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CLINICAL RESEARCH
Cardiac and vascular surgery

Frozen elephant trunk for acute type A aortic dissection: long-term outcomes over two decades

Wei-Guo Ma [1,2,3,†], Yu Chen [1,†], Su-Wei Chen [1], Wei Zhang [1], Jun Zheng [1,2], Qing-Guo Li [4], Lingeng Lu [5], Jun-Ming Zhu [1,2], Gabriele Piffaretti [6], John A. Elefteriades [3], and Li-Zhong Sun [1,2,7,*]

[1]Department of Cardiovascular Surgery, Beijing Anzhen Hospital of Capital Medical University, 2 Anzhen Road, Beijing 100029, China; [2]Department of Cardiovascular Surgery, Fu Wai Hospital and Cardiovascular Institute, Chinese Academy of Medical Sciences, 167 Northern Lishi Road, Beijing 100037, China; [3]Aortic Institute at Yale-New Haven, Yale University School of Medicine, 789 Howard Avenue, New Haven, CT, USA; [4]Department of Cardiovascular Surgery, Second Affiliated Hospital of Nanjing Medical University, Nanjing, China; [5]Department of Chronic Disease Epidemiology, Yale School of Public Health, New Haven, CT, USA; [6]Vascular Surgery—Department of Medicine and Surgery, University of Insubria, Varese, Italy; and [7]Department of Cardiovascular Surgery, DeltaHealth Shanghai Hospital, 109 Xule Road, Shanghai 201702, China

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Abstract

Background and Aims The management of acute type A aortic dissection (ATAAD) has evolved considerably over the decades and a more aggressive approach with extended arch repair has been increasingly adopted in the past 20 years. This study aims to evaluate the early and long-term outcomes of frozen elephant trunk and total arch replacement (FET + TAR) technique in patients with ATAAD.

Methods From April 2003 to December 2014, 850 patients with ATAAD (mean age 46.5 ± 10.7 years; 169 women [19.9%]; 136 with malperfusion syndrome [16.0%]) underwent FET + TAR at our center. Aortic root or valve procedures were performed in 456 patients (53.6%). The early and long-term outcomes of FET + TAR were analysed and compared to hemiarch repair in 72 propensity-matched pairs.

Results Operative mortality was 8.4% (71/850). Spinal cord injury occurred in 2.5% (21/850), stroke in 3.5% (30/850), re-exploration for bleeding in 5.6% (48/850) and acute kidney injury in 8.7% (74/850). Follow-up was complete in 99.2% (773/779) at mean duration of 12.5 ± 4.0 years (range .2–22.0). There were 153 late deaths and 90 reoperations at median 7.5 and 5.2 years (interquartile range 4.4–9.6 and 1.2–9.7), respectively. Cerebrovascular accident (hazard ratio [HR] 2.34; $P = .031$) and visceral ischaemia (HR 4.12; $P = .005$) were risk factors of late death. At 20 years, survival and freedom from reoperation were 70.0% and 85.4% (95% confidence interval [CI], 65.8%–74.0% and 80.1%–89.4%), respectively. In competing risks analysis, the incidences were 25%, 13% and 62% for death, reoperation and reoperation-free survival at 15 years, respectively. Compared to hemiarch repair, FET showed similar operative mortality (6.9% vs 4.2%, $P = .719$) and lower incidences of late adverse events (LAE), including death, reoperation and distal aortic dilation (16.4% vs 33.8%, $P = .048$), with significantly higher freedom from LAE at 20 years (78% vs 45.6%; 95% CI, 58.8%–89.0% vs 27.7%–61.8% $P = .042$).

Conclusions In this series spanning two decades, the FET + TAR technique achieved satisfactory long-term survival and freedom from reintervention in patients with ATAAD, showing lower risk of late death, reoperation and distal aortic dilation compared to hemiarch repair. These results argue favourably for the use of FET technique in ATAAD repair.

* Corresponding author. Tel: +86 10 6445 6168, Email: lizhongsun@outlook.com
† Drs. Chen and Ma contributed equally to this work

Structured Graphical abstract

Key Question

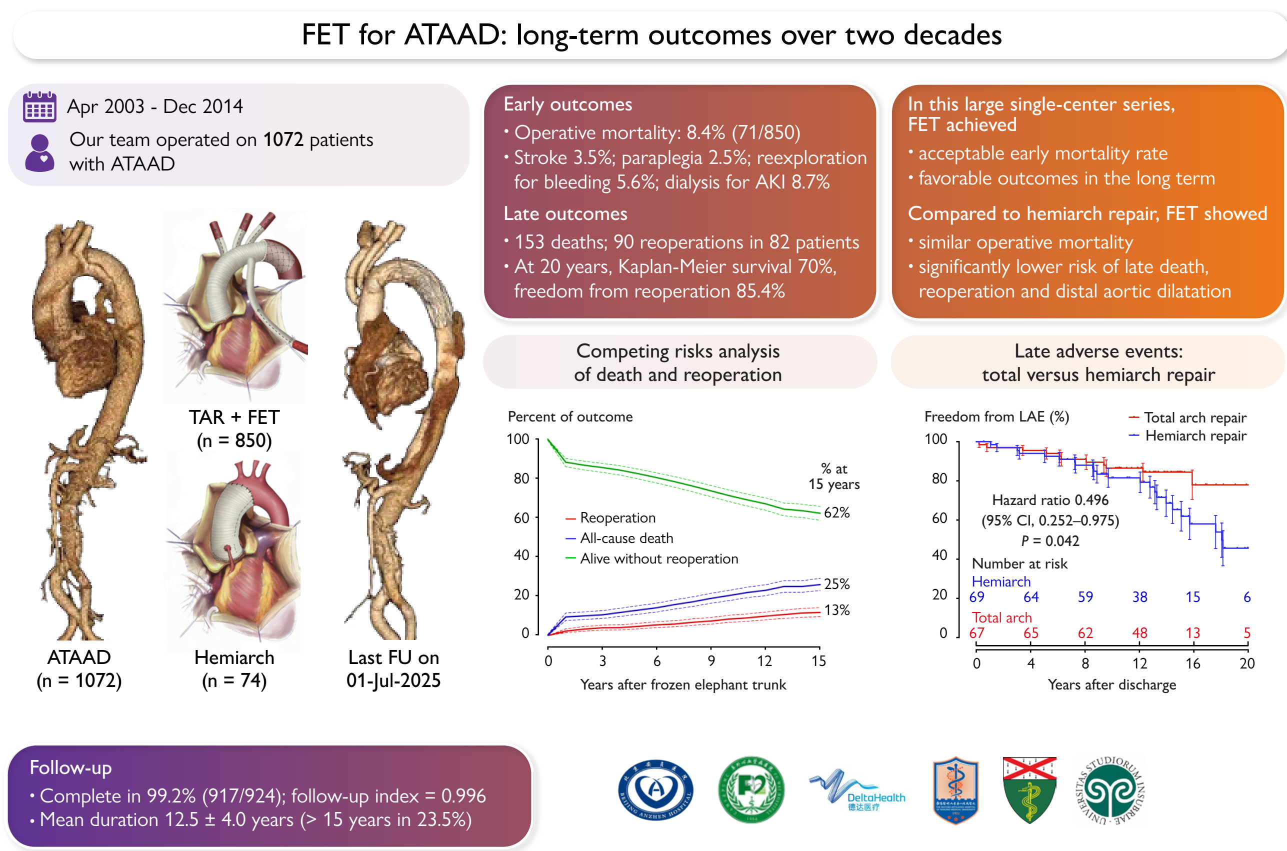
What are the safety and long-term efficacy and durability of the total arch repair with frozen elephant trunk technique (TAR + FET) in patients with acute type A aortic dissection (ATAAD)? How does TAR + FET compare to hemiarch repair?

