Featured Article

The Chinese experience with frozen elephant trunk: contemporary institutional outcomes of the Sun procedure

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Background: The Sun procedure has been widely adopted across China for the treatment of acute type A aortic dissection (ATAAD). Although favorable outcomes have been reported from high-volume centers, institutional series offering detailed early data using modern operative protocols remain limited. This study is structured in two parts: first, a review of the literature on the development and reported outcomes of the Sun procedure in different aortic populations across China; and second a presentation of contemporary operative characteristics and early outcomes in patients undergoing the Sun procedure for ATAAD at a single institution.

Methods: A retrospective analysis was conducted on 729 consecutive patients with ATAAD treated at DeltaHealth Hospital from 2016 to 2024. Among these, 573 patients (78.6%) underwent total arch replacement with frozen elephant trunk (FET) using the Sun procedure. Baseline characteristics, operative variables, and early outcomes were analyzed. Neurologic, renal, pulmonary, and systemic complications are reported.

Results: The mean age of patients was 52.7±14.1 years, and 73.5% were male. Cardiac tamponade was present in 19.1% of patients at presentation. The history of cerebrovascular disease was noted in 4.1%, 3.4% had chronic kidney disease and 13.6% had Marfan syndrome. In-hospital mortality was 4.1%. Major complications included stroke (10.2%), spinal cord injury (SCI) (2.6%), acute renal failure (8.4%), gastrointestinal complications (4.1%), and reoperation for bleeding (14.3%). Sternal dehiscence and limb ischemia occurred in 1.8% and 1.6% of patients, respectively. Outcomes were achieved despite the presence of significant preoperative malperfusion syndromes, cerebral (8.2%), coronary (13.6%), and spinal cord malperfusion (2.2%).

Conclusions: The Chinese experience with the Sun procedure highlights the potential of standardized surgical strategies in complex aortic disease. This dataset affirms the technique's safety, durability, and adaptability across acute, chronic, and heritable aortic pathologies.

Keywords: Aortic aneurysm; aortic dissection; aortic surgery; frozen elephant trunk (FET); Sun procedure

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Introduction

History of the frozen elephant trunk (FET) procedure

The classical elephant trunk technique, introduced by Borst *et al.* in 1983, involved arch replacement with a distal prosthetic graft left in the descending aorta to facilitate staged repair (1). In 1996, Kato *et al.* in Japan introduced "open stent grafting", deploying a stented graft into the descending aorta during arch repair. This hybrid strategy was a major step toward single-stage repair of extensive

