2)	0 (0)	1.000
Mediastinal infection	1 (0.2)	0 (0)	1.000
Coagulopathy	1 (0.2)	0 (0)	1.000
Morbidity			
Neurologic	28 (6.1)	16 (4.6)	.345
Stroke	13 (2.8)	3 (0.9)	.046
Spinal cord injury	11 (2.4)	8 (2.3)	.941
Paraplegia	7 (1.5)	2 (0.6)	.201
Paraparesis	4 (0.9)	6 (1.7)	.449
Recurrent laryngeal nerve injury	4 (0.9)	5 (1.4)	.679
Pulmonary*	95 (20.8)	30 (8.6)	<.001
Prolonged ventilation	84 (18.4)	26 (7.5)	<.001
Reintubation	33 (7.2)	12 (3.5)	.021
Pneumonia	8 (1.8)	2 (0.6)	.242
Pleural effusion	2 (0.4)	0 (0)	.509
Pneumothorax	1 (0.2)	1 (0.3)	1.000
Renal failure	18 (3.9)	9 (2.6)	.292
Low cardiac output syndrome	7 (0.8)	6 (1.7)	.829
Limb ischemia	3 (0.7)	4 (1.2)	.716
Reintervention	20 (4.4)	20 (5.8)	.374
Reexploration for bleeding	10 (2.2)	15 (4.3)	.085
Pericardial drainage for effusion	5 (1.1)	2 (0.6)	.687
Thoracoabdominal aortic replacement	0 (0)	2 (0.6)	1.000
Endovascular stent grafting for distal tear	2 (0.4)	1 (0.3)	1.000
Axillary-to-axillary bypass	1 (0.2)	0 (0)	1.000
Amputation	1 (0.2)	0 (0)	1.000
Redo Bentall procedure	1 (0.2)	0 (0)	1.000

*Number of patients in whom pulmonary complications occurred; specific morbidities are expressed by the number of cases that actually occurred.

greater than that in the other age groups but without statistical significance ($P = .185$; Table 5).

The patients with acute TAAD had a greater incidence of stroke (13 of 456, 2.2%, vs 3 of 347, 0.6%; $P = .046$) and respiratory complications (95 of 456, 20.8%, vs 30 of 347, 8.6%; $P < .001$). The overall incidence of stroke and spinal cord injury was 2.0% (16 of 803) and 2.4% (19 of 803), respectively. Stroke occurred in 13 (2.2%) and 3 (0.6%; $P = .046$) and caused 9 (69.2%) and 1 (33.3%) deaths in the acute and chronic groups, respectively. Spinal cord injury occurred in 11 (2.4%) and 8 (2.3%) patients with acute and chronic TAAD, respectively ($P > .05$), including paraplegia in 7 (1.5%) and 2 (0.6%) and paraparesis in 4 (0.9%) and 6 (1.7%). Albeit present only in 13 (1.6%) of the 803 patients, low cardiac output syndrome caused 7 of 7 deaths (100%) in the acute and 3 of 6 (50.0%) in the

TABLE 4. Mortality in patients with malperfusion syndrome

Pt. no.	Acuity	Malperfusion type	Cause of death
1	Acute	Renal	Acute renal failure
2	Acute	Renal, cerebral, visceral	Multiple organ failure
3	Acute	Spinal cord, lower limb	Stroke
4	Acute	Visceral	Stroke
5	Acute	Cerebral, visceral	Multiple organ failure
6	Acute	Spinal cord, lower limb	Multiple organ failure
7	Acute	Lower limb	Multiple organ failure
8	Acute	Cerebral, visceral	Multiple organ failure
9	Acute	Cerebral	Low cardiac output syndrome
10	Acute	Coronary	Low cardiac output syndrome
11	Acute	Cerebral	Stroke
12	Acute	Renal	Acute renal failure
13	Acute	Coronary	Coagulopathy
14	Acute	Coronary	Multiple organ failure
15	Chronic	Cerebral	Multiple organ failure
16	Chronic	Visceral	Multiple organ failure
17	Chronic	Cerebral	Stroke

Pt. no., Patient number.

chronic groups. Renal failure occurred in 27 (3.4%), with 18 (3.9%) in the acute and 9 (2.6%) in the chronic group ($P > .05$). The overall incidence of recurrent laryngeal nerve injury and limb ischemia was 1.1% (9 of 803) and 0.9% (7 of 803), respectively. Prolonged ventilation >48 hours was required in 84 patients (18.4%) in the acute versus 26 (7.5%) in the chronic group ($P < .001$). Tracheal reintubation occurred in 33 (7.2%) with acute and 12 (3.5%) with chronic TAAD ($P = .021$). Pneumonia occurred in 10 patients (1.2%), pneumothorax in 2 (0.2%), and pleural effusion in 2 (0.2%; Table 3).