Key Finding

In 924 patients with mean follow-up of 12.5 years (complete in 99%), TAR + FET showed an operative mortality of 8.4%, and achieved a survival of 70% and freedom from reoperation of 85% at 20 years. Compared to hemiarch repair, TAR + FET was associated with significantly lower risk of late death, reoperation and distal aortic dilatation (22% vs 54%; hazard ratio 0.5).

Take Home Message

TAR+FET may be the preferred approach over hemiarch repair in the management of ATAAD.



LAE was defined as a composite endpoint including all-cause mortality, reintervention and distal aortic dilatation that occurred after discharge

AKI, acute kidney injury; **ATAAD**, acute type A dissection; **CI**, confidence interval; **FU**, follow-up; **FET**, frozen elephant trunk; **LAE**, late adverse events; **TAR**, total arch repair

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The frozen elephant trunk technique showed superior long-term outcomes to hemiarch repair in patients with acute type A aortic dissection

Keywords Acute type A aortic dissection • Frozen elephant trunk • Total arch replacement • Hemiarch repair • Mortality • Survival • Reoperation

Introduction

Nowadays, surgical management of acute type A aortic dissection (ATAAD) is in a period of rapid transition,[1–5] owing to a deeper understanding of the significance of aortic valve (AV) function,[6] malperfusion,[7–9] false lumen patency[10] and risk of distal aortic dilatation to long-term prognosis. In many large-volume centres, the standard approach to surgical repair of ATAAD is now evolving from solely doing the simplest and fastest life-saving operation towards avoiding chronic complications and facilitating future open or endovascular reinterventions.[11] This has largely stimulated the adoption of the more extensive frozen elephant trunk (FET) technique, which has been increasingly used in the management of a variety of pathologies involving the aortic arch and descending aorta.[12–15] By estimation, four currently available FET prostheses have been implanted in over 185 000 patients worldwide (personal communication with manufacturers). However, despite the growing evidence supporting the safety of FET technique and its efficacy in aortic remodelling,[10,14,16–24] available data on its long-term outcomes in large series of patients with ATAAD are still scarce and few surpassed 10 years.[14,25–29]

Between 2003 and 2014, 850 consecutive patients with ATAAD underwent total arch replacement (TAR) with FET using a four-branched vascular graft (usually referred to as the Sun operation[30] in China) at our team. This study aims to assess the long-term outcomes of the FET + TAR technique for ATAAD as compared to hemiarch repair (HAR) and identify the risk factors for adverse events, elucidating the efficacy and durability of this extensive approach.

Methods

Patients

The inclusion criteria were defined as operative survivors having at least 10 years of follow-up after ATAAD repair. So, this study included 1072 patients with ATAAD treated between April 2003 and December 2014. Among these, limited repair included Bentall operation in 35, Bentall and partial arch repair in 18, ascending aortic (AAo) repair in 71, and hemiarch and/or AAo repair in 67 patients, and extended repair included isolated TAR in 31 and TAR + FET in 850 patients.

Included in final analysis were patients undergoing FET + TAR ($n = 850$) and HAR ($n = 74$). The early and late outcomes of FET + TAR were stratified by root procedure (valve-preserving vs valve-replacing vs none). A propensity score-matched cohort from logistic regression was created to compare the early and late outcomes of HAR and TAR + FET in 144 patients with acute DeBakey type I aortic dissection.

Surgical indications and techniques

In our team, TAR + FET would be performed for one of the following conditions in patients with ATAAD: (1) an entry tear in the arch or descending aorta; (2) arch branches involvement; (3) dilatation or anomaly of the arch or descending aorta; (4) concomitant Marfan syndrome;[21] (5) intimal intussusception of the arch or extensive intramural haematoma in the ascending aorta (AAo) and arch; and (6) retrograde type A dissection. Hemiarch repair under hypothermic circulatory arrest (HCA) would be chosen for ATAADs with (1) no intimal tear in the arch; and (2) an arch or descending aorta of < 35 mm in diameter. For ATAAD confined to the AAo that terminates proximal to the brachiocephalic artery (i.e. DeBakey type II dissection), our routine is to perform Bentall operation or AAo replacement. The procedure would be finally chosen via a shared decision-making approach with patients and family members, taking consideration of clinical presentation, operative risk, long-term prognosis, socioeconomic and cultural factors, and guideline recommendations.[1,14]

Our surgical techniques have been described in detail previously.[20,30–32] Briefly, right axillary artery (RAA) cannulation is used for cardiopulmonary bypass (CPB) and unilateral selective antegrade cerebral perfusion (uSACP) under HCA at 20–25°C. Femoral artery cannulation would be used when patients were too unstable for axillary cannulation. The procedure involves deployment of an FET, Cronus® (MicroPort Medical, Shanghai, China) in the descending aorta (above T6 in most cases), followed by TAR with a 4-branched vascular graft (Maquet Cardiovascular, Rastatt, Germany). The FET prosthesis is chosen according to the location of intimal tear, diameter of the descending aorta, and patient size. The length of the FET is determined by measuring the distance from the midpoint between the left carotid artery (LCA) and left subclavian artery (LSA) on preoperative computed tomography angiography (CTA), to its distal end reaching the level of the left atrium (below left pulmonary artery, usually above T6). The diameter of the FET is 1–2 mm less than or equal to the outer diameter of the descending aorta on CTA. Deployment of the FET, distal anastomosis, and LCA reconstruction are completed during uSACP (see Supplementary data online, *Figure S1*). The distal anastomosis is located between the LCA and LSA to facilitate suturing and haemostasis. To minimize the time of cerebral, myocardial and spinal cord ischaemia, HCA is terminated and distal perfusion is resumed once the distal anastomosis is completed, and the LCA is reconstructed first (after which uSACP is stopped, rewarming is started and the brain is perfused bilaterally), followed by the AAo (to resume myocardial perfusion), then the LSA, and finally, the innominate artery.

Root procedures (valve-preserving or replacing) were chosen according to our subcategorization system based on root diameter, degree of aortic insufficiency and competency of the sinotubular junction.[22] To decrease the times of CPB and cross-clamp, root or valve procedures, and some concomitant operations, if indicated, are performed during the cooling phase. For patients with preoperatively confirmed malperfusion in one or more organs, extra-anatomic bypass would be performed based on the finding of extremity pulselessness or a mean pressure difference of > 25 mmHg between the upper and lower extremities after completion of FET.

Our approach to neuroprotection includes uSACP via RAA, moderate hypothermia, distal first strategy to minimize duration of cerebral and spinal cord ischaemia, reconstruction of the LSA first, neuromonitoring with near-infrared spectroscopy, bispectral index, and evoked potentials, and pre-emptive placement of cerebrospinal fluid drain in high-risk patients.

Patient follow-up

All operative survivors were followed up regularly through clinic visits, phone calls, emails or letters. Patients were recommended to have computed tomography (CT) scan annually to detect thrombosis and obliteration of the false lumen, endoleak, residual intimal tear, or distal new entry, anastomotic leak, aneurysmal dilatation, rapid growth and other complications. Such patients would be monitored more rigorously and recommended to have timely reintervention to address the complications or disease progression. For patients with a known distal aortopathy at the time FET, reintervention is routinely planned and scheduled upon discharge.

Methods to confirm clinical events included reviewing medical records of outpatient follow-up, readmission and reintervention at our institution and other hospitals, retrieval and analysis of imaging data after discharge, examination of death records, and contacting patients, their relatives and referring physicians for details on complications, reintervention and cause of death. By the end of this study dated 1 July 2025, 673 patients were alive, 7 were lost to follow-up, and the censoring proportion was 73.6% (680/924).