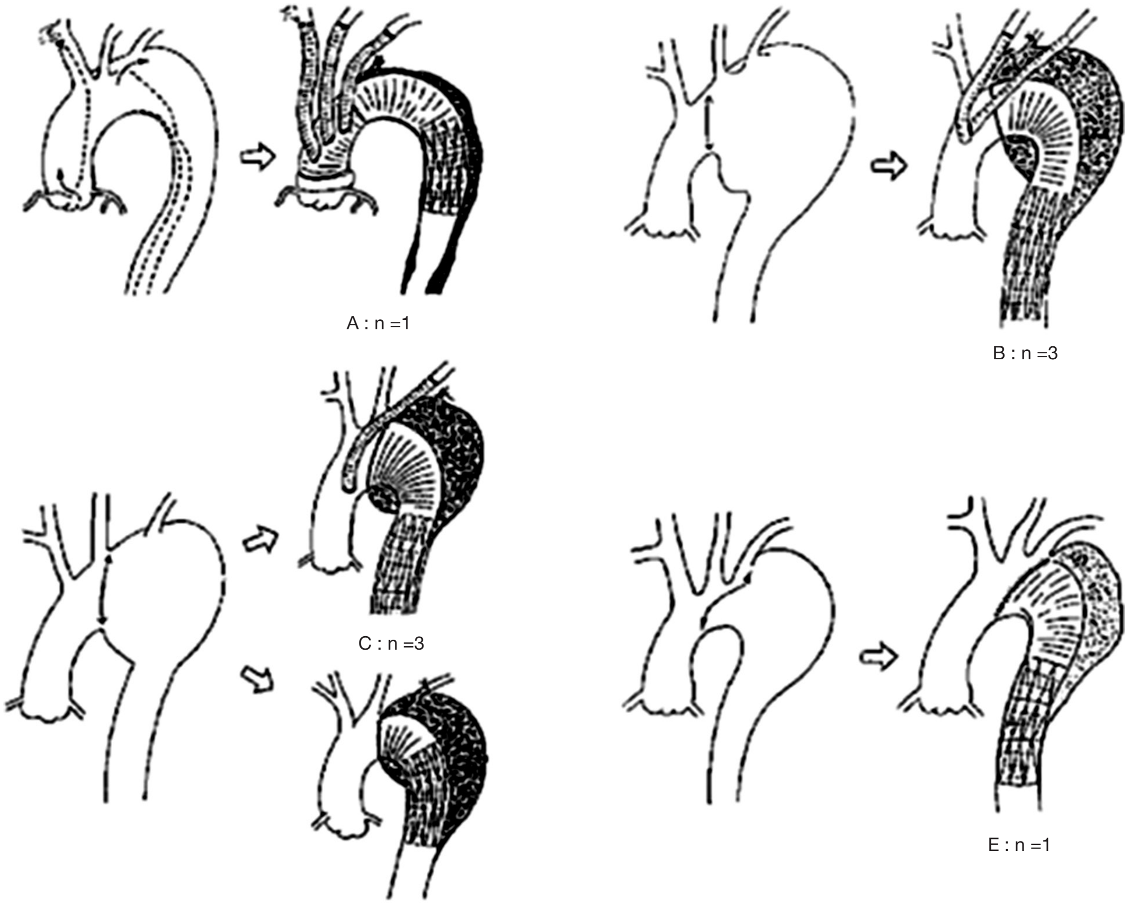

Figure 1 Different surgical procedures described by Kato *et al.* [1996]. In the first published record of the FET technique: (A) total aortic arch reconstruction and stented graft implantation (n=1); (B) left carotid and left subclavian artery reconstruction and stented graft implantation (n=3); (C,D) left subclavian reconstruction (C) or sacrifice (D) and stented graft implantation (reconstruction, n=3; sacrifice, n=2); (E) transection in the distal to left subclavian artery and stented graft implantation (n=1). Figure used with permission from Dr. Kato. FET, frozen elephant trunk.

disease. In nine of the ten cases presented by Kato *et al.*, an ascending aorta branched graft and a separate descending aortic stent graft in discontinuity were used and as such were not true FETs. However, one patient in this series described, had a total arch replacement and descending stent implanted in continuity which represents the first publication of the FET technique as we know it today (*Figure 1*, diagram “A”) (2,3).

It was not until 2001–2003, when European teams, notably under Haverich and Karck in Germany, further developed and first popularized the term “Frozen Elephant Trunk” to describe a composite arch and descending stent graft prosthesis (4). Around the same time in Beijing, Professor Sun began implementing a similar one-stage strategy using a custom-designed stented graft which he termed “stented elephant trunk”, originally for DeBakey type I dissections. Though first used in 2003 and published in China in 2004 (5), Sun’s work wasn’t widely reported internationally until 2006 (6).

Commercial hybrid devices followed. The E-vita Open (Germany), Frozenix (Japan), and Thoraflex Hybrid (UK) became widely adopted across Europe and Asia from the mid-2000s onward. In 2022, Thoraflex Hybrid became the first FET device to receive Food and Drug Administration (FDA) approval in the United States. By 2013, Sun’s group had published outcomes in 398 consecutive patients undergoing the Sun procedure, solidifying its role in the global landscape of complex aortic repair (*Figure 2*) (7).

