

A Novel Standardized Suturing Technique versus Conventional Sun's Procedure for Frozen Elephant Trunk Arch Replacement in Acute Type A Aortic Dissection

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Abstract

Background and Rationale: The elephant trunk technique with a frozen stent has become a widely used approach for aortic arch replacement in acute type A aortic dissection (AAAD), especially in Asia, and is linked to low operative mortality. However, complications—especially endo-leaks—remain common. In this study, we improved the anastomosis technique in AAAD surgery by standardizing and modularizing the suturing process. We analyzed data from AAAD patients treated at our center over seven years and compared the new technique with the traditional Sun's procedure to assess its clinical benefits. **Methods:** Between July 2018 to June 2025, our hospital has treated a total of 1,591 patients with aortic dissection and 1157 patients underwent operation. Among them, 720 cases of AAAD according to Stanford classification underwent total arch replacement with frozen elephant trunk. A total of 648 patients met enrollment criteria and were included in this study. Of these, the study group consisted of 138 patients who underwent the novel suture technique (Ma's procedure) for the total arch replacement with frozen elephant trunk procedure, while the control group included 510 patients who underwent conventional Sun's procedure.

Results: The in-hospital mortality rates for the study group and the control group were 5.07% and 7.25% respectively, with a significant difference ($P=0.366$, OR(Odds Ratio)=0.68 (95% CI: 0.30–1.57)). The study group had longer periods of deep hypothermic circulatory arrest and selective cerebral perfusion than the control group ($P < 0.05$), and significantly less intraoperative blood product usage ($P < 0.05$). The postoperative mechanical ventilation time, ICU stay time, and hospital stay time were all significantly shorter in the study group than in the control group ($P < 0.05$). The postoperative thoracic drainage volume and complication rate were lower in the study group ($P < 0.05$). The survival curve of the study group was significantly better than that of the control group during the follow-up period

($P < 0.05$). The rates of false lumen presence at the aortic root, distal anastomotic leakage, heart failure, aortic valve regurgitation, and atrial fibrillation were significantly lower in the study group than in the control group ($P < 0.05$).

Conclusions: This study suggests that Ma's procedure has successfully achieved thoraco-aortic remodeling and dissection closure and effectively reduced the incidence of complications and re-operation rate. It has indicated favorable mid-term clinical outcomes and seems to be considered as a safe alternative to conventional Sun's procedure.

Key Words: A novel suture technique, acute type A aortic dissection (AAAD), Sun's procedure
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Introduction

Acute aortic dissection is a highly lethal cardiovascular emergency [1], with acute type A aortic dissection (AAAD) carrying a 24-hour mortality rate as high as 50 percent if left surgically untreated. Emergency surgical repair is the first choice of treatment in AAAD and remains the cornerstone of management [2–4]. Repairing the intimal tear of the aorta and closing the resulting false lumen constitutes the primary surgical approach for managing AAAD. Although this strategy improves survival, it is associated with substantial long-term mortality and reintervention rates [5].

To address these limitations, aortic arch replacement surgery has emerged as an alternative, leading to substantial enhancements in survival rates and reoperation rates. Surgical strategies for AAAD have progressed from the early stage of total arch replacement (TAR) with elephant trunk graft implanted in descending aorta, to the era of total arch replacement with implantation of frozen elephant trunk (FET) stent [6, 7]. In China, Sun's procedure – a modified TAR with FET first reported in 2004 – has become the standard operation for AAAD [8]. This surgical approach initially employs the novel FET stent implantation technology to achieve favorable outcomes in closing and preventing bleeding of distal arch thoracic aortic dissection [7, 8]. Moreover, it effectively addresses bleeding issues specific to patients by utilizing a method that preserves the original blood vessel wall wrapping around the arch of the aorta for internal drainage. This strategy successfully mitigates significant blood loss and reduces surgical mortality rates [3].

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Clinical data has shown that Sun's procedure has achieved good clinical outcomes [8-10]. However, as Sun's procedure has become popular in China and other countries, limitations for this procedure have emerged [8, 9]. The operation involves intraluminal suture and preserves the part wall of ascending aorta and aortic arch [11]. To achieve hemostasis, this method that retains autologous arterial wall to wrap around vascular graft and directly connects to the right atrium, called a "right atrium shunt" or "internal drainage", is available [12]. However, vascular left-right shunt maybe impacts hemodynamics and leads to a series of complications. For patients of Asian ethnicity with coagulation mechanism defects [13], the technical requirements for anastomosis suture should be high if internal drainage is not wrapped by own blood vessels, especially in the case of no effective hemostatic glue is available, which is a challenge for Asian cardiovascular surgeons. Dr. Ma made a novel improvement on the anastomotic technique for the operation of AAAD. That is based on the anatomical characteristics specific to different anastomotic sites and tries to avoid bleeding caused by defective coagulation mechanisms in Asian ethnic groups. Additionally, he standardized and modularized suturing at each anastomotic step (Ma's procedure).

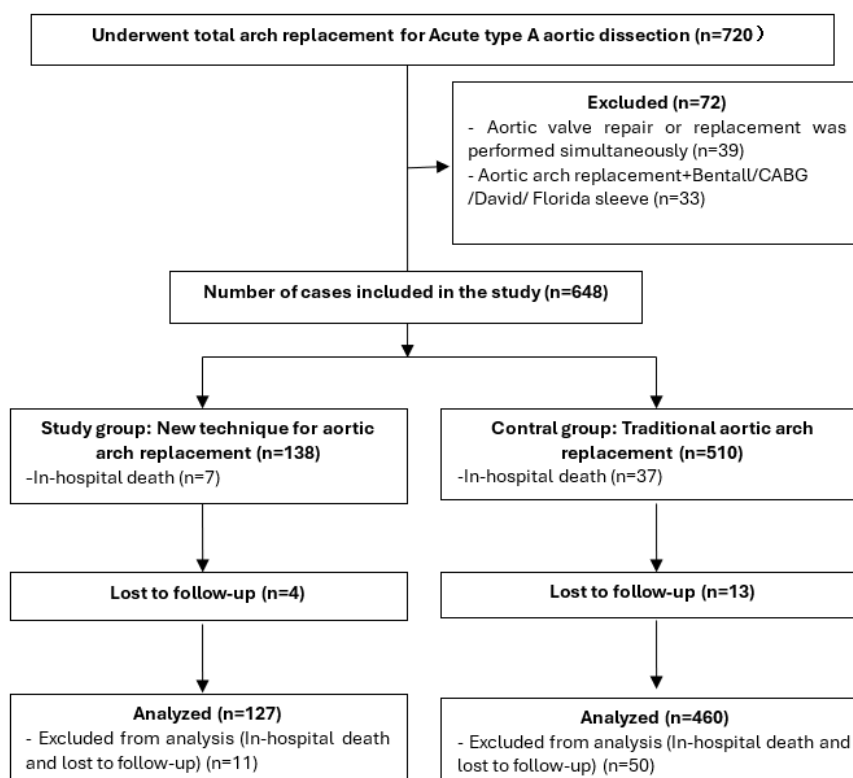
In this study, we retrospectively collected clinical data from the AAAD patients treated in our center near 7 years, and try to compare effectiveness of the novel method against conventional Sun's procedure.