Postoperative reintervention was required in 40 patients (5.0%), 20 in each group. Reexploration for bleeding was required in 25 patients (3.1%), and drainage of pericardial effusion in 7 (0.9%). An intimal tear at the distal end of the open stent graft necessitated endovascular stent grafting in 3 cases. Other reoperations included thoracoabdominal aortic repair in 2 patients with chronic TAAD, a redo Bentall procedure for aortic root bleeding in 1, an axillary to axillary bypass for left arm ischemia in 1, and an amputation for left leg thrombotic necrosis in 1 (Table 3).

TABLE 5. Operative mortality specific to age group in acute and chronic groups

Acuity	Age group-specific mortality (deaths/total patients)				P value
	<40 y	40-49 y	50-59 y	≥60 y	
Acute (n = 37)	9/126 (7.1)	8/156 (5.1)	14/127 (11.0)	6/47 (12.8)	.185
Chronic (n = 15)	4/100 (4.0)	4/112 (3.6)	5/92 (5.4)	2/43 (4.7)	.927
P value*	.314	.543	.147	.327	—

Data in parentheses are percentages. *Comparison of mortality in any age group between acute and chronic groups.

TABLE 6. Univariate analysis of operative mortality in acute and chronic groups

Variable	Acute (n = 456)	Chronic (n = 347)	P value
Acuity group	37/419 (8.8)	15/347 (4.5)	.031
Sex			.104
Male	35/376 (9.3)	11/264 (4.2)	
Female	2/80 (2.5)	4/83 (4.8)	
Hypertension			.404
Yes	29/333 (8.7)	10/228 (4.4)	
No	8/123 (6.5)	5/119 (4.2)	
Marfan syndrome			.234
Yes	2/34 (5.9)	1/52 (1.9)	
No	35/422 (8.3)	14/295 (4.7)	
Diabetes mellitus			.191
Yes	0/14 (0)	0/10 (0)	
No	37/442 (8.4)	15/337 (4.5)	
Coronary artery disease			.917
Yes	1/18 (5.6)	2/31 (6.5)	
No	36/438 (8.2)	13/316 (4.1)	
Chronic heart failure			.648
Yes	0/1 (0)	0/2 (0)	
No	37/455 (8.1)	15/345 (4.3)	
Cerebrovascular disease			.031
Yes	4/12 (33.3)	0/11 (0)	
No	33/444 (7.4)	15/336 (4.5)	
Chronic renal failure			.786
Yes	0/10 (0)	1/10 (10.0)	
No	37/446 (8.3)	14/337 (4.2)	
Malperfusion (as an entity)			<.001
Yes	14/56 (25.0)	3/32 (9.4)	
No	23/400 (5.8)	12/315 (3.8)	
Renal malperfusion			<.001
Yes	3/7 (42.9)	0/0 (0)	
No	34/449 (7.6)	15/347 (4.3)	
Coronary malperfusion			.022
Yes	3/9 (33.3)	0/5 (0)	
No	34/447 (7.6)	15/342 (4.4)	
Cerebral malperfusion			<.001
Yes	5/13 (38.5)	2/8 (25.0)	
No	32/443 (7.2)	13/339 (3.8)	
Spinal cord malperfusion			<.001
Yes	2/3 (66.7)	0/1 (0)	
No	35/453 (7.7)	15/346 (4.3)	
Visceral malperfusion			<.001
Yes	4/6 (66.7)	1/1 (100)	
No	33/450 (7.3)	14/346 (4.0)	
Lower limb malperfusion			.948
Yes	3/27 (11.1)	0/21 (0)	
No	34/429 (7.9)	15/326 (4.6)	
Malperfusion of ≥2 organs			<.001
Yes	5/8 (62.5)	0/4 (0)	
No	32/448 (7.1)	15/343 (4.4)	
Acute heart failure			.017
Yes	2/7 (28.6)	0/0 (0)	
No	35/449 (7.8)	15/347 (4.3)	