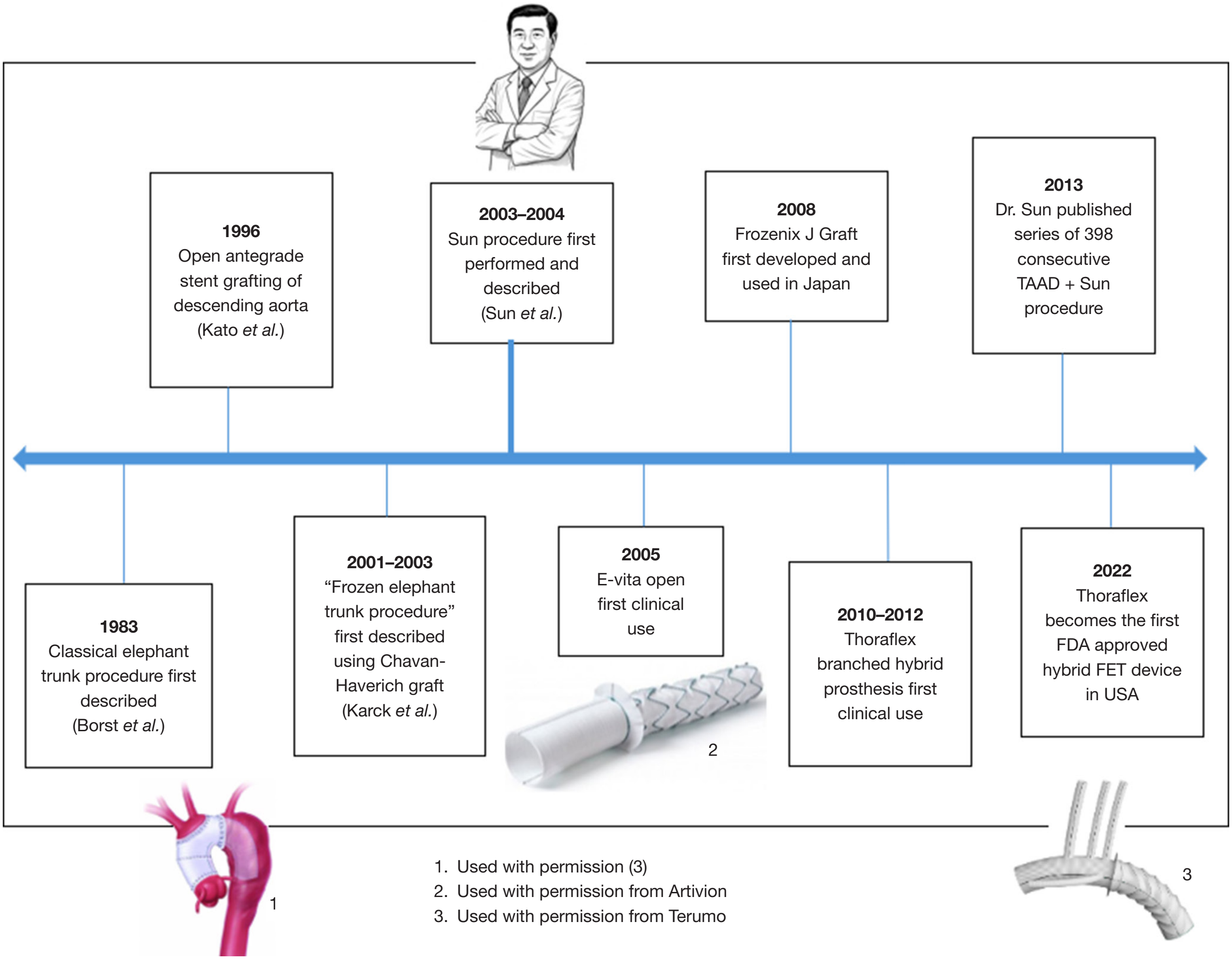

Figure 2 Timeline of the development of the frozen elephant trunk procedure. FDA, Food and Drug Administration; FET, frozen elephant trunk; TAAD, type A aortic dissection.

The evolution of the FET procedure in China: the Sun procedure

The Sun procedure has become virtually synonymous with the FET technique in China. Originally developed for use in acute and chronic type A dissections, over time its indications have expanded to include complex type B dissections, Marfan syndrome, and other heritable thoracic aortic diseases (HTADs). The nationwide growth in its use has been remarkable. From fewer than 100 cases in 2004, annual volumes surpassed 5,000 by 2016 and have continued to rise steadily. By 2024, nearly 13,000 FET procedures were being performed annually in China (*Figure 3*).

The Sun procedure

The Sun procedure is distinguished from other FET techniques by its use of the Cronus® stented graft (MicroPort, Shanghai, China) (*Figure 4*), although it can also be performed using other dedicated FET devices. Additionally, it employs a precise anastomotic sequence for arch vessel reimplantation that facilitates cerebral and spinal cord protection. The operation begins via median sternotomy, with cardiopulmonary bypass established through right axillary artery cannulation to allow selective antegrade cerebral perfusion. After cooling to 25 ℃ and initiating circulatory arrest, the aortic arch is opened and the stented graft deployed into the true lumen of the

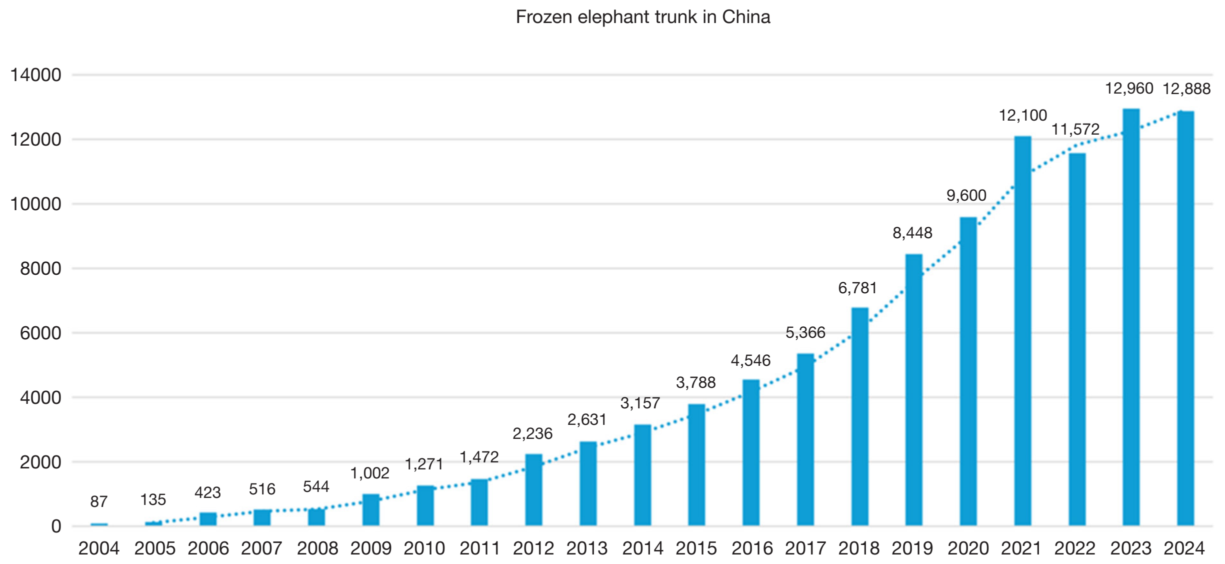

Figure 3 Growth of the frozen elephant trunk procedure in China [2004–2024]. Bar chart showing the annual number of FET procedure performed in China between 2004 and 2024. Y-axis represents the number of cases performed each year. FET, frozen elephant trunk.