Methods

Study Design and Patient Population

This study was approved by the Ethics Committee of Qilu Hospital of Shandong University. A total of 1591 acute aortic dissection patients (including type A and type B aortic dissection) from July 2018 to June 2025 at our hospital were screened and 1157 patients underwent operation, and 720 of AAAD patients underwent frozen elephant trunk with total arch replacement (FETAR). From this cohort, we excluded patients with chronic type A aortic dissection, as well as those who did not undergo either the Ma's procedure or the conventional Sun's procedure. After applying these exclusion criteria, a total of 648 patients were finally included in the study, with 138 patients in the Ma's procedure group and 510 patients in the Sun's procedure group. Details are in the Table 1.

TABLE 1. The Inclusion Criteria and Details Were Patients with Isolated AAAD.



Operative Technique (Ma's Procedure)

The study group used Ma's procedure. Extracorporeal Cardiopulmonary bypass circulation was established by right axillary artery combined with unilateral femoral artery cannulation for arterial perfusion, and both superior and inferior vena cava cannulation for venous drainage. The left heart vent was inserted via right upper pulmonary vein, and myocardial protection was mainly achieved through direct infusion of HTK cardioplegia solution into the left and right coronary ostia. In some cases, both antegrade and

retrograde cardioplegia infusion were performed for patients with coronary ostium injury. Nasopharyngeal temperature was induced to 26°C, and rectal temperature be below 30°C, at which point cardiopulmonary bypass was interrupted and selective cerebral perfusion was initiated via the right axillary artery.

A series of standardized steps for Ma's procedure including aorta root forming, distal anastomosis, proximal anastomosis and three-branch anastomosis followed.

The first step: Aorta root forming technique. The ascending aorta was clamped and the heart was arrested with HTK solution perfusion. The ascending aorta was transected at 1 cm above the junction of aortic sinus and ascending aorta, and the dissection intramural hematoma of aorta root was removed. Subsequently, two vascular grafts (Woven Vascular Prosthesis, Terumo Company,

Scotland), strips approximately 8mm wide were separately placed on both inner and outer edges of the residual end of the aorta root, followed by continuous horizontal mattress suturing using 4-0 prolene circumferentially in two layers, creating a “sandwich” configuration with the second layer crossing over the first layer (Figure 1(A1/A2)).

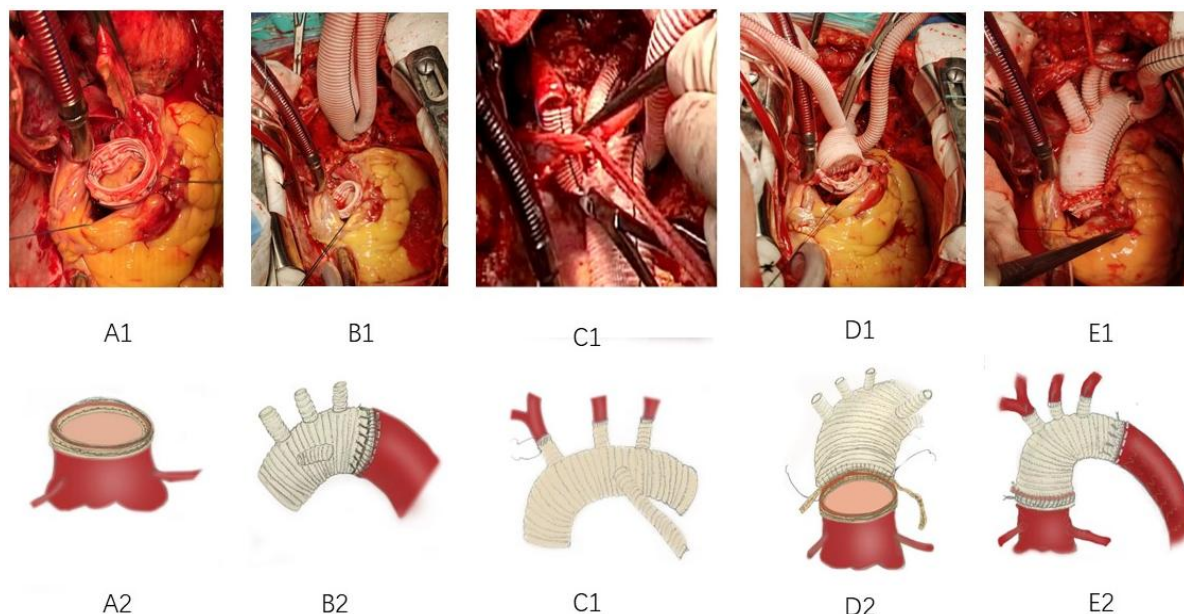


FIGURE 1. The morphology of each anastomosis and vascular graft shown in the frozen elephant trunk aortic arch replacement with novel suture technique.

A1/A2: Root manipulation shown in frozen elephant trunk aortic arch replacement with novel suture techniques: vascular grafts are placed on both sides of the proximal end of the ascending aorta, and a sandwich structure is formed by continuous horizontal mattress sutures two circles using 4-0 prolene. **A1:** Operative photo of the procedure. **A2:** Schematic diagram of the procedure.