(Continued)

TABLE 6. Continued

Variable	Acute (n = 456)	Chronic (n = 347)	P value
Cardiac tamponade			.002
Yes	4/15 (26.7)	0/1 (0)	
No	33/441 (7.5)	15/346 (4.3)	
Location of intimal tear			
Ascending aorta	15/202 (7.4)	7/152 (4.6)	.479
Aortic arch	9/92 (9.8)	0/0 (0)	.790
Descending aorta	9/101 (8.9)	6/106 (5.7)	.171
Multiple tears	4/44 (9.0)	0/46 (0)	.601
Unidentified	0/17 (0)	2/43 (4.7)	.406
Selective cerebral perfusion time			.575
>25 min	14/157 (8.9)	5/108 (4.6)	
<25 min	23/299 (7.7)	10/239 (4.2)	
Crossclamp time			.022
>100 min	24/250 (9.6)	9/136 (6.6)	
<100 min	13/206 (6.3)	6/211 (2.8)	
Cardiopulmonary bypass time			.014
>180 min	28/274 (10.2)	9/165 (5.5)	
<180 min	9/182 (4.9)	6/182 (3.3)	
Aortic valve or root procedures			.955
Aortic valve repair	3/63 (4.8)	0/22 (0)	.243
Repair of sinus of Valsalva	2/19 (10.5)	0/6 (0)	1.000
David procedure	0/1 (0)	0/0 (0)	1.000
Aortic valve replacement	0/5 (0)	0/5 (0)	.402
Wheat procedure	1/2 (50.0)	0/6 (0)	.487
Cabrol procedure	0/1 (0)	0/5 (0)	.518
Bentall procedure	13/130 (10.0)	6/119 (5.0)	.373
None	18/235 (7.7)	9/184 (4.9)	.955
Concomitant procedures			<.001
Yes	9/53 (17.0)	9/49 (18.4)	
No	28/403 (6.9)	6/298 (2.0)	
Coronary artery bypass grafting			.001
Yes	6/43 (14.0)	5/24 (20.8)	
No	31/413 (7.5)	10/323 (3.1)	
Mitral valve repair/replacement			.976
Yes	0/2 (0)	1/13 (7.7)	
No	37/454 (9.0)	14/334 (4.2)	
Extra-anatomic bypass			<.001
Yes	5/11 (45.5)	4/16 (25.0)	
No	32/445 (7.2)	11/331 (3.3)	

Data presented as deaths/total patients (%).

Univariate and Multivariate Analysis

Univariate analysis identified 16 variables associated with operative mortality and showed that the risk of operative mortality after the Sun procedure in those with acute TAAD was 1.95 times greater than that in those with chronic TAAD (odds ratio [OR], 1.95; 95% confidence interval [CI], 1.00-3.63; $P = .031$; Table 6). However, multivariate analysis failed to identify acuity as a risk factor (OR, 1.67; 95% CI, 0.83-3.38; $P = .152$). The risk factors for operative mortality were previous cerebrovascular disease (OR, 7.01; 95% CI, 2.16-22.73; $P = .001$); malperfusion of the brain (OR, 7.10; 95% CI, 2.08-24.21; $P = .002$), kidneys

TABLE 7. Difference in operative mortality between acute and chronic groups was not affected by acuity of aortic dissection but by 7 other risk factors

Variable	OR	95% CI	P value
Group (acute vs chronic)	1.67	0.83-3.38	.152
Previous cerebrovascular disease	7.01	2.16-22.73	.001
Spinal cord malperfusion	22.79	2.27-228.97	.008
Visceral malperfusion	22.98	3.23-163.38	.002
Renal malperfusion	12.67	2.11-75.97	.005
Cerebral malperfusion	7.10	2.08-24.21	.002
Extra-anatomic bypass	9.50	3.25-27.81	<.001
Cardiopulmonary bypass time	1.01	1.00-1.016	<.001
Coronary malperfusion	4.50	1.00-20.22	.050

OR, Odds ratio; CI, confidence interval.