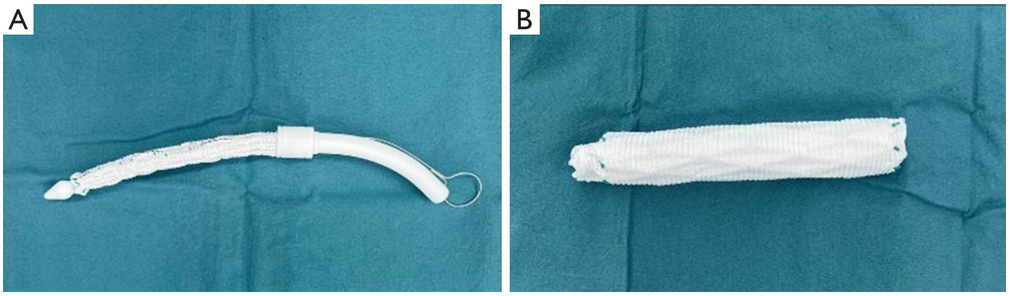

Figure 4 Cronus® stented prosthesis. (A) Pre deployment; (B) post deployment.

descending aorta (*Figure 5*). Total arch replacement follows using a tetrafurcate graft, with arch vessels reimplanted in a defined sequence: descending aorta, left carotid artery, ascending aorta, left subclavian artery, and innominate artery (*Figures 6-10*). Reperfusion of the lower body begins immediately after the distal anastomosis to minimize ischemic time. The early reimplantation of the left carotid artery facilitates prompt bilateral cerebral perfusion, allowing for systemic rewarming. These technical steps are designed to reduce the duration of hypothermic arrest and improve neurologic outcomes (8). Next, completion of the proximal aortic anastomosis permits release of the aortic cross clamp and reperfusion of the heart. The subclavian and innominate arteries are reimplanted during systemic rewarming. A detailed operative description is available online (https://www.annalscts.com/article/view/2723/html).

Outcomes of the Sun procedure

Acute type A aortic dissection (ATAAD)

Operative mortality and neurological complications

Across multiple FET configurations, early outcomes for ATAAD have steadily improved. In high-volume centers, in-hospital mortality typically ranges from 6–10%, with stroke and spinal cord injury (SCI) rates between 3–7% and 2–5%, respectively (9,10). The addition of FET to arch replacement is a class 2 recommendation during ATAAD repair to promote favorable aortic remodeling (11). Specific to the Sun procedure, outcomes are at least comparable and often favorable. In Sun's original 398-patient cohort, in-hospital mortality was 7.8%, with stroke and SCI each occurring in 2.5% (*Table 1*) (7).

Aortic remodelling and false lumen thrombosis (FLT)

The FET technique promotes distal aortic remodeling

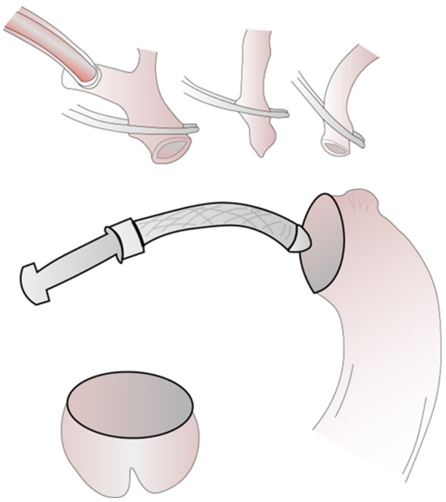

Figure 5 Deployment of stented prosthesis into descending aorta and distal aortic anastomosis. Reperfusion of the lower body commenced after the distal aortic anastomosis. Original work by Dr. Liang Chen.

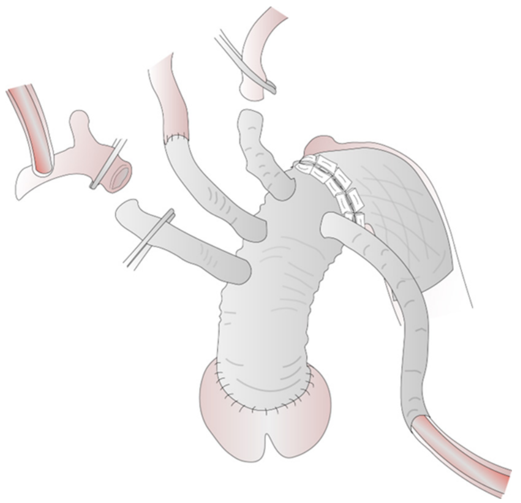

Figure 7 Ascending aortic anastomosis. Original work by Dr. Liang Chen.

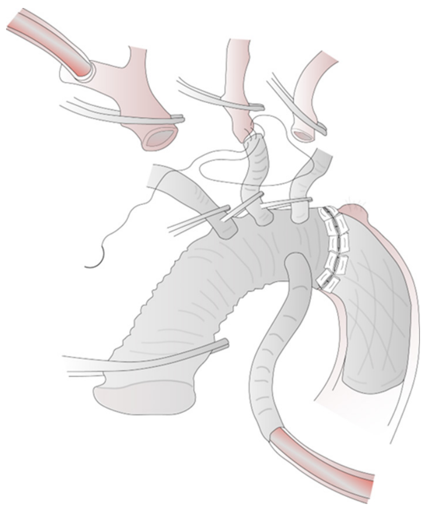

Figure 6 Left common carotid artery anastomosis. Original work by Dr. Liang Chen.

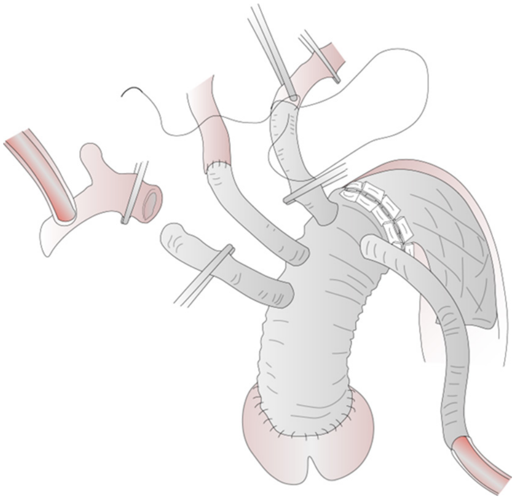

Figure 8 Left subclavian artery anastomosis. Original work by Dr. Liang Chen.

through induction of FLT and true lumen expansion. Imaging studies across FET configurations show FLT rates exceeding 90–95% in the stented segment at 3–6 months, with complete thrombosis at the level of the diaphragm occurring in up to 66% (18,19).