Statistical analysis

Statistical analysis was performed using SPSS 27.0 (IBM SPSS, Armonk, NY), GraphPad Prism 10.3.1 (GraphPad Software, San Diego, CA), R 4.4.1 (R Development Core Team) and PASS 2021 (NCSS, LLC. Kaysville, UT). Continuous variables are expressed as mean ± standard deviation (SD) for normal distribution or median (interquartile range, IQR) for abnormal distribution, and compared using the Student's *t*-test or Mann-Whitney U test after the homogeneity of variance was assessed. Categorical variables are expressed as *n* (%), and compared with Pearson χ^2 test or Fisher's exact probability test. Normality of continuous variables was assessed with the Kolmogorov-Smirnov test and Q-Q plots (see Supplementary data online, *Figure S2*). Of the entire cohort, only four values (.4%) were missing for one variable, uSACP time, which were not included in the descriptive and multivariable regression analyses.[33]

Risk factors for operative mortality and morbidity were identified using logistic and modified Poisson regression models.[34] Two separate Cox regression models were used to identify predictors for late death and reoperation. The criteria of selecting candidate variables were either factors that are of clinical relevance or have been reported frequently in literature, or those that exhibited significance in univariate analysis (with a P value of $< .1$). Variables considered in the models included age (year), gender (binary), Marfan syndrome, malperfusion syndrome (binary), ischaemia of specific organs, history of cerebrovascular accident and aortic surgery, times of CPB, cross-clamp, and selective antegrade cerebral perfusion (in minutes), types of root procedure, coronary artery bypass grafting (CABG), and extra-anatomic bypass. All variables associated with the outcomes of interest in univariate analysis were evaluated as covariates in multivariable regression models with forward stepwise approach. Proportional hazards assumption was tested using Schoenfeld residuals, which indicated that the model assumptions were not violated ($P > .050$). Restricted cubic spline (RCS) was used to assess the linearity assumption underlying logistic and Cox regression models for quantitative predictors (see Supplementary data online, *Table S1*). The logistic regression models were calibrated using the Hosmer–Lemeshow goodness-of-fit test.

Patient follow-up was reported with absolute duration and completeness expressed as follow-up index according to von Allmen *et al.*[35] Rates of survival and freedom from reoperation were estimated using Kaplan-Meier method, and intergroup comparisons made with log-rank test. The date of surgery was time zero, and the end time was the date of either death, or reoperation, or the last follow-up.

Competing risks of death and reoperation, considered as mutually exclusive events, were estimated based on decomposition of time-related events into component phases, as described by Blackstone and associates.[36] It uses estimated hazard function for each event to simultaneously deplete the proportion of patients at risk at each point in time (see Supplementary data online, *Appendix I*). Although the patients are being removed from risk, they are also being accumulated into an actual proportion experiencing each event. At each point in time, the sum of these proportions is equal to one (100%).[37]

A 1 to 1 nearest neighbour matching without replacement was used with a calliper size of .01 to generate 72 pairs according to age, gender, hypertension, Marfan syndrome, malperfusion/ischaemia, and the year of surgery (see Supplementary data online, *Table S2* and *Figure S3*), in which the early and late outcomes were compared between HAR and TAR + FET. Based on the difference in the rates of late adverse events between HAR and TAR from literature,[38] a sample size of 144 had a power of > 80% with a type I error of .05 by estimation. Absolute standardized mean difference (SMD) was utilized to assess the balance of confounders after propensity score matching, with an SMD of < .1 indicating good balance.

All statistical tests were 2-sided and a P value of < .05 was considered statistically significant.

Results

Baseline characteristics

Of the 850 consecutive patients undergoing FET + TAR for ATAAD, mean age was 46.5 ± 10.7 years (range, 17–78) and 681 were male (80.1%). Comorbidities and past medical history included hypertension in 647 patients (76.1%), Marfan syndrome in 80 (9.4%), coronary artery disease (CAD) in 31 (3.6%), chronic kidney disease in 30 (3.5%), and prior cerebrovascular accident in 25 (2.9%).

Based on clinical presentation and imaging evidence, 203 cases of malperfusion syndrome were confirmed in 136 patients (16.0%) preoperatively (*Table 1*). Ten patients (1.2%) presented with cardiogenic shock or cardiac arrest.

Operative data

Root or valve operations were performed in 456 patients (53.6%), including valve-replacing in 297 (34.9%) and valve-preserving procedures in 159 (18.7%). Bentall procedure was performed in 291 patients (34.2%) and AV replacement in 6 (.7%). Valve-preserving procedures included aortic valve resuspension in 120 patients (14.1%), uni- or bi-Yacoub remodelling in 35 (4.1%) and David reimplantation in four patients (.5%).

Extra-anatomic bypass was performed in 26 patients (3.1%) (see Supplementary data online, *Table S3*). CABG was done for dissection-related coronary ischaemia in 48 (5.6%) and for pre-existing CAD in 15 patients (1.8%).

The mean durations of CPB, cross-clamp, uSACP and HCA were 203 ± 54, 115 ± 38, 27 ± 11 and 22 ± 11.5 min, respectively (*Table 2*). The times of CPB and cross-clamp were significantly longer in patients with root procedures than those without (207 ± 49 vs 194 ± 52 min, $P < .001$ and 122 ± 36 vs 104 ± 33 min, $P < .001$), while the uSACP time did not differ significantly between two groups (27.5 ± 13 vs 27 ± 10 min, $P = .677$).

Early outcomes

Operative mortality and morbidity

Operative mortality was 8.4% (71/850), which was similar between groups with and without root procedures (8.6% [39/456] vs 8.1% [32/394], $P = .901$), but significantly higher in patients with malperfusion (16.9% [23/136] vs 6.7% [48/714], $P < .001$). The leading cause of death was multiorgan failure, identified in 40 of 71 patients (56.3%). Stroke and low cardiac output led to 11 (15.5%) and 10 (14.1%) deaths, respectively. One patient (1.4%) died from distal aortic rupture. Other causes of death included respiratory failure, cardiac arrest, mediastinal infection and coagulopathy in three, two, three and one, respectively.

Operative morbidity included stroke in 30 patients (3.5%), spinal cord injury (SCI) in 21 (2.5%), acute kidney injury (AKI) in 74 (8.7%), visceral or lower limb ischaemia in 19 (2.2%), low cardiac output in 25 (2.9%), and recurrent laryngeal nerve injury in 11 (1.3%). Tracheal re-intubation was required in 53 patients (6.2%). Re-exploration for bleeding was performed in 48 (5.6%) and drainage of pericardial effusion in five patients (.6%) (*Table 3*).

Risk factors for operative mortality were age (year) (odds ratio [OR] 1.05; 95% confidence interval [CI], 1.02–1.08; $P = .001$), malperfusion syndrome (OR, 2.03; 95% CI, 1.12–3.68; $P = .019$), CPB time (min) (odds ratio [OR], 1.008; 95% CI, 1.002–1.012; $P < .001$), CABG (OR 3.28, 95% CI, 1.63–6.58; $P = .001$) and extra-anatomic bypass (OR 3.32, 95% CI, 1.23–8.95; $P = .017$). Prior cerebrovascular accident was predictive of stroke (OR 7.89, 95% CI, 2.59–24.00; $P < .001$). Visceral malperfusion (OR 6.21, 95% CI, 1.46–26.41; $P = .013$) and CPB time (min) were predictors of AKI. These predictors were confirmed in modified Poisson regression models (see Supplementary data online, *Table S4*).