(OR, 12.67; 95% CI, 2.11-75.97; $P = .005$), spinal cord (OR, 22.79; 95% CI, 2.27-228.97; $P = .008$), and viscera (OR, 22.98; 95% CI, 3.23-163.38; $P = .002$); concomitant extra-anatomic bypass (OR, 9.50; 95% CI, 3.25-27.81; $P < .001$); and CPB time >180 minutes (OR, 1.01; 95% CI, 1.00-1.016; $P < .001$). Coronary malperfusion may also affect operative mortality (OR, 4.50; 95% CI, 1.00-20.22; $P = .050$; Table 7).

DISCUSSION

During the past 2 decades, the surgical outcomes of TAAD have improved considerably and various techniques have been proposed for surgical repair. However, the operative mortality has remained high, and several aspects of surgical management remain controversial. The most important issue is the extent of distal aortic repair⁴⁻⁶ (ie, the use of a limited approach such as ascending/hemiarch repair⁶ or an extensive approach such as the FET technique⁸). Although it has been used more widely,^{8,10} the safety of FET in the acute setting remains debated,²⁴ owing to its technical complexity and longer cerebral perfusion and circulatory arrest times, which might increase the risk of mortality and neurologic events.^{12,13} Another important concern is that surgical repair in the acute phase of TAAD was reported to be associated with greater operative mortality than in the chronic phase.¹ The present study of the early outcomes after the Sun procedure in a large series of 803 patients with acute and chronic TAAD is helpful in addressing these 2 important issues.

First, the present study addressed the issue of the safety of the FET technique in patients with TAAD. The overall operative mortality was 6.5%, and the incidence of stroke and spinal cord injury was 2.0% and 2.4%, respectively. Except for respiratory morbidities, other postoperative complications such as renal failure, reexploration for bleeding, recurrent nerve injury, and limb ischemia were consistently infrequent, occurring in only 3.3%, 3.1%, 1.1%, and 0.9% of all patients, respectively. These early results have indicated that the Sun procedure is a safe

surgical approach for patients with acute and chronic TAAD and will possibly pave the way for wider use of the FET technique.²⁴ Moreover, in our previous series of 148 patients with acute TAAD, we achieved a mortality of only 4.7%, which compared favorably with that of a similar group of patients undergoing hemiarch repair, with a mortality of 6.1%.¹⁹ Uchida and associates⁹ also reported that the FET technique could be performed safely for acute TAAD and might reduce the need for reintervention on the residual false lumen. The results of both studies argue in favor of wider use of the extensive FET when determining the extent of distal repair for patients with TAAD.

Second, although the operative mortality of the Sun procedure was significantly greater in the acute group than in the chronic group (8.1% vs 4.3%, $P = .031$), multivariate analysis proved that acuity did not affect operative mortality (OR, 1.67; 95% CI, 0.83-3.38; $P = .152$) in this cohort. This is in agreement with the conclusion of Sabik and colleagues²⁵ that the acuity of dissection was not a risk factor for early mortality. In the present series of 803 patients with TAAD, the risk factors for operative mortality after the Sun procedure were previous cerebrovascular disease, malperfusion syndrome (including cerebral, renal, spinal cord, and visceral ischemia), extra-anatomic bypass, and a CPB time >180 minutes. These results imply that, in the absence of these risk factors, performing emergency FET with total arch replacement in the setting of acute TAAD will not impose a greater risk of operative mortality compared with an identical procedure performed electively in the setting of chronic TAAD. The present results add evidence that cardiovascular surgeons can safely use this more aggressive FET technique with total arch replacement for cases of acute type A dissections without the fear of worse outcomes for the patient. Because devices and systems are evolving toward an ideal open stent graft, with the accrual of evidence from registry data with longer follow-up,²⁶ FET with total arch replacement could become the next standard of care for patients with TAAD for whom arch repair is required.^{8,15,16,27}