B1/B2: Distal anastomosis handling shown in frozen elephant trunk aorta arch replacement with novel suture technique: The distal end of the four branch vascular grafts was sutured continuously with 4-0 prolene with the frozen elephant trunk stent and the distal aortic vessel wall. Subsequently, they were sutured intermittently with 3-0 prolene with felt shim suture in horizontal mattress for 1 circle. **B1:** Operative photo of the procedure. **B2:** Schematic diagram of the procedure. **C1/C2:** Three-branch vascular anastomosis shown in frozen elephant trunk aorta arch replacement with novel suture technique: 5-0 prolene continuous suture vessel and the native vessel stump, with a margin of approximately 3-4mm, to maintain the expansion force at the anastomotic site of the prosthetic graft. **C1:** Operative photo of the procedure. **C2:** Schematic diagram of the procedure.

D1/D2: Proximal anastomosis handling shown in frozen elephant trunk aorta arch replacement with novel suture technique: The proximal end of the four branch vascular grafts was sutured continuously with 4-0 prolene with the edge of the sandwich structure at the root of the ascending aorta. In addition, autologous pericardial strips were embedded in the anastomosis. **D1:** Operative photo of the procedure. **D2:** Schematic diagram of the procedure. **E1/E2:** The shape of the vascular blood vessel and the hemostasis of the anastomotic stoma are shown in the frozen elephant trunk aortic arch replacement with novel suture technique. **E1:** Operative photo of the procedure. **E2:** Schematic diagram of the procedure.

The second step: Distal anastomosis technique. When the patient's body temperature dropped to 26°C in the nasopharynx, circulatory arrest was initiated, and the selective cerebral perfusion was maintained at a flow rate of 5-10 ml/kg/min. The innominate artery, left common carotid artery, and left subclavian artery were separately cross clamped by atraumatic hemostatic forceps. The ascending aorta and aortic arch were resected up to the distal site of the left subclavian artery opening, then the intramural thrombus was cleared. Under direct view, a frozen elephant trunk stent graft (Cronus, Endovastec, MicroPort Co. LTD, Shanghai, China) was inserted and released in the thoracic descending aorta. We used 4-0 prolene suture to continuously suture the distal edge of the four-branched vascular graft (Woven Vascular Prosthesis, Terumo Company, Scotland) and the proximal edge of the elephant trunk

stent graft together with the arterial wall of distal arch (As shown in Figure 1 (B1/B2)). Subsequently, horizontal mattress using 3-0 prolene suture with felt pad was performed for the second circle to reinforce distal anastomosis. Finally, the proximal end of the four-branched vascular graft is clamped and the cardiopulmonary bypass was restarted.

The third step: Three-branch anastomosis technique. The proximal end of the left subclavian artery and the branch of the vascular graft were sutured continuously using 5-0 prolene thread. The key technique for the anastomosis is to widen the stitching margin appropriately. After opening the vascular graft, the de-airing was performed by releasing the vascular clamp, and knotting the sutures (Figure 1 (C1/C2)).

The last step: Proximal anastomosis technique. By continuous suturing using 4-0 prolene thread, the trimmed proximal vascular graft was anastomosed to the reconstructed aortic root with sandwich technique. An autologous pericardial strip about 1 cm width was interposed at the anastomotic site to achieve good hemostasis, and the stitches were tightened sequentially (Figure 1 (D1/D2)). After de-airing of the left heart system, the ascending aorta cross clamped was released to resume cardiac perfusion and autonomous heart-beat.

The same suturing technique with the third step was performed to reconstruct the innominate artery. Finally, all of the anastomosis are checked for the bleeding, and make sure the good layout of the vascular graft. (Figure 1 (E1/E2)).

Additional intraoperative measures included intermittent ice slurry for myocardial protection and tension-free suturing. Each stitch was tightened gently with a nerve hook applied perpendicular to the suture line to avoid tearing. After rewarming to a nasopharyngeal temperature of 36.5°C, the cardiopulmonary bypass was maintained for an additional 30 minutes until core temperature (rectal temperature) reached 35°C. Once patients were hemodynamically stable, the cardiopulmonary bypass was weaned off, then the protamine was given to neutralize the heparin. Adequate hemostasis was ensured prior to chest closure.

In our hospital, the frozen elephant trunk (FET) graft and Four-branched vessel prosthesis is available in only two diameter sizes (26 mm and 28 mm). Because preoperative CTA often cannot accurately measure the true intimal diameter due to the presence of dissection, our size selection is primarily based on the intraoperative measurement of the aortic intimal diameter. Specifically, we chose the 28-mm graft when the measured intimal diameter is ≥ 28 mm, and the 26-mm graft was chose when it is < 28 mm. It also should be noted that bilateral near-infrared spectroscopy (NIRS) for cerebral oxygen saturation monitoring to ensure adequate cerebral perfusion was not used as a routine measure because of the limited availability of monitoring equipment during the study period.

Sun's Procedure (Control Group)

The control group underwent conventional Sun's procedure which involved a longitudinal incision of the aorta as described previously [7]. The ascending aorta and aortic arch were routinely preserved. An elephant trunk stent was implanted in the distal end of the arch under direct visualization. The vascular graft was respectively anastomosed to the opened vessels at their proximal and distal ends. Subsequently, the three branches of aortic arch were constructed. To control bleeding, autologous arterial wall or pericardial patch was used to wrap around the vascular graft, forming a false lumen that was connected with the right atrium ("internal drainage" technique; Figure 2). No biologic or hemostatic was applied at any anastomotic site.

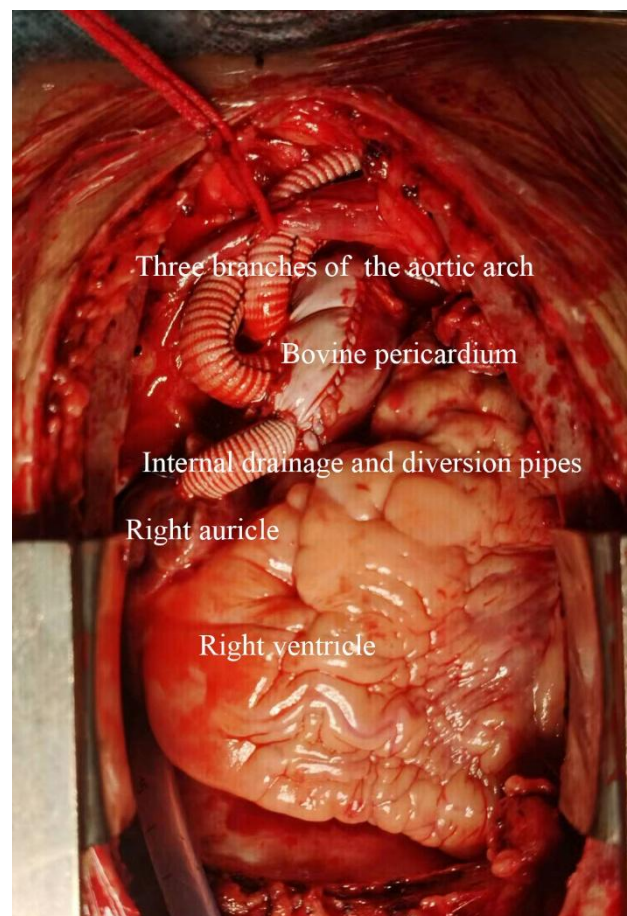


FIGURE 2. The ascending aorta and aortic arch wrapping technique are shown in the conventional Sun's procedure.