Early reintervention

Early aortic reintervention was required in six patients (.7%) during the primary hospitalization or within 30 postoperative days. A new entry at the distal end of the FET necessitated thoracic endovascular aortic repair (TEVAR) in four patients (.5%). One patient (.1%) who sustained distal aortic rupture was successfully managed with an emergent thoraco-abdominal aortic replacement. An axillary-to-axillary bypass was performed for ischaemia of the left upper extremity in one patient (.1%).

Other reoperations included redo CABG for thrombosed saphenous vein graft and amputation for left leg thromboembolic necrosis in one patient (.1%) each.

Long-term outcomes

Clinical follow-up was complete in 99.2% (773/779) for a mean duration of 12.5 ± 4.0 years (range .2–22.0; IQR 11.0–14.8), exceeding

Table 1 Baseline characteristics of patients undergoing frozen elephant trunk for acute type A aortic dissection

Variable	Total ($n = 850$)	Aortic root procedure ($n = 456$)		No root procedure ($n = 394$)	*P* value
		Valve-preserving ($n = 159$)	Valve-replacing ($n = 297$)		
Age, year	46.5 ± 10.7	50.1 ± 8.6	43.7 ± 11.5*	47.2 ± 10.3	.091
Male sex	681 (80.1)	120 (75.5)	245 (82.5)	316 (80.2)	.085
Hypertension	647 (76.1)	132 (83.0)	179 (60.3)*	336 (85.3)	< .001
Marfan syndrome	80 (9.4)	10 (6.3)	58 (19.5)§	12 (3.0)	< .001
Coronary artery disease	31 (3.6)	4 (2.5)	8 (2.7)	19 (4.8)	.100
Chronic renal failure	30 (3.5)	2 (1.3)	6 (2.0)	22 (5.6)	.003
Cerebrovascular accident	25 (2.9)	10 (6.3)	2 (.7)¶	13 (3.3)	.685
Diabetes mellitus	22 (2.6)	5 (3.1)	5 (1.7)	12 (3.0)	.518
COPD	18 (2.1)	0	5 (1.7)	13 (3.3)	.031
Congestive heart failure	8 (.9)	0	6 (2.0)	2 (.5)	.297
Proximal aortic surgery	33 (3.9)	2 (1.3)	11 (3.7)	20 (5.1)	.110
Malperfusion syndrome[a]	136 (16.0)	23 (14.5)	56 (18.9)	57 (14.5)	.262
Lower limb ischaemia	64 (7.5)	14 (8.8)	29 (9.8)	21 (5.3)	.027
Cerebral ischaemia	38 (4.5)	5 (3.1)	18 (6.1)	15 (3.8)	.410
Cardiac tamponade	24 (2.8)	5 (3.1)	6 (2.0)	13 (3.3)	.535
Renal ischaemia	26 (3.1)	5 (3.1)	5 (1.7)	16 (4.1)	.161
Coronary ischaemia	14 (1.6)	2 (1.3)	4 (1.3)	8 (2.0)	.433
Acute heart failure	19 (2.2)	1 (.6)	9 (3.0)	9 (2.3)	1.000
Visceral ischaemia	14 (1.6)	0	7 (2.4)	7 (1.8)	.794
Spinal cord ischaemia	6 (.7)	1 (.6)	5 (1.7)	0	.033

Values are presented as mean ± standard deviation, or *n* (%).
P values refer to comparison between patients with and without aortic root procedures.
For comparison between valve-replacing and valve-preserving procedures, *$P < .0001$; §$P = .0002$; ¶$P = .0007$.
[a]This row lists the number of patients. The following rows report malperfusion of specific tissue or organ as the number of cases that occurred.
COPD, chronic obstructive pulmonary disease.

15 years in 23.5% (183/779). Contact with 6 patients were lost after they had been followed for 5.5, 8.0, 10.5, 12.2, 12.2, and 4.4 years, respectively. The overall follow-up index was .996 ± .048.

Late reoperation

At median 5.2 years (IQR 1.2–9.7) after FET, 82 patients underwent 90 reinterventions. Of these, 25 (27.8%) were planned, and 65 (72.2%) were unplanned at the time of FET. The most frequent cause of distal reoperation was aneurysm or rapid growth of the thoracoabdominal aorta, followed by multiple residual tears, and distal new entry.

Open thoraco-abdominal aortic aneurysm repair (TAAAR) was performed in 32 patients for distal aortic aneurysm at a median 7.3 years (IQR 1.6–9.8) after FET. TEVAR was done for residual dissection or distal new entry in 25 patients at median 2.8 years (IQR .8–6.4). Six patients underwent an extra-anatomic bypass at median 5.3 years (IQR .1–10.0) for extremity ischaemia, including axillo-to-axillary bypass in four and femoro-to-femoral bypass in two. Abdominal aortic replacement was performed in four patients for recurrent dissection at 6.6 ± 2.7 years (*Table 4*).

Seven patients underwent closure of anastomotic leak (six open; one transcatheter) at median .8 years (IQR .3–4.5), which were located at distal anastomosis in five and AAo in two. A patient with an aberrant right subclavian artery developed a type II endoleak into descending aorta at .6 years, which was successfully managed with transcatheter coil embolization via the right radial artery.

Two patients underwent Bentall operation at .4 and 9.5 years, and another two underwent AV replacement for severe regurgitation after aortic valve resuspension at .4 and 4.0 years, respectively. These four procedures were performed via a median resternotomy under CPB with femoral cannulation. Ascending aortic replacement was performed at 2.6 and 12.7 years, in one patient each.

Seven patients (one with Marfan syndrome) underwent mitral valve replacement at median 7.5 years (IQR 5.9–11.3) either during aortic reoperation (two TAAARs, one ascending aortic repair) or for isolated valve regurgitation (one AV replacement, two MVR + tricuspid valve repair, one MitraClip).

Marfan syndrome (hazard ratio [HR] 1.94; 95% CI, 1.08–3.49; $P = .026$) and younger age (year) (HR .97; 95% CI, .95–.99; $P = .007$) were predictive of late reoperation.

Table 2 Operative data of total arch repair with frozen elephant trunk for acute type A aortic dissection

Variable	Total ($n = 850$)	Aortic root procedure ($n = 456$)		No root procedure ($n = 394$)	*P* value
		Valve-preserving ($n = 159$)	Valve-replacing ($n = 297$)		
Procedural times, min					
Cardiopulmonary bypass	203 ± 54	207 ± 48	213 ± 59	194 ± 52	< .001
Aortic cross-clamp	115 ± 38	120 ± 36	126 ± 41	104 ± 33	< .001
uSACP	27 ± 11	29 ± 14	26 ± 12	27 ± 10	.677
Root or valve procedure					
Aortic valve replacement	6 (.7)	–	6 (2.0)	–	NA
Bentall operation	291 (34.2)	–	291 (98.0)	–	NA
Aortic valve resuspension	120 (14.1)	120 (75.5)	–	–	NA
Partial Yacoub remodeling	35 (4.1)	35 (22.0)	–	–	NA
David reimplantation	4 (.5)	4 (2.5)	–	–	NA
Concomitant procedure					
Extra-anatomic bypass[a]	26 (3.1)	3 (1.9)	14 (4.7)	9 (2.3)	.117
CABG	63 (7.4)	9 (5.7)	33 (11.1)	21 (5.3)	.035
Mitral valve surgery	7 (.8)	2 (1.3)	5 (1.7)	0	.017

Values are presented as mean ± standard deviation, or *n* (%).
P values refer to comparison between patients with and without aortic root procedures.
CABG, coronary artery bypass grafting; NA, not applicable; uSACP, unilateral selective antegrade cerebral perfusion.
[a]A total of 29 extra-anatomic bypass grafts were performed for 26 patients (see Supplementary data online, *Table S3* for details).