The results of the present study have shown that FET with total arch replacement is not associated with greater early mortality and morbidity compared with totally conventional techniques. One of the reasons for such favorable outcomes might be the special FET used in this procedure, the Cronus (MicroPort Medical Co, Ltd). It can be implanted very easily and quickly, thereby decreasing the circulatory arrest time, as evidenced by the cerebral perfusion time of 25 ± 8 minutes in the present series, which was much shorter than the weighted value of 52 ± 31 minutes in the meta-analysis by Tian and associates.¹⁰ The technical simplicity results in a lower learning curve, which is very important for the wider and quicker spread of this approach in regions with

large patient populations. The sewing cuffs at the proximal and distal ends make anastomosis easier, which help minimize the risk of proximal endoleak and facilitate manipulations in subsequent operations, should any be required.¹⁶ An algorithm dictating surgical strategies using our subcategorization of the Stanford system that divides TAAD into subtypes might also have contributed to the better results of the Sun procedure.¹⁹

Focusing on the effect of patient age on outcome, we failed to identify age as a risk factor for operative mortality, similar to the results of Chiappini and associates.²⁸ The most likely reason for this paradoxical finding is the predominance of younger patients in our series, with only 90 of 803 patients (11.2%) aged ≥ 60 years. In contrast, one third of the patients in the International Registry of Aortic Dissection²⁹ and 29.9% in the German Registry for Acute Aortic Dissection Type A were aged ≥ 70 years.³⁰ However, in contemporary FET cohorts, the patients have also been relatively young, with a mean age of 45 to 61 years, irrespective of geographic differences.^{10,31,32} In a group of 355 patients with acute TAAD, Kimura and associates³³ found that the early and late surgical outcomes were not better in patients aged ≤ 45 years, with an increased risk of reoperation, possibly because ascending aortic or hemiarch replacement was performed in $>80\%$ of the patients. Their results conversely imply that the more extensive FET procedure should be chosen for younger patients.

Malperfusion phenomena have an incidence of 16% to 33%, and clinically apparent malperfusion of any type increases the mortality risk.^{3,34,35} In the present cohort, 4 of the 7 risk factors for operative mortality belonged to malperfusion syndrome, which occurred in 88 patients (10.9%) and led to a mortality of 19.3%, with even greater mortality (25.0%) in the acute group. Of all malperfusion phenomena, visceral malperfusion is the most lethal, heralding an extremely poor prognosis,³ as evidenced by a mortality of 71.4% (5 of 7) and a 23-fold increased risk of death (OR, 22.98). Spinal cord malperfusion carried almost the same risk (OR, 22.79), with a death rate of 50.0% (2 of 4). Renal malperfusion often responds well to aortic repair³ but increased the risk of death by 12.67 times in the present series, with a mortality of 42.8% (3 of 7). With an OR of 4.50, the effect of coronary malperfusion needs to be further validated in a larger sample with more events ($P = .050$). The results of the present study have highlighted the malignant effect of malperfusion on the clinical outcome of patients with TAAD. In many patients, malperfusion itself is an indication for aortic repair, which is expected to save life and reperfuse the ischemic organs. In some cases, reperfusion necessitates concomitant procedures, which will inevitably entail longer CPB, crossclamp, and circulatory arrest times, thus forming a vicious cascade of

“malperfusion $\rightarrow$ concomitant procedure $\rightarrow$ longer time of CPB, crossclamp, and circulatory arrest $\rightarrow$ higher mortality.” This has been corroborated by the results of multivariate analysis, in which malperfusion (of 4 organs), extra-anatomic bypass (to correct malperfusion), and the resultant longer CPB time were all identified as independent risk factors for operative mortality.

The present retrospective study had several limitations. First, $>80\%$ of our patients had been diagnosed at peripheral or remote hospitals and transferred for a long distance to our institution. Many patients with severe TAAD died of aortic rupture, tamponade, or malperfusion during transfer, while in the emergency room, or even while awaiting surgical repair. Thus, we were treating a group of less severe patients who had survived the initial attack of aortic dissection. Second, our patients were young, with a mean age of 46 years and only 11.2% of them aged ≥ 60 years, in contrast to the International Registry of Aortic Dissection²⁹ and German Registry for Acute Aortic Dissection Type A³⁰ registries in which $\geq 29.9\%$ of patients were aged ≥ 70 years. In the European series, the patients are “all comers,” with most of them presenting within the first few hours of dissection. In contrast, only 6.6% of our patients with acute TAAD presented within the first 10 hours of onset. Therefore, it was very difficult to make direct comparisons between our data and those from Europe and North America. Third, the results of the present study were certainly influenced by the vast experience gained by our group, which is the largest aortic surgical center in China, with an annual case volume of 1100. Such favorable conditions are not commonly found or replicated elsewhere. Most importantly, data of late survival and freedom from late distal reintervention were limited, and our efforts with long-term follow-up of patients are ongoing.