Definition of Postoperative Complication

Hypoxemia was defined as a partial pressure of arterial oxygen (PaO_2) < 60 mmHg or peripheral oxygen saturation (SpO_2) < 90% while on mechanical ventilation. Severe cardiac failure was defined as a left ventricular ejection fraction (LVEF) < 30% assessed by bedside echocardiography. Severe liver dysfunction was defined as serum transaminase levels (primarily ALT and AST) exceeding 5 times the upper limit of normal (ULN), Bilirubin levels rise sharply, with a daily increase potentially $\geq 17.1 \mu\text{mol/L}$ and concentrations often exceeding $171 \mu\text{mol/L}$, and/or developed phenomenon of "bilirubin-enzyme dissociation" (characterized by persistently elevated bilirubin levels accompanied by a decline in transaminase levels). Severe kidney failure was defined as the need for continuous renal replacement therapy (CRRT) postoperatively. Cerebral complications were defined as new cerebral infarction or hemorrhage confirmed by computed tomography (CT), accompanied by clinical manifestations such as hemiplegia, confusion, coma, or lethargy. Paraplegia was defined as motor dysfunction of both lower extremities. New-onset atrial fibrillation was defined as atrial fibrillation newly diagnosed postoperatively in patients without a prior history of atrial fibrillation. Incision infection was defined as poor wound healing with positive bacterial culture after wound dressing changes.

Data Collection

Clinical data were collected based on case records, perioperative data included in-hospital mortality, operative time, cardiopulmonary bypass (CPB) time, aortic clamping time, time of hypothermic circulatory arrest, selective cerebral perfusion time, mechanical ventilation time, intensive care unit (ICU) stay time, postoperative hospitalization duration, blood product usage during operation and drainage volume within 24 hours after operation, complication (such as secondary tracheal intubation post-operation,

severe cardiac failure, severe liver dysfunction, cerebral complication, hypoxemia, paraplegia, incision infection) were also collected. Follow-up data were collected include false lumen existed in aortic root, re-operative rate, incidence of endo-leak in distal anastomosis, incidence of permanent atrial fibrillation.

Statistical Analysis

All data were analyzed using Stata SE 18 software. Descriptive statistics for continuous variables were presented as mean $\pm$ standard deviation, and the Student t-test was used for continuous variable comparisons. Categorical variables were reported as frequencies (percentages). Association between categorical variables were evaluated by using Chi-squared test or Fisher's exact test. Postoperative survival rates and incidence of adverse events were analyzed using Kaplan-Meier survival analysis (95% CI), with a significance level set at $P < 0.05$ to indicate statistical significance.

Results

In-Hospital Mortality

Baseline preoperative characteristics were comparable between the groups with no significant difference (Table 2). The primary endpoint of perioperative endpoints is death. In study group had 7 cases of in-hospital deaths (7/138), with a mortality rate of 5.07%. These deaths were due to pulmonary infections caused by multiple antibiotic-resistant bacteria, multiple organ failure, and myocardial infarction. In the control group, there were 37 cases of in-hospital deaths (37/510), with a mortality rate of 7.25%. The main causes of death in the control group included pulmonary infections caused by multiple antibiotic-resistant bacteria, multiple organ failure, paraplegia, myocardial infarction and heart failure. The difference in mortality between groups was statistically significant ($P = 0.366$, OR (Odds Ratio) = 0.68 (95% CI: 0.30–1.57)).

TABLE 2. Comparison of The Baseline Characteristics between The Study Group and The Control Group.

Baseline Characteristics	Study group (n=138)	Control group (n=510)	t/ χ^2	P value
Age	54.4 $\pm$ 13.0	56.3 $\pm$ 12.3	-1.596	0.140
Male/female	84/54	286/224	1.018	0.313
From symptom onset to surgery			1.811	0.404
<24h	31	89		
1-13d	98	285		
>14d	9	36		
Hypertension	95	340	0.233	0.630
Previous cardiac operation	6	27	0.130	0.718
Marfan syndrome	16	62	1.504	0.220
Cerebrovascular disease	9	17	3.138	0.076
Diabetes mellitus	23	80	1.949	0.163
Chronic kidney disease	6	18	0.327	0.568
Primary entry			0.576	0.902
Ascending aorta	86	326		
Arch	16	63		
Type B Reverse tear	29	93		
Multiple entry	7	28		
Aortic valvular regurgitation	32	137	0.761	0.383
Hydrothorax	105	398	0.238	0.625
Pericardial tamponade	19	97	2.038	0.153
ECG s-t changes	35	135	0.069	0.793
Acute visceral ischemia	12	40	0.030	0.862

Acute renal insufficiency	9	36	0.048	0.826
Lower limb ischemia	7	28	0.037	0.847
Transient cerebral coma	6	18	0.204	0.652

ECG: electrocardiograph.

The secondary endpoint of perioperative endpoints is postoperative complication. The study group had significantly longer hypothermic circulator arrest and selective cerebral perfusion times than the control group ($P<0.05$). However, there was no significant difference in operation time, cardiopulmonary bypass time and

aortic clamping time between the two groups ($P>0.05$). The study group used significantly fewer blood products (red blood cell suspension, Frozen plasma) during operation compared with the control group ($P<0.05$) (Table 3).

TABLE 3. Comparison of Clinical Indicators between The Study Group and The Control Group.