Late death

Among 779 hospital survivors, 153 expired at median of 7.5 years (IQR 4.4–9.6 years). The cause of death was confirmed to be distal aortic rupture in 35 patients (22.9%), stroke in 21 (13.7%), pneumonia and sepsis in seven each (4.6%), congestive heart failure and acute kidney injury in six each (3.9%), cancer in two (1.3%), and could not be identified in 69 (45.1%) (*Table 4*). Patients with root procedure were more likely to expire from stroke than those without root procedure (4.1% [17/417] vs 1.1% [4/362]; $P = .011$). Risk factors for late death were preoperative cerebrovascular accident (hazard ratio [HR] 2.34; 95% CI, 1.08–5.07; $P = .031$) and visceral ischaemia (HR 4.12; 95% CI, 1.52–11.17; $P = .005$).

Specifically, among 82 patients undergoing reoperation, no death occurred within 30 days postoperatively; during follow-up, 11 patients died at a median 4.5 years (IQR 1.2–6.5) after the reintervention. The causes of death were confirmed to be aortic rupture in three patients. Survival was 87.6% at 5 years and 80.3% through 15 years (95% CI, 76.5%–93.6% and 66.6%–88.9%).

Survival analysis

For the whole series, the freedom from reoperation were 94.1%, 90.5%, 87.4% and 85.4% at 5, 10, 15 and 20 years, respectively (95% CI, 92.2%–95.6%, 88.1%–92.4%, 84.5%–89.8% and 80.1%–89.4%) (*Figure 1*), the corresponding survival rates were 86.2%, 77.7%, 72.4% and 70.0% (95% CI, 83.7%–88.3%, 74.8%–80.4%, 69.0%–75.5% and 65.8%–74.0%) (*Figure 2*). In adjusted analysis, survival did not differ significantly between valve-preserving and valve-replacing procedures, nor between patients with and without root procedures, while malperfusion syndrome was linked to significantly decreased survival (*Figure 3*), which were 65.4% vs 80.1% at 10 years (95% CI, 56.8%–72.7% vs 77.0%–82.9%) and 59.1% vs 71.0% at 20 years (95% CI, 48.9%–67.9% vs 65.8%–75.6%) (HR .473, 95% CI, .324–.692; $P < .0001$).

In competing risks analysis, the cumulative incidences were 13% and 21% for all-cause death (95% CI, 10.9%–15.3% and 17.9%–23.1%), 5% and 8% for reoperation (95% CI, 3.5%–6.3% and 6.8%–10.4%), and 82% and 71% for reoperation-free survival (95% CI, 79.6%–84.5% and 68.0%–73.9%) at 5 and 10 years, respectively. At 15 years, mortality was 25% (95% CI, 22.9%–29.1%), 13% underwent reoperation (95% CI, 9.6%–14.3%), and 62% of patients (95% CI, 58.5%–65.6%) were alive without reoperation (*Figure 4*).

Other adverse events

Coronary ischaemia occurred in six patients at 4.5 ± 1.9 years (angina in four and myocardial infarction in two), five of whom were managed with coronary artery stenting. Pacemaker was implanted in two patients for bradycardia at 6 and 10.4 years, respectively. One patient underwent radiofrequency ablation for atrial fibrillation at 1.8 years. Endocarditis and chronic renal failure occurred in one patient each at 5 and 4 months, respectively.

Comparison of TAR to hemiarch repair

Of the matched cohort, baseline characteristics and operative data were comparable between the two groups (all $P > .050$), except the longer times of CPB (198 vs 162 min, $P < .001$), cross-clamp (112 vs 84 min, $P < .001$) and cerebral perfusion (28 vs 19 min, $P < .001$) in the TAR + FET group (*Table 5*). Operative mortality was lower in the

Table 3 Operative outcomes of total arch repair with frozen elephant trunk for acute type A aortic dissection

Variable	Total ($n = 850$)	Aortic root procedure ($n = 456$)		No root procedure ($n = 394$)	P value
		Valve-preserving ($n = 159$)	Valve-replacing ($n = 297$)		
Operative mortality	71 (8.4)	14 (8.8)	25 (8.4)	32 (8.1)	.901
Operative complications					
Stroke	30 (3.5)	8 (5.0)	7 (2.4)	15 (3.8)	.713
Spinal cord injury	21 (2.5)	5 (3.1)	7 (2.4)	9 (2.3)	.827
Acute kidney injury	74 (8.7)	11 (6.9)	25 (8.4)	38 (9.6)	.394
Re-exploration for bleeding	48 (5.6)	12 (7.5)	20 (6.7)	16 (4.1)	.074
Tracheal re-intubation	53 (6.2)	21 (13.2)	16 (5.4)[a]	16 (4.1)	.015
Low cardiac output	25 (2.9)	1 (.6)	15 (5.1)	9 (2.3)	.316
Visceral or lower limb ischaemia	19 (2.2)	4 (2.5)	4 (1.3)	11 (2.8)	.357
Recurrent laryngeal nerve injury	11 (1.3)	1 (.6)	5 (1.7)	5 (1.3)	1.000
Distal aortic rupture	2 (.2)	0	1 (.3)	1 (.3)	1.000
Early aortic reintervention	6 (.7)	1 (.6)	3 (1.0)	2 (.5)	.691
TEVAR	4 (.5)	1 (.6)	2 (.7)	1 (.3)	1.000
TAAAR	1 (.1)	0	0	1 (.3)	.464

Values are presented as *n* (%).
Operative mortality was defined all deaths within 30 days of surgery (regardless of place) or before final hospital discharge, including any death that occurred after transfer to a secondary hospital or long-term care facility.
P values refer to comparison between patients with and without aortic root procedures.
TEVAR, thoracic endovascular aortic repair; TAAAR, thoraco-abdominal aortic aneurysm repair.
[a]Valve-replacing vs valve-preserving, $P = .036$.

HAR group (4.2% [3/72]) compared to the TAR group (6.9% [5/72]), but without statistical significance ($P = .719$). Neither did the incidences of operative complications differ significantly between two groups (25% [18/72] vs 26.4% [19/72], $P = .841$).

Follow-up was complete in 99.3% (135/136) for a mean duration of 12.6 ± 4.7 years (range .2–21.8), which were not significantly different between two groups (*Table 6*). Late death occurred in 17 of 68 patients with HAR, compared to nine of 67 patients with TAR (25% vs 16.4%, $P = .088$). Distal aortic rupture was the most common cause of late death after HAR, leading to seven of 17 deaths (41.1%) vs one of nine (11.1%) in TAR group ($P = .190$). Reintervention was performed in five and two patients of the HAR and TAR groups at median 5.3 years (IQR 2.8–10.9), respectively (7.4% vs 3.0%, $P = .441$), including TAAAR in four patients at median 9.7 years (IQR 2.1–11.3), TEVAR in one at 5.2 years, and Bentall + TAR + FET in one at 5.3 years. One patient was found to have a thoraco-abdominal aortic aneurysm at 17.6 years after HAR, and TAAAR was scheduled, but he refused surgery and elected to have conservative treatment under close surveillance.

At 5 years, two groups showed similar survival (88.9% vs 90.1% [95% CI, 79.0%–93.3% vs 80.0%–95.2%]). Survival was 80.5% (95% CI, 69.5%–88.2%) from 10 to 20 years in the TAR group, compared to 78.1% and 60.7% at 10 and 20 years respectively (95% CI, 66.3%–86.2% and 42.6%–74.7%) in the HAR group ($P = .286$). Compared to HAR, total arch repair showed significantly higher freedom from late adverse events (including death, reoperation and distal aortic dilation), which were 86.5% vs 81.6% at 10 years, and 78% vs 45.6% at 20 years (HR .496; 95% CI, .252–.975; $P = .042$) (*Figure 5*).