CONCLUSIONS

In the present group of patients with TAAD, acuity was not a risk factor for operative mortality of frozen elephant trunk and total arch replacement (the Sun procedure). Patients with previous cerebrovascular disease; malperfusion of the brain, kidneys, spinal cord, and viscera; concomitant extra-anatomic bypass, and longer cardiopulmonary bypass time (>180 minutes) had a greater risk of operative mortality.

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Discussion

Dr Malakh Lal Shrestha (Hannover, Germany). I want to congratulate you on your excellent presentation. Since Hans Borst did the first elephant trunk in 1982 in Hannover, the indications have obviously been expanded.

In 1989, our co-chair of this session, Professor Schäfers, performed the first elephant trunk implantation in acute aortic dissection. Since 2001, we have been doing the same as what you have been doing here, initially as a bailout procedure in the DeBakey type I dissection with intimal tears in the distal arch or proximal descending aorta. However, with more experience, we have also expanded our indications to clinically stable young patients with DeBakey type I dissections even without intimal tears or reentry in the distal arch or descending aorta.

As a high-volume center, what we have learned is that patients with acute and chronic aortic dissection are 2 totally different subsets of patients in terms of clinical presentation and mortality. The greatest danger to the patient with acute aortic dissection is during the first few hours immediately after the dissection, with most patients dying without surgical intervention.

In Germany, owing to the small geographic size compared with the United States and also to excellent emergency services, we receive patients within the first hour, sometimes 2 hours. Even then, when we operate, the mortality is still high. Also, we saw in the Aortic Symposium in New York that the German database shows that in >3000 patients, a difference in mortality exists whether you do an ascending aortic replacement or the FET; that is, a 10% difference, and it was 24% with FETs.

So, I would like to ask you a couple of questions. First, what is the duration in your case series from the occurrence of dissection

to surgery? Also, what was the percentage of patients coming within the first few hours?

The second question is, does your series include all comers, or was there some sort of preselection? Because if the patients come later on, whether you operate on them later or the patients are arriving later, it might be in terms of classification acute, but if they come after 4 days, that is a large difference from patients coming in the first day. Thank you.

Dr Ma. Thank you for your comments and questions. You have made inquiries on an important issue of our study. I am not sure if I understood your second question correctly, but I have an answer to your first question.

Please take a look at this table (in slide 6). The first line is the time from the onset of symptoms to the diagnosis. It was 3.2 ± 3.1 days on average in the acute group. In the chronic group, the mean time was almost 190 days.

The second line is the duration from diagnosis to surgery. It averaged 2 days, and the median time was 1 day in the acute group. So, most acute patients would have had to wait for 1 day before surgery.

The third line is the time from symptom onset to surgery, which was 5.0 ± 3.8 days in the acute group, with a median time of 4 days.

Dr Shrestha. So that means that on the basis of classification, you can still say it is acute. But there has been some sort of “natural selection.” So that means, I think at least for the title or the conclusion, you need to qualify the statement saying that no difference exists between acute and chronic, because it is obviously not the same subset of patients that we see in the Western world.

Dr Ma. Yes. Because about 80% of our patients were referrals, they were transferred from hundreds of miles away or even more remote areas. Therefore, many patients expired on the way to our hospital, in the emergency room, or even while awaiting surgery in the operating room. That is a result of natural selection.

Dr Shrestha. So that means that you would agree with me that in conclusion one cannot say that no difference exists between patients with acute and chronic type A dissection in terms of mortality, right? Because from the onset to surgery was 5 days or 5.5 on average; thus, it was not all comers. So perhaps if you are operating on patients on the first day, that is different than operating on these type of patients?

Dr Ma. Yes. If the patient could be operated on immediately after their arrival at the hospital, the operative mortality might increase.

Dr Shrestha. Thank you.

Dr D. Craig Miller (*Stanford, Calif*). This was, again, another wonderful presentation by Dr Ma of Dr Sun’s vast experience. As I asked Dr Sun a few days ago in New York at the Thoracic Aortic Summit, I continue to be totally flummoxed by why the average age here is 46, and even younger, for those with acute type A dissection. He answered that this was because of the many patients with severe hypertension. Clearly, they probably have an extremely high incidence of aortic dissection in China.