In Sun's series, FLT at the stented segment was achieved in over 94% of patients, while distal FLT to the level of the diaphragm ranged from 66–75%, depending on follow-up interval and imaging protocol (*Table 1*) (12).

Long-term survival and reinterventions

Long-term outcomes after FET are encouraging, with five-year survival rates of 80–85% reported across various configurations (20). In Sun-specific cohorts, outcomes are comparable with a reported three-year survival of approximately 85% (21).

Reintervention rates are also reduced due to the comprehensive nature of the Sun repair. In Tian *et al.*'s systematic review of 4,178 FET cases (including various techniques), freedom from any reintervention at five years was 87%, with most late procedures being planned second-

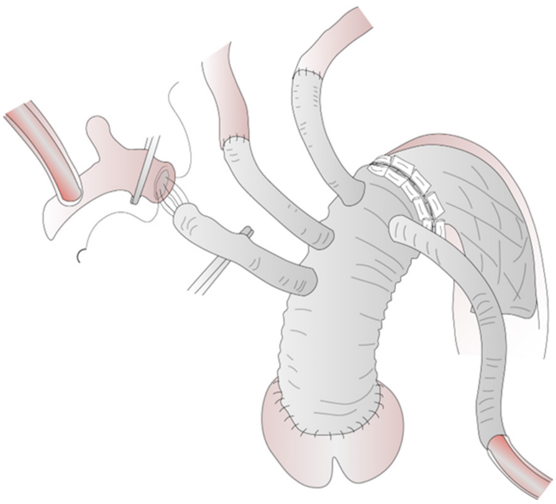

Figure 9 Innominate artery anastomosis. Original work by Dr. Liang Chen.

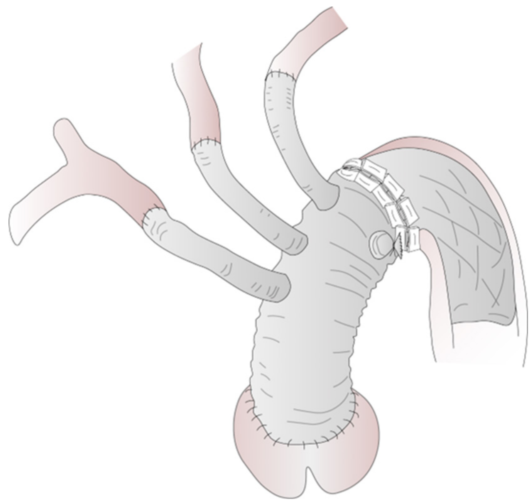

Figure 10 Completed Sun procedure. Original work by Dr. Liang Chen.

Table 1 Summary of previously reported outcomes of the Sun procedure in different aortic populations

Group	30-day mortality (%)	Stroke (%)	SCI (%)	Reintervention (%)	FLT at stented segment (%) at 3–6 months	Complete FLT (%)	Survival (5-year) (%)
Acute type A (7,12)	7.8	2.5	2.5	10–15	94	66–75	85
Chronic type A (10,13)	3.4–4.3	2–5	2–5	10–15	94.2	61.6	75–85
Complex type B (acute) (14,15)	0–4.1	0–1.9	0	3.8	92.3	67.3	91.7
Complex type B (chronic) (16)	5.2	0	0	5.3	94.1	N/A	N/A
HTAD/Marfan (17)	6.6	0.9	0.9	11 (6-year); 15–20 (10-year)	74–85	69–84.6	87

FLT, false lumen thrombosis; HTAD, hereditary thoracic aortic diseases; N/A, not available; SCI, spinal cord ischemia.

stage interventions rather than emergency reoperations (20). In Sun's experience, 85–90% of patients remained free of distal aortic reintervention at five years, highlighting the durability of this one-stage approach (17).

Chronic type A aortic dissection

Chronic type A aortic dissection presents unique technical challenges due to fibrosis, altered tissue planes, and persistent false lumen perfusion. Across all FET configurations, elective repair in this setting is generally safer than in the acute phase, with reported operative mortality ranging from 5–13% (20).

Operative mortality and neurologic complications

In Sun's early 89-patient series [2003–2007], in-hospital mortality ranged from 1–4% (12,13). A larger analysis by Ma *et al.* reported 4.3% mortality in chronic cases, significantly lower than acute presentations. Stroke and SCI rates remain low in high-volume Chinese centers, typically 2–5%, aided by spinal protection strategies such as cerebrospinal fluid drainage and early revascularization of the left subclavian artery (*Table 1*) (10).

Aortic remodelling and reintervention

Rate of FLT and distal remodeling in chronic cases are typically lower due to persistent distal perfusion channels and chronic scarring. In Sun's cohort, FLT at the stented segment was achieved in 94.2% of patients, while thrombosis at the level of the diaphragm reached 61.6% (13).