Discussion

Given the scarce data on the long-term outcomes of FET in large series, the results of our study have shown that the FET technique may be a safe, effective and durable surgical approach to ATAAD involving the arch and descending aorta, as evidenced by the favourable late outcomes and lower risks of late death and reoperation compared to HAR in the matched cohort (*Structured Graphical Abstract*). This may be an important reason for the widespread adoption of the FET technique in recent years.[12,13] As current devices are evolving towards an ideal FET prosthesis by making the technique simpler and safer,[39–47] this study provides long-term outcomes data supporting wider use of the FET technique for thoracic aortic pathologies, which may become the next standard of care for patients with ATAAD involving repair of the arch and proximal descending aorta.[12] As the Thoraflex Hybrid FET prosthesis has been approved in the United States recently,[48] the case volume of FET procedure is expected to surge in North America.

The operative mortality and morbidity highlight the continued need for improving surgical technology and perioperative management,[49–54] which has stirred up multiple modifications to the FET technique and prostheses, such as zone 0 graft with inner[41] or outer[42] branches, stent bridging to the supra-aortic vessels,[40] and branched stented anastomosis.[43] Peterss and associates pioneered a technique to create an anastomosis between a tetrabranched arch grafts and supraaortic vessels, achieving a 89.1% freedom from stent-related events at 3 years.[40] In a series of 196 patients undergoing zone 0 FET for ATAAD reported by Wada and colleagues,[55] in-hospital mortality was 6.6%, survival was

Table 4 Late outcomes of total arch repair with frozen elephant trunk for acute type A aortic dissection

Variable	Total (*n* = 779)	Aortic root procedure (*n* = 417) Valve-preserving (*n* = 145)	Aortic root procedure (*n* = 417) Valve-replacing (*n* = 272)	No root procedure (*n* = 362)	*P* value
Late death	153 (19.6)	26 (17.9)	50 (18.4)	77 (21.3)	.320
Distal aortic rupture	35 (4.5)	9 (6.2)	8 (2.9)	18 (5.0)	.258
Stroke	21 (2.7)	3 (2.1)	14 (5.1)	4 (1.1)	.007
Sepsis	7 (.9)	3 (2.1)	2 (.7)	2 (.6)	.459
Pneumonia	7 (.9)	2 (1.4)	3 (1.1)	2 (.6)	.459
Congestive heart failure	6 (.8)	2 (1.4)	1 (.4)	3 (.8)	1.000
Acute kidney injury	6 (.8)	0	2 (.7)	4 (1.1)	.424
Cancer	2 (.3)	2 (1.4)	0	0	.714
Unknown	69 (8.9)	11 (7.6)	27 (9.9)	31 (8.6)	.701
Late reintervention	82 (10.5) [a]	18 (12.4)	39 (14.3)	25 (6.9)	.002
TAAAR	32 (4.1)	6 (4.1)	21 (7.7)	5 (1.4)	< .001
TEVAR	25 (3.2)	7 (4.8)	9 (3.3)	9 (2.5)	.315
Repair of anastomotic leak	7 (.9)	0	1 (.4)	6 (1.7)	.054
Extra-anatomic bypass	6 (.8)	1 (.7)	4 (1.5)	1 (.3)	.223
Abdominal aortic replacement	4 (.5)	1 (.7)	0	2 (.6)	1.000
Endovascular aortic repair	2 (.3)	0	1 (.4)	1 (.3)	1.000
Aortic valve replacement	2 (.3)	2 (1.4)	0	0	.502
Bentall operation	2 (.3)	1 (.7)	0	1 (.3)	1.000
Ascending aortic replacement	2 (.3)	1 (.7)	0	1 (.3)	1.000
Coil embolization of ARSA	1 (.1)	1 (.7)	0	0	1.000
Mitral valve surgery	7 (.9)	3 (2.1)	4 (1.5)	0	.039

Values are presented as *n* (%).
P values refer to comparison between patients with and without aortic root procedures.
TAAAR, thoraco-abdominal aortic aneurysm repair; TEVAR, thoracic endovascular aortic repair; ARSA, aberrant right subclavian artery.
[a]82 patients underwent a total of 90 procedures during reintervention.

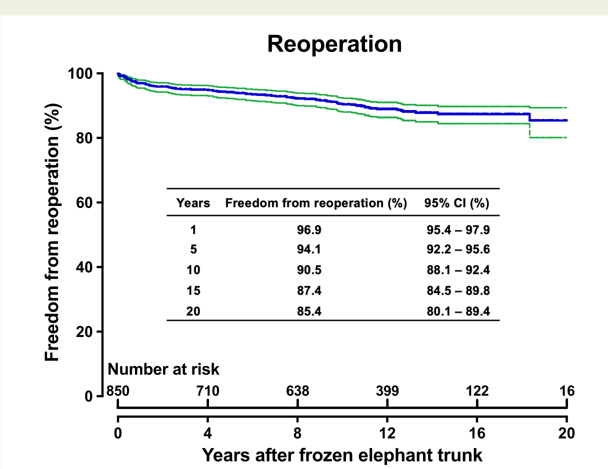

Figure 1 Freedom from reoperation after total arch replacement and frozen elephant trunk for acute type A aortic dissection

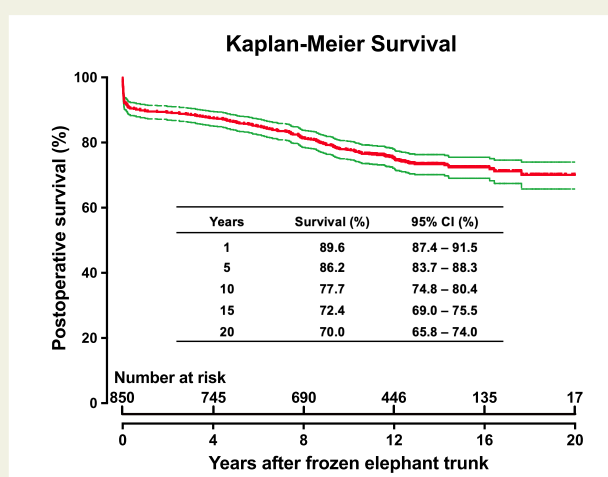

Figure 2 Survival after total arch replacement and frozen elephant trunk for acute type A aortic dissection

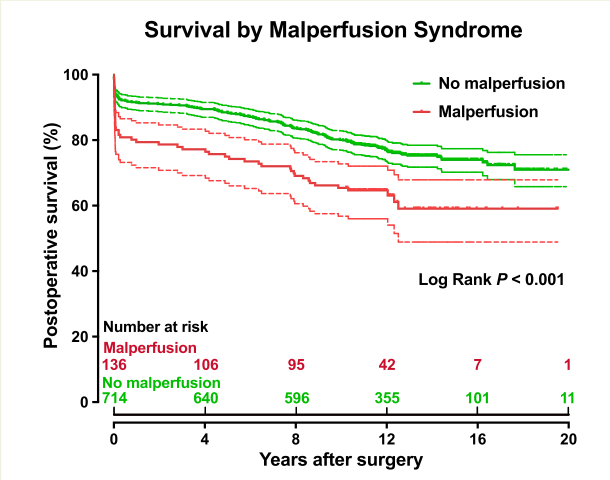

Figure 3 Malperfusion syndrome significantly decreased survival after frozen elephant trunk and total arch repair in patients with acute type A aortic dissection