Clinical index	Study group (n=138)	Control group (n=510)	t/u/ χ^2	P value
Operative time (min)	387.1±57.5	396.8±53.6	-1.872	0.850
CPB time (min)	185.4±36.1	180.5±38.5	1.350	0.807
Aortic clamping time (min)	133.9±36.9	127.8±37.7	1.686	0.883
Time of hypothermic circulatory arrest(min)	37.7±4.9	25.5±6.0	22.040	0.005
Selective cerebral perfusion time (min)	49.0±5.0	32.5±6.0	29.621	0.004
Mechanical ventilation time(h)	33.6±21.8	39.3±25.7	-2.398	<0.001
Length of ICU stay (day)	2.89±1.92	3.44±2.08	-2.799	<0.001
Length of hospital stay post operation	10.64±2.55	12.10±3.50	-4.597	<0.001
Blood product dosage				
Red blood cell suspension (U)	5.69±2.23	6.50±2.83	-3.119	0.005
Frozen Plasma (ml)	541.3±197.7	599.2±237.1	-2.632	0.011
Drainage volume within 24 hours after operation (ml)	435.8±177.9	498.2±208.2	-3.214	0.190
In-hospital mortality rate (%)	5.79 (7/138)	7.05 (37/510)	0.817	0.366
Complication (%)				
hypoxemia (%)	1.45 (2/138)	8.82 (45/510)	8.780	0.003
Severe Cardiac Failure (%)	4.35 (6/138)	7.06 (36/510)	1.317	0.251
Severe Liver dysfunction (%)	3.62 (5/138)	7.25 (37/510)	2.363	0.124
Severe Kidney failure (%)	4.35 (3/138)	8.24 (42/510)		0.144*
Cerebral complications (%)	2.17 (3/138)	3.14 (16/510)		0.777*
Paraplegia (%)	0.72 (1/138)	1.17 (6/510)		1.000*
New-onset atrial fibrillation	7.24 (10/138)	17.06 (73/510)	4.857	0.028
Incision infection (%)	0 (0/138)	1.76 (9/510)		0.216*

CPB: cardiopulmonary bypass; ICU: intensive care unit; *calculated by Fisher's exact test.

The study group had significantly shorter time on mechanical ventilation, length of ICU stay and length of postoperative hospital stay compared to the control group ($P<0.05$). The study group also had lower drainage volume within 24 hours after operation compared to the control group, but the results have no statistical significance ($P>0.05$). Additionally, the study group had lower complication incidence such as hypoxemia, atrial fibrillation, liver dysfunction, kidney failure has statistical significance ($P<0.05$), but severe cardiac failure, cerebral complication, paraplegia, incision infection, these results also have no statistical significance ($P>0.05$) (Table 3).

Morbidity at Follow-up

Apart from 4 cases in the study group and 13 case in the control group lost follow up, all other discharged patients received follow-up for 3-70 months. The average follow-up time in the study group and control group were 32.4 ±16.8 months and 31.2 ±15.6 months, the median follow-up time was 31.6 months in the study group and 31.2 months in the control group, respectively. Scheduled post-

operative surveillance included thoraco-abdominal aortic CTA and cardiac echocardiography at 3 months and every year after operation. They were followed up with regularly through outpatient visits or phone calls.

The primary endpoints of follow-up in this study were death and secondary endpoints were other adverse events. 5 deaths were observed in the study group and 43 deaths in the control group during the follow-up period. The survival curve of the study group was significantly better than that of the control group after operation (Log-Rank Test, $\chi^2=4.158$, $P=0.041$) (Figure 4).

The study group demonstrated a significantly lower incidence of persistent false lumen in the aortic root compared with the control group ($P<0.05$). In addition, incidence of anastomotic leak in distal anastomosis, rate of heart function classification level III/IV after surgery, incidence of re-operation rate, incidence of regurgitation of the aortic valve above moderate, incidence of permanent atrial fibrillation and infection rate of prosthetic implants were all significantly reduced in the study group ($P<0.05$; Table 4).



FIGURE 3. Follow-up Chest Aorta CTA Image at 12 Months after Novel Suturing Procedure.

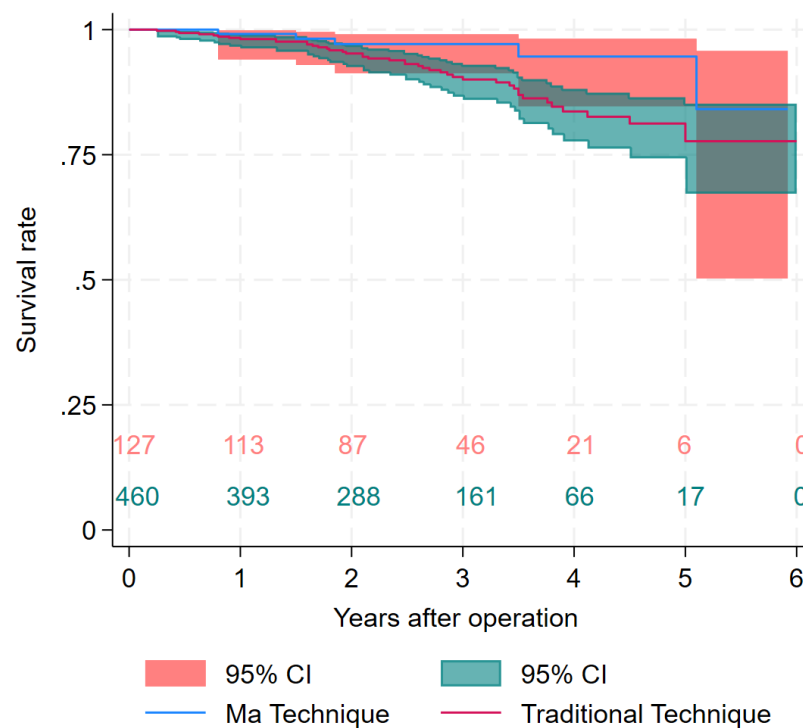


FIGURE 4. Comparison of postoperative survival rates between two groups of patients during follow-up.

TABLE 4. Comparison of follow-up indexes between the study group and the control group.