Long-term survival

Five-year survival after FET in chronic dissection cases is favorable. Most contemporary series report five-year survival between 75–85% (22). These outcomes are slightly lower than those in acute cases, likely due to differences in baseline comorbidities and chronic tissue remodeling but remain excellent compared to historical outcomes with limited arch repairs.

Freedom from distal reintervention at five years exceeds 85–90% in most Sun procedure series (17,21). The single-stage nature of the repair avoids the interval risk seen in classical two-stage operations and reduces the burden of staged intervention. When reoperations are needed, they are typically elective and performed in favorable anatomic settings created by the initial repair.

Complex type B aortic dissection

Complex type B aortic dissections involving the aortic arch that require open surgery can pose considerable challenges. Within China, guidelines subclassify Type B dissections as either complex (C) or Simple (S). The dissection is considered complex if (I) it involves the origin of the left subclavian artery or the distal aortic arch; (II) it is accompanied by cardiac diseases, such as valvular disease or coronary artery disease requiring intervention; (III) it is associated with proximal aortic pathologies, such as aortic root aneurysm, ascending aortic aneurysm, or aortic arch aneurysm or; (IV) it is caused by a HTAD, such as Marfan syndrome. The Committee of Great Vessels of Chinese Association of Cardiovascular Surgeons recommends the FET procedure for all complex type B dissections (23).

Acute complicated type B aortic dissection with arch involvement

Thoracic endovascular aortic repair (TEVAR) is the preferred approach for acute type B dissections requiring intervention, given its minimally invasive nature and favorable early outcomes. However, in a small subset of patients with arch extension, proximal tear location, or malperfusion, TEVAR may be inadequate or technically infeasible.

In such anatomically complex cases, the Sun procedure can be safely performed. In a series of 53 patients from 2011–2016 with acute type B dissection involving the arch there were no 30 day operative mortalities, the stroke rate was 2% and the reintervention rate was 3.8% at a mean follow-up of 31 months. Imaging demonstrated 92.3% FLT at the stented level, 67.3% at the diaphragmatic level and five-year survival reached 91.7% (*Table 1*). Another study of 24 consecutive patients with acute type B dissection treated with the Sun procedure reported a 30-day mortality of 4.1% (14). These results support the Sun procedure as a viable alternative in carefully selected patients where TEVAR is not appropriate (15).

Subacute and chronic type B aortic dissection with arch involvement

In the subacute and chronic phases, persistent false lumen perfusion and aneurysmal progression are common. TEVAR can be limited by inadequate proximal landing zones and high endoleak or reintervention rates (24).

In Sun's cohort of 19 patients with chronic type B dissection involving the arch, operative mortality was 5.2%, with low rates of neurologic complications. Although distal aortic progression led to reintervention in 5.3% aortic remodeling was favorable, with FLT in the thoracic segment and improved true lumen expansion (*Table 1*) (16). Comparative studies show the Sun procedure achieves lower endoleak rates (1.8%) than TEVAR/hybrid repair (9.9%) and lower operative mortality (1.3% *vs.* 12.4% respectively). Neurologic outcomes remain acceptable, with no significant difference between groups (25).

Long term survival and reinterventions

Although physiologically more demanding than TEVAR, the Sun procedure provides durable false lumen exclusion and long-term survival, particularly in younger patients with complex anatomy (16).

Importantly, the one-stage repair addresses proximal pathology and creates a stable landing zone for potential future endovascular extensions.

Marfan and HTADs

Operative mortality

The Sun procedure has been widely adopted in China for patients with Marfan syndrome and other HTAD presenting with extensive aortic disease. In Professor Sun's early series [2004–2006] of 13 Marfan patients with acute type A dissection, all survived to hospital discharge, establishing early feasibility (26). Larger single-institution series show acceptable early mortality. In a subset of 106 Marfan patients, Ma *et al.* reported an operative mortality of 6.6% (*Table 1*) (17). For chronic dissection, a separate series of 44 Marfan patients (19 acute, 25 chronic) undergoing arch replacement with FET, reported 8% mortality (27). Internationally, outcomes vary—a dual-institution European study of 437 arch replacements with FET, including 30 Marfan patients, reported an overall in-hospital mortality of 14.9%, with Marfan syndrome identified as a risk factor for mortality (28). Notably, many of the favorable Chinese outcomes were reported from high-volume centers using standardized Sun procedure protocols, whereas international data often reflects broader variability in surgical experience, patient selection, and device choice.

Neurological outcomes

Neurologic complication rates in HTAD patients undergoing the Sun procedure are low. In a study of 106 Marfan patients, the stroke and paraplegia rates were <1%, with similarly low complication rates seen in chronic cases (17). HTAD patients are also typically younger and have fewer cerebrovascular risk factors, which may reduce baseline susceptibility.

Aortic remodelling

Effective remodeling of the dissected aorta is particularly important in HTAD patients given their diffuse aortic wall fragility. In Sun's early Marfan series, complete FLT was observed in 84.6% around the stented segment and 69.2% at the diaphragm (26). Subsequent studies confirmed high rates of false lumen obliteration in the stented segment (~74%), with reduced thrombosis distally. Although persistent false lumen flow beyond the stent—especially in the abdominal segment—remains common, proximal control prevents rapid degeneration and delays the need for secondary interventions. These findings emphasize the importance of addressing the arch and descending thoracic aorta in HTAD patients, rather than limiting repair to the ascending aorta alone.