Respectfully, I still just do not understand this skewing of the population, meaning that the patients that arrive at your center in Beijing are so young. Is it because of economic reasons that the older patients are not being transferred to your hospital or not

undergoing surgery? Dr Sun told me in New York that the patients come from 1000, 2000, 3000 km away. Obviously, a lot of natural selection must be occurring just with a natural piece to the disease. I wonder if an economic selection is also occurring, such that only the younger middle class have the financial resources to reach your center and undergo surgery. I just do not understand why you have an average age that is ≥ 20 years younger than the European, North American, and South American series of acute type A dissection.

Dr Ma. I think hypertension is a disease related to the change in lifestyles and environment associated with rapid economic development and social alterations. Nowadays, many young people in China smoke tobacco and drink, they are obese and lack physical exercise, and many patients simply do not know they have hypertension at all. Also, even if some people know they have hypertension, their hypertension is not well controlled. Of course, there are many patients with Marfan syndrome or other connective tissue disorders as well. However, many of the elderly in China fortunately did not go through these rapid changes in lifestyle and environment that many young people have to experience. Thus, there are fewer seniors over 60 who suffered from hypertension, which also contributes to the predominance of young patients. I should note that there was no economic factor when we made treatment decisions for the older patients.

Dr Miller. In Japan, they also are very hypertensive, but their age of dissection is older than even in Europe and North America. I simply do not understand this skewed patient population; there must be other factors involved.

But, my main point here today is I think we have to move beyond the fact that “it can be done,” which Dr Sun and others have demonstrated. We have to determine which patient with acute type A dissection should undergo distal FET. Should it be just be those with a connective tissue disorder, who probably are at higher risk of late downstream aortic complications? Second, there is no “free lunch” here: we have to justify the increased risk (mainly paraplegia and death) incurred when one does something at the initial operation downstream in the descending aorta. In the large German Registry for Acute Aortic Dissection Type A registry, if the arch was replaced (with or without concomitant FET) electively without a compelling reason to do so, a 10% increment occurred in the operative mortality rate. So the main questions is whom should it be done in, not just can it be done safely. Does that make any sense to you?

Dr Ma. We have already initiated a study on those young patients 3 years ago and are seeking to identify some genetic causes in those younger patients. Also, we are striving to set up aortic surgical training centers across China, so that patients will not have to travel such a long distance to receive appropriate surgical management. In addition, our colleagues in cardiology and other specialties are trying hard to educate patients to have adequate control of their blood pressure.

Regarding which patients should undergo distal FET, we believe that those patients who are young, who are unlikely to come back for subsequent intervention on downstream aorta, and who are at continuing risk for distal aortic dilation and dissection (such as Marfan syndrome) may benefit most from the Sun operation because of the specifics of the Chinese patient population, their lifestyles, and risk factors.

Dr Miller. One last question. You have 550 patients with acute and subacute type A dissection; your point that these cases were not chronic dissections (many years after the initiating event) is important. How many of all these cases did not undergo a Sun procedure or distal FET?

Dr Ma. Because most of those patients were transferred from remote or peripheral hospitals, those peripheral or local hospitals might have kept the easier cases and referred those more complicated cases to us. That is 1 point.

Another point is, before 2009, we tended to do simpler operations, such as the hemiarch repair. Let me show you here on this slide (slide 16).

In this group of patients, 148 patients with acute dissection who underwent a Sun operation. The mortality after the Sun operation was 4.7%. In a similar group of 66 patients with acute

type A dissection who had a hemiarch repair, the mortality was 6.1%.

Dr Miller. What about today, does anybody not receive a Sun procedure at your center?

Dr Ma. Yes. If a patient with type A dissection does not have any of these 5 indications for the Sun procedure (listed on this slide [slide 7]), this patient will receive a different operation.

Dr Miller. A simpler operation?

Okay. How many of these patients did you have in the same period?

Dr Ma. As far as I can recall, the number was approximately 300. We looked it up in our database last year. There were about 300 such patients.

Dr Miller. So you do both, okay. Some day I will understand why they are so young. Thank you.

Dr Ma. Thank you.