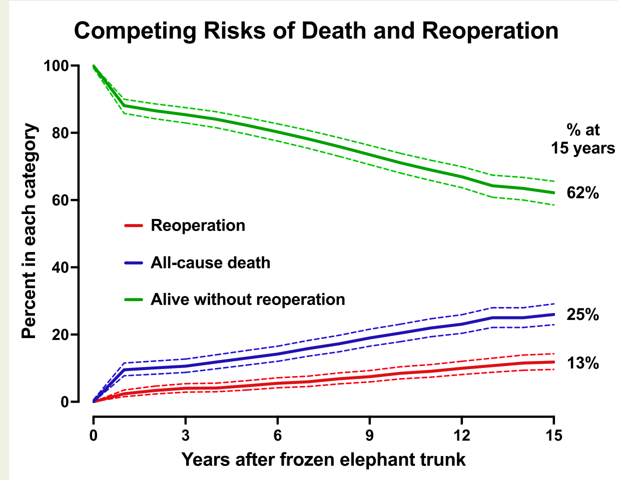

Figure 4 Competing risks analysis of death and reintervention after frozen elephant trunk and total arch repair in patients with acute type A aortic dissection

85.1%, and 89.9% were free from distal reintervention at 5 years. The outcomes in our study compare favourably to those of the recent developments.[40–47,55] Over time, the authors' team have made continued efforts to refine and improve surgical techniques, such as the use of warmer temperature for HCA,[56] bilateral cerebral perfusion, and more recently, cerebral perfusion via cannulation of RAA, LCA and LSA and use of an FET with an unstented proximal graft with the arch clamped at the LSA orifice.[57] These represent our endeavour towards an 'optimum' neuroprotection strategy in arch surgery, which may avoid the need for distal anastomosis, decrease HCA time, and improve left hemisphere perfusion.

The low incidence of spinal cord injury in this series corroborates previous finding that FET does not increase the incidence of paraplegia in patients with ATAAD.[16] In our experience, SCI after FET often occurs in three scenarios: (1) the false lumen located at the spinal side of the aorta, or with intussusception of the descending aorta; (2) early thrombosis of the false lumen after surgery; and (3) in patients with hypertension, suggesting inadequate perfusion during surgery or in ICU. Our implantation techniques, including the use of a short FET (mean length 10 cm), deployment above T6 level in most cases, and a brief period of circulatory arrest (averaging 22 min) at 20–25°C may have neutralized the risk factors identified in other studies.[17,58] However, five of the six early reinterventions were likely related to the FET, which underlines the need for continued refinement of the prosthesis and implantation technique.

In this series, although patients undergoing root procedures were more likely to have Marfan syndrome and ischaemia of the lower extremity and spinal cord, and required longer CPB and cross-clamp times, neither did early mortality and morbidity nor did long-term survival and freedom from reoperation differ significantly between those with and without concomitant root procedures. In the matched cohort, FET + TAR showed similar operative mortality and morbidity rates as well as 5-year survival to HAR, but achieved superior freedom from death and reoperation up to 20 years. These results imply that in experienced aortic centres, the surgeon can safely perform an extended repair by adding TAR + FET (distally) to a routine limited ascending or root repair (proximally) in emergency settings for patients with acute type I dissection, without fear of increasing the risks of early and long-term mortality and reintervention. Although the evidence is scarce and mixed from studies comparing limited and extended repair (see Supplementary data online, *Table S5*),[59] Roselli and associates found that FET posed no additional risk over conventional limited and extended approaches in a wide variety of patients with acute type I dissection.[60] Their experience, together with that of ours and others,[61] add evidence supporting the use of the extensive TAR + FET approach in patients with ATAAD, despite the marked differences in the age, race, comorbidities of patients, study period and surgical techniques between two centres.

The results of this study and many others highlight the profound impact of malperfusion syndrome on the early and long-term outcomes of ATAAD and the need for optimization of the management of such patients,[7,9,18,47] which represents an important direction for future works. Despite controversies regarding the optimal approach to malperfusion and the role of FET in ATAAD repair,[14,62,63] recent years have witnessed a trend towards reperfusion-first strategy followed by proximal aortic repair in the hybrid operating room.[1,63,64] The experience of other centres and ours show that an FET deployed in the descending aorta could expand the true lumen, thereby improving blood flow and preventing or resolving distal malperfusion. With the aid of modern imaging technologies and hybrid operating room, our strategy is now shifting towards a more aggressive one based on conventional aortic repair. For patients with ischaemia confirmed by preoperative imaging who did not respond well to FET, our routine is reperfusion with extra-anatomic bypass or endovascular stenting or fenestration during TAR + FET.[18,64] Before discharge, TEVAR would be performed for patients with peripheral arterial ischaemia that was confirmed by symptoms, lab tests, morphologies of the FET and true lumen, and perfusion to peripheral arteries.

Study limitations

This retrospective study is limited by the young age of patients,[65,66] and inclusion of the less severe 'self-selected' patients surviving the first 48–72 h of initial dissection attack,[20] as shown by the low incidence of cardiogenic shock and malperfusion in this series, which represents a selection bias arising from the 'centralized care' system in China. This study did not include a strictly selected control group (i.e. isolated TAR

Table 5 Total arch vs hemiarch repair: baseline and operative data in the matched cohort

Variable	Hemiarch repair (*n* = 72)	Total arch repair (*n* = 72)	ASMD	*P* value
Baseline characteristics				
Age, year	49.1 ± 12.6	48.2 ± 12.2	− .073	.366
Male sex	44 (61.1)	48 (66.7)	.120	.488
Hypertension	46 (63.9)	43 (59.7)	− .100	.607
Marfan syndrome	4 (5.6)	5 (6.9)	.070	1.000
Comorbidities				
Diabetes mellitus	3 (4.2)	1 (1.4)	− .170	.620
Coronary artery disease	3 (4.2)	3 (4.2)	0	1.000
Cerebrovascular accident	3 (4.2)	2 (2.8)	− .080	1.000
Chronic obstructive pulmonary disease	1 (1.4)	1 (1.4)	0	1.000
Chronic kidney disease	0	2 (2.8)	.170	.497
Prior aortic or cardiac procedure	5 (6.9)	4 (5.6)	− .040	1.000
Malperfusion syndrome				
Cerebral ischaemia	7 (9.7)	4 (5.6)	− .157	.347
Myocardial ischaemia	2 (2.8)	1 (1.4)	− .096	1.000
Visceral ischaemia	2 (2.8)	1 (1.4)	− .096	1.000
Lower extremity ischaemia	2 (2.8)	3 (4.2)	.076	1.000
Cardiac tamponade	3 (4.2)	3 (4.2)	0	1.000
Renal malperfusion	1 (1.4)	1 (1.4)	0	1.000
Spinal cord ischaemia	0	0	NA	NA
Acute heart failure	0	1 (1.4)	.168	1.000
Operative data				
Procedural times, min				
Cardiopulmonary bypass	162 ± 43	198 ± 47	.805	< .001
Aortic cross-clamp	84 ± 29	112 ± 30	.950	< .001
Selective antegrade cerebral perfusion	19 ± 11	28 ± 10	.870	< .001
Root or concomitant procedure				
Wheat procedure	2 (2.8)	0	− .020	.497
Bentall procedure	18 (25.0)	27 (37.5)	.270	.150
Aortic valve resuspension	8 (11.1)	11 (15.3)	.120	.460
Partial Yacoub remodeling	4 (5.6)	2 (2.8)	− .160	.681
Coronary artery bypass grafting	5 (6.9)	4 (5.6)	− .040	1.000
Extra-anatomic bypass	2 (2.8)	1 (1.4)	− .096	1.000
Mitral valve replacement	0	1 (1.4)	.168	1.000

Values are expressed as mean ± standard deviation (SD) or *n* (%).
ASMD, absolute standardized mean difference; *NA*, not applicable.

without FET) with good sample size, which precludes evaluation of the impact of FET on distal malperfusion.