Long-term survival and reinterventions

Long-term survival in HTAD patients after the Sun procedure is excellent given the complexity of their disease. In a 106-patient Marfan cohort, five-year survival was 87%, with eight-year survival around 74% (17). Late reintervention is infrequent. In Sun's Marfan cohort, only 11% of patients required reoperation over a mean follow-up of 6 years. Freedom from reoperation was 88.8% at 5 years and ~80–85% at 10 years. Most late procedures involved the distal aorta and were often planned extensions of the initial repair (17). Importantly, studies show that patients undergoing more extensive initial repairs (i.e., total arch + FET) have better long-term survival than those who receive limited root or ascending repairs requiring future staged procedures (29). Experience with other HTADs is more limited. Loeys-Dietz patients may be treated similarly to Marfan patients, with individualized risk stratification. Vascular Ehlers-Danlos patients, due to extreme tissue fragility, are rarely candidates for FET.

Contemporary institutional outcomes of the Sun procedure

The Sun procedure has been widely adopted across China for the treatment of ATAAD. Although favorable outcomes have been reported from high-volume centers, institutional series offering detailed early data using modern operative protocols remain limited. Delta Health Hospital in Shanghai is a dedicated aortic program where Professor Sun performs the Sun procedure as the default strategy for arch repair. This study aims to present the contemporary operative characteristics and early outcomes of patients undergoing the Sun procedure for ATAAD at DeltaHealth between 2016 and 2024.

Methods

A retrospective analysis was conducted on 766 consecutive patients with ATAAD treated at DeltaHealth Hospital from 2016 to 2024. 729 patients underwent surgical repair whereas 37 were managed non-operatively. In DeltaHealth five surgeons, including Professor Sun, performed the procedures. The Sun procedure is standardized across all technical steps at DeltaHealth, enabling consistent execution by surgeons at different experience levels. Surgical fellows initially assist in at least 50 cases before advancing to the primary surgeon role under senior surgeon supervision from the first assistant position. The primary difference between junior and senior surgeons is operative duration, with clinical outcomes remaining consistent. Thus, the presented results reflect institutional performance achievable by both senior and trained junior surgeons.

The Sun procedure was performed in the standard fashion as previously described. Patients underwent postoperative surveillance for neurological, renal, pulmonary, and systemic complications. Patients were followed postoperatively at standardized intervals: pre-discharge, and at 1, 3, 6, and 12 months, then annually thereafter. At each time point, follow-up was conducted either through in-person clinic visits or virtual consultations and included computed tomography imaging.

Baseline characteristics including age, sex, body mass index (BMI), and history of comorbidities, and operative details were summarized as mean (standard deviation) for continuous variables and number (percentage) for categorical variables. Outcomes, including 30-day mortality, stroke, SCI, reintervention, FLT at stented segment at 3–6 months, complete FLT, and survival, were calculated as percentages across different aortic procedure groups: acute type A, chronic type A, complex type B (acute), complex type B (chronic), and HTAD/Marfan.

Table 2 Baseline characteristics

Variable	Values (N=729)
Age (years)	52.7±14.1
Male gender	536 (73.5)
Body mass index (kg/m^2)	26.3±4.7
Comorbidities	
Hypertension	496 (68.0)
Diabetes mellitus	27 (3.7)
Cerebrovascular accident	30 (4.1)
Coronary artery disease	33 (4.5)
Chronic obstructive pulmonary disease	9 (1.2)
Chronic renal insufficiency	25 (3.4)
Current or previous smoker	77 (10.6)
Known aortic aneurysm	12 (1.6)
Marfan syndrome	99 (13.6)
Dual antiplatelet therapy	97 (13.3)
Coronary artery malperfusion	99 (13.6)
Central nervous system malperfusion	60 (8.2)
Spinal cord malperfusion	16 (2.2)
Lower limb malperfusion	25 (3.4)
Cardiac tamponade	139 (19.1)

Data are presented as mean ± standard deviation or n (%).

Table 3 Operative details

Variable	Values (N=729)
Pre-operative time (minutes)	88.0±60.7
Operation time (minutes)	355.8±108.7
Cardiopulmonary bypass time (minutes)	189.1±64.7
Cross-clamp time (minutes)	116.3±43.2
Hypothermic circulatory arrest time (minutes)	17.7±5.7
Aortic valve resuspension	312 (42.8)
Aortic root	
Bentall procedure	141 (19.3)
David procedure	3 (0.4)
Wheat procedure	10 (1.4)
Arch	
Hemi arch	88 (12.1)
Sun procedure (TAR + FET)	573 (78.6)
Combined operation	
CABG	49 (6.7)
MVP/MVR	7 (1.0)
TVP	7 (1.0)
Reoperation	33 (4.5)
Length of stay (days)	16.3±11.5

Data are presented as mean ± standard deviation or n (%). Pre-operative time: arrival time to DeltaHealth to skin incision. CABG, coronary artery bypass grafting; FET, frozen elephant trunk; MVP, mitral valve plasty; MVR, mitral valve replacement; TAR, total arch replacement; TVP, tricuspid valve plasty.