Follow-up Indexes	Study group (n=127)	Control group (n=460)	t/ χ^2	P value
Follow-up time (month)	32.4±16.8	31.2±15.6	0.691	0.684
False lumen existed in aortic root (%)	7.09 (9/127)	23.04 (106/460)	22.750	<0.001
Re-operation rate (%)	1.57 (2/127)	7.83 (28/460)		0.041*
Incidence of anastomotic leak in	0 (0/127)	6.96 (32/460)		<0.001*

Distal anastomosis (%)				
The incidence of regurgitation of the aortic valve above moderate (%)	1.57 (2/127)	7.61 (32/460)		0.018*
Incidence of permanent atrial fibrillation (%)	2.36 (3/127)	12.83 (50/460)		0.002*
Heart function Classification level III/IV (NYHA) (%)	9.45 (12/127)	19.78 (91/460)	7.346	0.007
Infection rate of prosthetic implants (%)	0 (0/127)	1.08 (5/460)		0.591*

NYHA: New York Heart Association; *Calculated by Fisher's exact test.

Discussion

The success of arch replacement in AAAAD depends primarily on secure closure of the proximal and distal dissections of aortic arch and ensure good hemostasis at the anastomotic site. The conventional Sun's procedure [7, 14, 15] has been widely adopted as the standard technique in China [16, 17], yet post operative complications including hypoxemia, right heart failure, renal dysfunction, hepatic dysfunction, endo-leakage from the true lumen or wrap-around space of the aortic dissection into the right atrium, and permanent atrial fibrillation [18-20], remain significant concerns. These complications are primarily attributable to two factors: firstly, suturing within the preserved aorta and aortic arch could affect suture quality, and secondly, there are deficiencies when using autologous aortic wall to wrap the vascular graft and achieve hemostasis through drainage into the right atrium [21]. Several alternative strategies have been proposed to address these limitations, including the branch-first approach [22, 23], hybrid technique with an aortic arch stent graft [24, 25], reverse anastomosis technique [26, 27] and aortic arch inclusion technique [28]. However, these modified techniques are not without drawbacks, including greater surgical complexity, increased risk of endo-leak, and the absence of robust long-term outcome data. In this context, our study demonstrates that a novel suturing technique for arch replacement may overcome several of these limitations. By eliminating the residual dissected wall, reinforcing the anastomoses, and avoiding right atrial drainage, this approach achieved superior hemostasis and translated into improved clinical outcomes.

In our cohort, the patients undergoing the novel suture technique for arch replacement surgery has significantly lower in-hospital mortality compared to those with conventional Sun's procedure. Ma's procedure group also showed significantly higher survival rates and lower incidence of complications than conventional Sun's procedure. Furthermore, the study group required significantly fewer blood products and had reduced drainage volume within 24 hours after operation compared with control group. The absence of residual dissected aortic wall provided better visualization and an adequate operative space when performing both proximal and distal anastomosis. In addition, embedding an autologous pericardial strip at the proximal anastomotic site served as a buttress, buffering the tension of prolene sutures and reducing the risk of cut-through. Circumferential interrupted suturing at the distal anastomotic site proved reliable to achieve hemostasis. Finally, avoidance of right atrial drainage prevented constant shunting, thereby reducing the risk of hemodynamic instability, pulmonary embolism, endo-leak, hypoxemia, infection and secondary tracheal intubation [10].

The results of this study also revealed that the cardiopulmonary bypass time and cardiac arrest time were comparable between the two groups. However, patients in the Ma's procedure group

experienced a significantly longer hypothermic circulatory arrest and selective cerebral perfusion times, largely due to the use of continuous plus interrupted suturing at the distal anastomosis. Despite this prolongation, post-operative complications involving major organs including the heart, liver, kidney, lung, and brain, were significantly less frequent compared with the control group. These findings suggest that within the durations observed in this cohort, longer arrest and cerebral perfusion times associated with the novel procedure were not accompanied by worse outcomes [29, 30]. Although we employed the Ma's procedure such as sandwich suturing at the proximal aorta and continuous plus intermittent suturing to increase hypothermic circulatory arrest and selective cerebral perfusion times, we ensured anastomosis quality at aortic junctions and avoided internal drainage operation. Once the heart resumed beating, additional hemostasis at the anastomotic sites was rarely required. These factors likely contributed to the reduced blood transfusion requirements and drainage volume observed within 24 hours postoperatively. Therefore, these findings suggest that improved anastomotic hemostasis may have contributed to the observed reduction in postoperative complications. That should be paid more attention for cardiovascular surgeons.

The follow-up results of this study confirmed that the Ma's procedure achieved excellent outcomes in sealing off both the proximal and distal dissections of the aorta. The proximal sandwich configuration and the distal interrupted horizontal mattress sutures ascending aorta and aortic arch reconstruction, while also ensuring effective false lumen closure and reducing the risk of early or progressive endo-leak. In recent years, some surgeons have focused on aortic root reconstruction for AAAAD, but seldomly emphasized for the aortic arch form. In our study, careful graft orientation was used to preserve the natural arch curvature, which may help prevent the beak phenomenon [31], kinking, pseudoaneurysm formation, and aortic valve regurgitation caused by excessively long vascular grafts [28]. Follow-up CTA imaging demonstrated that the vascular blood vessels using the novel suturing technique showed natural morphology which commonly indicates better hemodynamics (As shown in Figure 3). These technical and morphological advantages likely contribute to significantly lower mortality, fewer re-operations and reduced incidence of aortic valve regurgitation compared to conventional Sun's procedure. Taken together, the novel suturing technique appears to provide an effective method of reducing complications after thoracic aorta reconstruction of AAAAD.

Implant infection remains a serious complication following arch replacement for AAAAD, with postoperative bleeding recognized as an independent risk factor for infection [32]. In this study, the incidence of implant infection was significantly lower in the Ma's procedure group compared with the control group. One possible

explanation is that the conventional Sun's procedure leaves a false lumen surrounding the graft which may increase the incidence of implant infection. Additionally, AAAD patients with atrial fibrillation have higher in-hospital mortality rates compared to those without atrial fibrillation [33, 34]. The use of right atrium shunting in the Sun's procedure may increase the load of right ventricle or atrium and may contribute to the development of atrial fibrillation. In contrast, Ma's procedure, by avoiding persistent internal drainage, was associated with reduced occurrences of postoperative atrial fibrillation and permanent atrial fibrillation. This finding highlights the potential link between continuous right atrial shunting and atrial fibrillation.