The authors are fully aware of the high percentage of TAR and low proportion of HAR in this series, which reflects the peculiarities and difficulties related to the geographic, cultural, psychological and economic constraints in our work. As a result, the majority of our patients are extremely unwilling to return for a secondary intervention on distal aorta. Under such circumstances, it may be more reasonable and

Table 6 Total arch vs hemiarch repair: early and late outcomes in the matched cohort

Variable	Hemiarch repair ($n = 72$)	Total arch repair ($n = 72$)	*P* value
Operative outcomes			
Mortality	3 (4.2)	5 (6.9)	.719
Stroke	1 (1.4)	1 (1.4)	1.000
Spinal cord injury	0	1 (1.4)	1.000
Re-exploration for bleeding	4 (5.6)	3 (4.2)	1.000
Acute kidney injury	6 (8.3)	6 (8.3)	1.000
Low cardiac output	3 (4.2)	3 (4.2)	1.000
Tracheal re-intubation	4 (5.6)	5 (6.9)	1.000
Late outcomes	**($n = 68$)[a]**	**($n = 67$)**	
Duration of follow-up, year	12.3 ± 5.0	12.8 ± 4.2	.410
Late adverse events	23 (33.8)	11 (16.4)	.048
Late reoperation	5 (7.4)	2 (3.0)	.441
Thoracoabdominal aortic aneurysm repair	4 (5.9)	1 (1.5)	.366
Thoracic endovascular aortic repair	0	1 (1.5)	.496
Bentall + TAR + FET	1 (1.5)	0	1.000
Distal aortic dilation (awaiting surgery)	1 (1.5)	0	1.000
Late death	17 (25.0)	9 (13.4)	.088
Distal aortic rupture	7 (10.3)	1 (1.5)	.359
Stroke	0	3 (4.5)	.249
Pneumonia	4 (5.9)	1 (1.5)	.366
Sepsis	0	1 (1.5)	.497
Unknown	6 (8.8)	3 (4.5)	.326
Freedom from late adverse events			.042
5 years	94.0 (85.8–97.7)	95.5 (86.7–98.5)	
10 years	81.6 (69.8–89.2)	86.5 (75.7–91.7)	
15 years	65.4 (49.5–77.4)	84.5 (73.0–91.4)	
20 years	45.6 (27.7–61.8)	78.0 (58.8–89.0)	

Values are expressed as *n* (%), mean ± standard deviation, or Kaplan-Meier estimates (95% confidence interval).
Late adverse events include death, reoperation, and aortic dilation during follow-up.
TAR, total arch repair; FET, frozen elephant trunk.
[a]One patient with hemiarch repair was lost to follow-up at 1.1 years after discharge.

beneficial to operate on the descending aorta during the primary surgery. Given the difference of our patients from western series,[60] the comparison to limited repair should be interpreted cautiously, and the results of this study cannot be generalized in a way that the FET technique should be advocated for all patients with type I dissection unless convincing evidence is available from randomized controlled studies, which is unlikely to happen. Although propensity score matching was used to control for potential baseline confounders based on literature and subject-matter knowledge, which, however, were not inferred via the causal directed acyclic graph (cDAG),[67] neither were pure risk factors of outcomes included in the matching, nor is it possible to eliminate confounding given the retrospective nature of this study.

As this series spanned two decades, limitation exists in the interpretation of the time-to-event outcomes with regard to potential built-in selection bias.[68] The reported period-specific hazard ratios should be interpreted with caution, primarily as measures of association conditional on survival at that time, rather than as definitive causal effects. Nevertheless, the presented survival curves have provided a more robust summary of the cumulative treatment effects of FET over time, which is less susceptible to selection bias. Moreover, the constant evolution in the standard of care and surgical technologies may also influence event-related risks across different patient cohorts, and these findings were based on a single-team experience with a relatively small sample size, which may not be generalized to today's clinical practice at

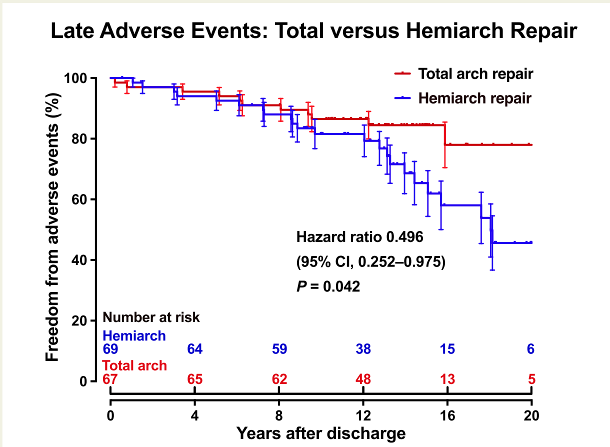

Figure 5 Compared to hemiarch repair, total arch repair with frozen elephant trunk showed significantly lower risk of late adverse events (including death, reoperation and distal aortic dilatation) in patients with acute type A dissection

other institutions. Multicentre collaborations with larger patient cohorts will be warranted to further validate these findings.

Another important weakness pertains to the unknown causes of late death in 69 patients, which was very likely to be distal aortic rupture because most of them died suddenly and given the huge number of adults with hypertension (approximately 240 million) and low rates of awareness (38.3%), treatment (34.6%) and control (12.0%) in China, despite the improvements over the past decade according to six rounds of a national survey.[69] At 15 years, 13% patients underwent a reoperation, and 72% of the reinterventions were unplanned at the time of FET. This is a sobering alert that 'no patient should be considered as cured of the (aortic) disease', which underscores the necessity of lifelong rigorous imaging and clinical surveillance.

More importantly, radiologic follow-up is only available in two thirds of survivors because 80% of patients in this cohort had travelled to us from far-reaching regions,[70] and due to logistic and administrative reasons. Complete CT data would help to delineate the anatomical features of aortic pathology and remodeling,[10,23,24,71] and, particularly, elucidate the underlying causes for the inferior late outcomes of malperfusion syndrome.[71] However, our unpublished data of 169 patients who had preoperative CTA and two or more postoperative CT scans showed that the false lumen was obliterated at the proximal end of FET in 98% and at mid-descending aorta in 81%; with a temporal trend of true lumen expansion and false lumen shrinkage, which is particularly pronounced in thoracic aorta; and the diameters of downstream aortic segments remained stable in 75% at mean 7.5 years. Although this may serve, in part, as evidence for positive remodelling, further efforts to collect more CT scans and additional imaging studies on aortic remodelling are warranted to better understand the long-term effects of the FET technique in patients with ATAAD.

Conclusions

In this series spanning two decades, the TAR and FET technique achieved acceptable early mortality and morbidity and favourable late survival and freedom from reoperation as compared to HAR in patients with ATAAD. This study adds long-term evidence supporting the use of this extensive approach in ATAAD repair. Future efforts should be directed towards optimizing the management of malperfusion syndrome, a strong predictor for early and late death, and improving medical treatment and imaging surveillance during follow-up, which are essential to achieving better long-term outcomes.

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Supplementary data

Supplementary data are available at *European Heart Journal* online.

Declarations

Disclosure of Interest

All authors declare no disclosure of interest for this contribution.

Data Availability

The authors declare that the data supporting the findings of this study are available within the paper and its Supplementary Information files.

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Ethical Approval

The Ethics Committee of Beijing Anzhen Hospital of Capital Medical University approved this retrospective study and waived the need for informed consent (Approval #KS2019034; date: 12/12/2019).

Pre-registered Clinical Trial Number

Not applicable.

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