Results

The baseline patient characteristics and comorbidities are represented in *Table 2*. The mean age of patients was 52.7±14.1 years, and 73.5% were male. Mean body mass index (BMI) was 26.3±4.7 kg/m^2. Hypertension was present in 68% of patients, followed by coronary artery disease (4.5%), diabetes mellitus (3.1%) and chronic obstructive pulmonary disease (1.2%). The history of cerebrovascular disease was noted in 4.1%, while 3.4% had chronic kidney disease, 13.6% had Marfan syndrome and 19.1% had cardiac tamponade at presentation. Operative times were as follows: mean total operative time was 355.8±108.7 minutes, cardiopulmonary bypass time was 189.1±64.7 minutes, aortic cross-clamp time was 116.3±43.2 minutes, and circulatory arrest duration was 17.7±5.7 minutes. Among the 729 patients who underwent surgery, 573 patients (78.6%) underwent total arch replacement with FET using the Sun procedure, and 12.1% underwent a hemi arch repair. Aortic valve resuspension was performed in 42.8% of patients and 19.3% of patients underwent Bentall procedures. Concomitant procedures included coronary artery bypass grafting (6.7%) and mitral or tricuspid valve repair in 2% of cases (*Table 3*).

Operative/30-day complication rates are summarized in *Table 4*. In-hospital mortality was 4.1%. Major complications included stroke (10.2%), reflecting broader inclusion of transient neurologic symptoms and asymptomatic infarcts; temporary neurological deficit 3%, permanent neurological deficit 7.1%, SCI (2.6%), acute renal failure (8.4%), gastrointestinal complications (4.1%), and reoperation for bleeding (14.3%). Sternal dehiscence and limb ischemia occurred in 1.8% and 1.6% respectively. In hospital length of stay (LOS) was 16.3±11.5 days.

Table 4 Postoperative complications

Variable	Values
Pre-operative death (or could say… died prior to aortic repair/medically managed)	37/766 (4.8)
In-hospital death	30/729 (4.1)
Reoperation for bleeding	104/729 (14.3)
Sternal dehiscence	13/729 (1.8)
Stroke	74/729 (10.2)
Temporary neurological deficits	22/729 (3.0)
Permanent neurological deficits	52/729 (7.1)
Spinal cord injury	19/729 (2.6)
Acute renal failure	61/729 (8.4)
Pulmonary complication	45/729 (6.2)
Limb ischemia	12/729 (1.6)
Gastrointestinal complication	30/729 (4.1)

Data are presented as n/N (%).

Discussion

The FET technique has redefined the surgical management of complex thoracic aortic disease. Although numerous FET variations have emerged worldwide, the Chinese experience—centered on the Sun procedure—stands apart in scale, procedural consistency, and reproducibility across institutions.

The Sun procedure, first introduced by Professor Li-Zhong Sun in 2003, rapidly gained national traction and is now the predominant FET strategy in China, with over 100,000 cases performed nationwide. This large-scale adoption, driven by a standardized surgical sequence, the Cronus® stented graft, and uniform cerebral protection protocols, enables longitudinal outcome analysis rarely feasible in more heterogeneous Western datasets.

One distinguishing feature of the Chinese experience is the younger demographic of ATAAD patients. In this series, the mean age was 52.7 years—approximately a decade younger than reported in the IRAD registry and Western cohorts (30). This may reflect higher prevalence of HTADs, higher rates of uncontrolled hypertension, earlier referral patterns, and differences in disease detection.

Despite a high proportion of patients presenting with critical features—including cardiac tamponade (19.1%), coronary malperfusion (13.6%), and central nervous system malperfusion (8.2%)—operative mortality in this data set remained low at 4.1%. These results compare favorably to leading international centers, where in-hospital mortality for ATAAD with FET often ranges from 6–10% (31).

Neurologic complications were within expected ranges for FET. At presentation 8.2% of patients had evidence of cerebral malperfusion. Post-operative outcome data showed that stroke occurred in 10.2% of patients, though this figure reflects a broader diagnostic framework that includes transient neurologic symptoms and radiologic infarcts without lasting deficits. SCI occurred in 2.6%, which compares with contemporary data (20).

This dataset also confirms the durability of the Sun procedure in HTAD patients, particularly those with Marfan syndrome, who represented 13.6% of this cohort. Five-year survival in prior Marfan-specific Sun series exceeds 85%, and distal reintervention rates remain low (~10–15% at 10 years), most of which are planned second-stage procedures (17). High rates of proximal thrombosis and true lumen expansion suggest that even in syndromic aortopathy, the Sun procedure achieves stable remodeling of the thoracic aorta.

Finally, operative times and complication rates in this cohort support the notion that, despite the technical demands of total arch replacement, the Sun procedure remains efficient and reproducible when performed in experienced settings. Although the Sun procedure compares favorably to international registry data for platforms such as Thoraflex, E-vita Open, and Frozenix, direct comparisons may be confounded by limitations of registry data as well as differences in patient selection, institutional volume, and reporting standards (32). Importantly, existing evidence suggests that when used appropriately, all contemporary FET techniques achieve the fundamental goals of proximal aortic control, distal remodeling, and long-term durability.

A potential limitation of this study is the inherent selection bias related to the structure of the Chinese healthcare system. Due to geographic and systemic disparities in access to care, patients with aortic disease often travel long distances to tertiary centers, typically after self-selecting for survival and stability. As a result, outcomes may reflect a somewhat preselected cohort and may not fully represent the broader national patient population.

Conclusions

The Chinese experience with the Sun procedure highlights the potential of standardized surgical strategies in complex aortic disease. This national dataset affirms the technique's safety, durability, and adaptability across acute, chronic, and heritable aortic pathologies. As global interest in FET continues to grow, the Sun procedure may serve as a model for high-volume, reproducible, and scalable aortic surgery.

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