Since the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) advocated for standardization as a means to improve the quality of healthcare services, there has been a natural trend towards individual disease-specific treatment methods. However, in the case of AAAD, achieving standardization still faces multiple obstacles. First, AAAD is an acute and life-threatening condition, making it difficult to conduct controlled studies, especially randomized controlled trials. Second, currently, there is no standardized surgical procedure that can achieve expected outcomes. And third, there are relatively few reports on high-volume cases. Therefore, relying on individual center-reported treatment outcomes remains the approach to achieve standardization based on potential rule-based therapeutic strategies. In this study, patients were grouped and compared based on different surgical methods with a 6-year follow-up period. The findings demonstrate that the Ma's procedure has advantages in terms of in-hospital mortality rate, postoperative complication rate, and post-discharge survival rate. This study also shows that novel suturing techniques can be beneficial attempts for operative quality control. But we also should acknowledge that the results reflect the overall standardized surgical strategy rather than the isolated effect of a single suturing modification.

We should also be aware of the potential influence of a learning curve and temporal improvements in institutional care. With the accumulation of surgical experience and the elevation of clinical standards over time, outcomes are likely to continue to improve.

Limitations

This study is a systematic retrospective review and has not yet undergone corrective matching or randomization. Therefore, the persuasiveness of the data analysis needs to be strengthened. All surgeries were performed by surgeons of comparable expertise; however, inter-operator variability between groups cannot be excluded. Surgeon preference and case selection may have introduced some degree of heterogeneity, particularly in borderline anatomical scenarios. Considering the small sample size and difference of number between two groups, considering the small sample size and difference of number between two groups, the potential for bias is present, particularly when exploring a novel suturing method, caution should be exercised in drawing conclusions. While our mid-term follow-up data are encouraging, the duration of follow-up is still limited, and longer-term observations are still necessary to confirm these findings. Although the procedures have been standardized, further validation through

large-scale multicenter randomized controlled trials is still necessary compared to conventional Sun's procedure.

Conclusions

In summary, the Ma's procedure has successfully achieved effective aortic arch and thoraco-aortic remodeling with secure dissection closure, and effectively reduced in-hospital mortality and re-operation rate. These results suggest favorable mid-term clinical outcomes and seems to be considered as a safe alternative to conventional Sun's procedure for treating AAAD.

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Ethical Approval

This study involving human participants was reviewed and approved by the Medical Research Ethics Committee of Qilu Hospital of Shandong University. Approval No. [KYLL-2026-01-044-1]. Date of Approval: [13 April 2026]. The pre-registered clinical trial number is ChiCTR2600124004.

Conflicts of Interest

None.

Declared

This research was approved by Clinical Research Management Committee of Qilu Hospital of Shandong University. Approval number: KYLL-2026-01-044-1. Approval date: April 13th, 2026.

REFERENCES

1. Kato Y, Sasaki K, Yamauchi H, Kanno Y, Jinno T, Yamada M, Kiyama H, Koyanagi T. Aortic root remodelling with external ring annuloplasty in acute type A aortic dissection. *Interact Cardiovasc Thorac Surg*. 2020;**30**:85-90.
2. Xue Y, Zhou Q, Pan J, Cao H, Fan F, Zhu X, Chong H, Wang D. Root reconstruction for proximal repair in acute type A aortic dissection. *J Thorac Dis*. 2019;**11**:4708-4716.
3. Sun LZ, Qi RD, Chang Q, Zhu JM, Liu YM, Yu CT, Lv B, Zheng J, Tian LX, Lu JG. Is total arch replacement combined with stented elephant trunk implantation justified for patients with chronic Stanford type A aortic dissection? *J Thorac Cardiovasc Surg*. 2009;**138**:892-896.
4. Mussa FF, Horton JD, Moridzadeh R, Nicholson J, Trimarchi S, Eagle KA. Acute Aortic Dissection and Intramural Hematoma: A Systematic Review. *JAMA*. 2016;**316**:754-763.
5. Benedetto U, Dimagli A, Kaura A, Sinha S, Mariscalco G, Krasopoulos G, Moorjani N, Field M, Uday T, Kendal S, Cooper G, Uppal R, Bilal H, Mascaro J, Goodwin A, Angelini

- G, Tsang G, Akowuah E. Determinants of outcomes following surgery for type A acute aortic dissection: the UK National Adult Cardiac Surgical Audit. *Eur Heart J*. 2021;**43**:44-52.
6. Kouchoukos NT, Masetti P, Mauney MC, Murphy MC, Castner CF. One-stage repair of extensive chronic aortic dissection using the arch-first technique and bilateral anterior thoracotomy. *Ann Thorac Surg*. 2008;**86**:1502-1509.
7. Sun L, Qi R, Zhu J, Liu Y, Zheng J. Total arch replacement combined with stented elephant trunk implantation: a new "standard" therapy for type A dissection involving repair of the aortic arch? *Circulation*. 2011;**123**:971-978.
8. Sun L, Qi R, Zhu J, Liu Y, Chang Q, Zheng J. Repair of acute type A dissection: our experiences and results. *Ann Thorac Surg*. 2011;**91**:1147-1152.
9. Ma WG, Zhang W, Wang LF, Zheng J, Ziganshin BA, Charilaou P, Pan XD, Liu YM, Zhu JM, Chang Q, Rizzo JA, Elefteriades JA, Sun LZ. Type A aortic dissection with arch entry tear: Surgical experience in 104 patients over a 12-year period. *J Thorac Cardiovasc Surg*. 2016;**151**:1581-1592.
10. Sun LZ, Ma WG, Zhu JM, Zheng J, Liu YM, Ziganshin BA, Elefteriades JA. Sun's procedure for chronic type A aortic dissection: total arch replacement using a tetrafurcate graft with stented elephant trunk implantation. *Ann Cardiothorac Surg*. 2013;**2**:665-666.
11. Larsen M, Trimarchi S, Patel HJ, Di Eusanio M, Greason KL, Peterson MD, Fattori R, Hutchison S, Desai ND, Korach A, Montgomery DG, Isselbacher EM, Nienaber CA, Eagle KA, Bartnes K, Myrmel T. Extended versus limited arch replacement in acute Type A aortic dissection. *Eur J Cardiothorac Surg*. 2017;**52**:1104-1110.
12. Smith HN, Boodhwani M, Ouzounian M, Saczkowski R, Gregory AJ, Herget EJ, Appoo JJ. Classification and outcomes of extended arch repair for acute Type A aortic dissection: a systematic review and meta-analysis. *Interact Cardiovasc Thorac Surg*. 2017;**24**:450-459.
13. Singhal D, Smorodinsky E, Guo L. Differences in coagulation among Asians and Caucasians and the implication for reconstructive microsurgery. *J Reconstr Microsurg*. 2011;**27**:57-62.
14. Safi HJ, Miller CC 3rd, Estrera AL, Huynh TT, Rubenstein FS, Subramaniam MH, Buja LM. Staged repair of extensive aortic aneurysms: morbidity and mortality in the elephant trunk technique. *Circulation*. 2001;**104**:2938-2942.
15. Ikeno Y, Yokawa K, Matsueda T, Yamanaka K, Inoue T, Tanaka H, Okita Y. Long-term outcomes of total arch replacement using a 4-branched graft. *J Thorac Cardiovasc Surg*. 2019;**157**:75-85.e3.
16. Sun X, Guo H, Liu Y, Li Y. The aortic balloon occlusion technique in total arch replacement with frozen elephant trunk. *Eur J Cardiothorac Surg*. 2019;**55**:1219-1221.
17. Jiang D, Huo Y, Liu Y, Wang Y, Zhou J, Sun X, Zhao F, Du Y, He S, Liu C, Sun W. One minute of circulatory arrest for acute type A aortic dissection ----- a simple operation for acute type A aortic dissection (AAAD). *J Cardiothorac Surg*. 2020;**15**:328.
18. Sugano Y, Anzai T, Yoshikawa T, Satoh T, Iwanaga S, Hayashi T, Maekawa Y, Shimizu H, Yozu R, Ogawa S. Serum C-reactive protein elevation predicts poor clinical outcome in patients with distal type acute aortic dissection: association with the occurrence of oxygenation impairment. *Int J Cardiol*. 2005;**102**:39-45.
19. Dai XF, Chen LW, Chen DZ, Lin F, Wang QM, Huang ZY, Qiu HF, Cao H. [Analysis of surgical treatment for Stanford type A aortic dissection]. *Zhonghua Wai Ke Za Zhi*. 2008;**46**:823-825.
20. Jiao R, Lu XR, Ding H, Liu MM, Liu N. Prognosis factors for death within 90 days of discharge in patients with acute kidney injury requiring continuous renal replacement therapy after surgery for Stanford type A acute aortic dissection. *Zhonghua Wai Ke Za Zhi*. 2022;**60**:466-471.
21. Ma WG, Zheng J, Dong SB, Lu W, Sun K, Qi RD, Liu YM, Zhu JM, Chang Q, Sun LZ. Sun's procedure of total arch replacement using a tetrafurcated graft with stented elephant trunk implantation: analysis of early outcome in 398 patients with acute type A aortic dissection. *Ann Cardiothorac Surg*. 2013;**2**:621-628.
22. Abt BG, Bojko M, Elsayed RS, Han S, Wang A, Vu I, Wishart D, Fleischman F. Branch-first aortic arch replacement strategy decreases perioperative mortality. *J Thorac Cardiovasc Surg*. 2024;**167**:2005-2012.e1.
23. Sharma VJ, Kanagarajah AR, Seevanayagam S, Kim M, Matalanis G. Branch-first Continuous Perfusion Aortic Arch Replacement: Midterm Results. *Ann Thorac Surg*. 2023;**116**:280-286.
24. Weichao Zhao, Mian Li, Wuhui Hou, Xiyan Zhu, Qi Hu. One-stop hybrid versus conventional surgery for acute type A aortic dissection: a randomized controlled trial. *J Cardiothorac surg*. 2025;**21**:15-23.
25. Banno H, Mutsuga M, Sugimoto M, Tokuda Y, Kodama A, Usui A, Komori K. Midterm Outcomes of Zone 0 Antegrade Endograft Implantation During Type I Hybrid Aortic Arch Repair. *Eur J Vasc Endovasc Surg*. 2021;**61**:938-944.
26. Pinaud F, Daligault M, Enon B, de Brux JL. Endovascular treatment of inoperable acute type A dissection via the transapical approach. *Eur Heart J*. 2013;**34**:3236.
27. Zou Y, Teng P, Ma L. Four-branched graft inversion technique for the distal anastomosis in acute aortic dissection. *J Cardiothorac Surg*. 2021;**16**:317.

28. Liu K, Zhu C, Zheng X, Wang T, Xu R, Zhu Z, Li D, Piao H, Li B, Wang Y, Zhang S, Sun W. A new aortic arch inclusion technique with frozen elephant trunk for type A aortic dissection. *Ann Surg*. 2020;**271**:978-983.
29. Urbanski PP, Lenos A, Irimie V, Bougioukakis P, Zacher M, Diegeler A. Acute aortic dissection involving the root: operative and long-term outcome after curative proximal repair. *Interact Cardiovasc Thorac Surg*. 2016;**22**:620-626.
30. Pinheiro BB, Fagundes WV, Muniz LF, Dreifaldt M, Arbeus M, Souza DS. Dacron Graft Intussusception Technique for Treatment of Type A Aortic Dissections: Technical Notes and Preliminary Results. *Braz J Cardiovasc Surg*. 2016;**31**:115-119.
31. Cosset B, Boussel L, Davila Serrano E, Millon A, Douek P, Farhat F, Sigovan M. Hemodynamic Changes Before and After Endovascular Treatment of Type B Aortic Dissection by 4D Flow MRI. *Front Cardiovasc Med*. 2022;**9**:873144.
32. Wu B, Wang Y, Wang C, Cheng Y, Rong R. Intraoperative platelet transfusion is associated with increased postoperative sternal wound infections among type A aortic dissection patients after total arch replacement. *Transfus Med*. 2014;**24**:400-405.
33. Campia U, Rizzo SM, Snyder JE, Pfefferman MA, Morrison RB, Piazza G, Goldhaber SZ. Impact of Atrial Fibrillation on In-Hospital Mortality and Stroke in Acute Aortic Syndromes. *Am J Med*. 2021;**134**:1419-1423.
34. Matsuura K, Ogino H, Matsuda H, Minatoya K, Sasaki H, Kada A, Yagihara T, Kitamura S. Prediction and incidence of atrial fibrillation after aortic arch repair. *Ann Thorac Surg*. 2006;**81**:514-518.