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Aorta: Research

Triple-Branched Stent Graft Implantation for Acute Non-A–non-B Aortic Dissection

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ABSTRACT

BACKGROUND The optimal treatment for acute non-A–non-B aortic dissection remains controversial. Triple-branched stent graft (TBSG) implantation has been used to treat acute type A aortic dissection. This study aimed to evaluate the safety and efficacy of TBSG as a treatment for acute non-A–non-B aortic dissection.

METHODS Fifty patients with non-A–non-B dissection received TBSG implantation in our center between January 2014 and December 2019. Early mortality, morbidity, and dissected aorta remodeling during follow-up were calculated.

RESULTS There were no deaths in-hospital or within 30 days. Postoperative complications included pneumonia (n = 12), acute kidney injury (n = 6; preoperative renal malperfusion, n = 4), transient cerebral injury (n = 6; preoperative cerebral malperfusion, n = 4), pleural effusion (n = 4), and pericardial effusion (n = 2). During follow-up, 1 patient experienced a stroke, and 2 patients required secondary interventional therapy for residual dissection below the level of the TBSG. All implanted TBSGs had good positioning, and all sidearm stent graft grafts were fully patent. No retrograde aortic dissection or type I endoleak was detected.

CONCLUSIONS TBSG implantation for acute non-A–non-B aortic dissection had a low incidence of mortality and morbidity, featuring good remodeling of the dissected aortic wall during follow-up. The early outcomes of this technique were satisfactory.

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Aortic dissection (AD) is a fatal disease in which blood flowing from a tear in the aorta dissects the aortic wall into a true and false lumen. Arch involvement either by the most proximal tear or by retrograde extension is referred to as non-A-non-B dissection,[1] which has a reported incidence of 16.5% to 25.5%.[2] Compared with AD limited to the descending thoracic aorta, AD involving the aortic arch has a greater risk of cardiac and neurologic consequences and dissection-related death.[3] Thus, acute non-A-non-B dissection frequently requires emergency aortic repair due to organ malperfusion or aortic rupture.[4]

The optimal surgical management of non-A-non-B dissection is controversial. Repairing aortic arch dissection and descending dissection via a median sternotomy using the conventional procedure is challenging. Traditional open approaches are associated with significant morbidity and mortality, particularly in high-risk patients who do not tolerate circulatory arrest well.[5-7] The minimally invasive supraarch debranched technique followed by thoracic endovascular aortic repair is favored in some centers.[8-10] However, serious risks of stroke, paraplegia, retrograde type A AD, and endoleaks requiring reintervention remain.[9-13]

Recently, endovascular technology and techniques allowing for aortic branch perfusion have been developed. Several methods have been used to secure cerebral blood flow in total endovascular arch repair, including fenestration, parallel grafting, and branched stent grafting.[14] These techniques are less invasive, resulting in lower mortality and complication rates. However, the incidences of endoleak and retrograde type A AD remain high.[15-17]

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Sun and associates[18] utilized frozen elephant trunks to treat acute type B AD involving the distal arch, achieving satisfactory results. We previously introduced triple-branched stent grafting (TBSG) through a sternotomy for arch repair in acute type A AD with good early and midterm outcomes.[19-24] This retrospective study aimed to evaluate the clinical outcomes of TBSG for treating non-A-non-B dissection.

PATIENTS AND METHODS

PATIENTS. From January 2014 to December 2019, 1251 patients with aortic dissection admitted in our center. Non-A-non-B aortic dissection and organ malperfusion was diagnosed by computed tomography angiography and symptoms. Acute dissection was defined as occurring within 2 weeks of symptom onset. Cerebral malperfusion is defined as acute aortic dissection with newly developed neurologic symptoms in the presence of radiographically evident high-grade stenosis or lack of opacification through the supraarch vessels. Exclusion criteria in this study included chronic aortic dissection, aortic aneurysm, ascending aortic involvement, and abnormal arch anatomy that was unfit for TBSG implantation (such as bovine arch, aberrant right subclavian artery, distance between right subclavian artery orifice and innominate artery less than 35 mm, etc.). Fifty patients who did not have contraindications were enrolled after they signed an informed consent. All patients were urgently taken to operation room as soon as the diagnosis was confirmed, and the family signature was made. The present research protocol was reviewed and approved by the institutional review board of Union Hospital of Fujian Medical University in Fuzhou, China (No. 2015083).

TRIPLE-BRANCHED STENT GRAFT. The TBSG used in this study was conceived and designed by one of our own (Dr Chen) and manufactured by Yuhengjia Sci Tech Corp Ltd, Beijing, China. The graft features have been previously described[21,22] (Figure 1). The size of the sidearm grafts depended on the diameter of supraarch vessels. We sized the distal stented graft based on the diameter of the proximal descending aorta.

SURGICAL PROCEDURE. The surgical procedure has been previously described.[21,22] After general anesthesia, a median sternotomy was performed. Cardiopulmonary bypass (CPB) was established via the right atrium, femoral, and right axillary arteries and the patient's temperature was decreased. Then, the bases of the innominate and left common carotid arteries were mobilized. When ventricular fibrillation was induced by the low temperature, the ascending aorta was cross-clamped and cardioplegia was induced. After nasopharyngeal temperature reached 25°C-28°C, circulatory arrest began and antegrade cerebral perfusion (ACP) was established through the right axillary cannula (flow rate, 10 $mL \cdot kg^{-1} \cdot min^{-1}$). The cross-clamp was removed, and 2 incisions were made in the aorta. The first transverse incision was at the front wall of the normal aorta, closing to the junction of the ascending aorta and aortic arch. The second incision was transected obliquely from the bottom of the first incision to the end of the arch. Most of the lesser curvature was incised, after which 3 arch vessel orifices and the true lumen of the proximal descending aorta were clearly identified. The distal portion of the main graft was inserted into the true lumen of the descending aorta, and each sidearm graft was positioned inside the corresponding aortic arch vessel. The grafts were deployed by withdrawing their restraining strings (Figure 2A). Two pledgeted mattress sutures were individually placed through the first 2 sidearm grafts and the native aortic arch vessel wall. ACP was stopped transiently during TBSG implantation and fixation. A cannula was placed into the left common carotid artery through the orifice of its sidearm

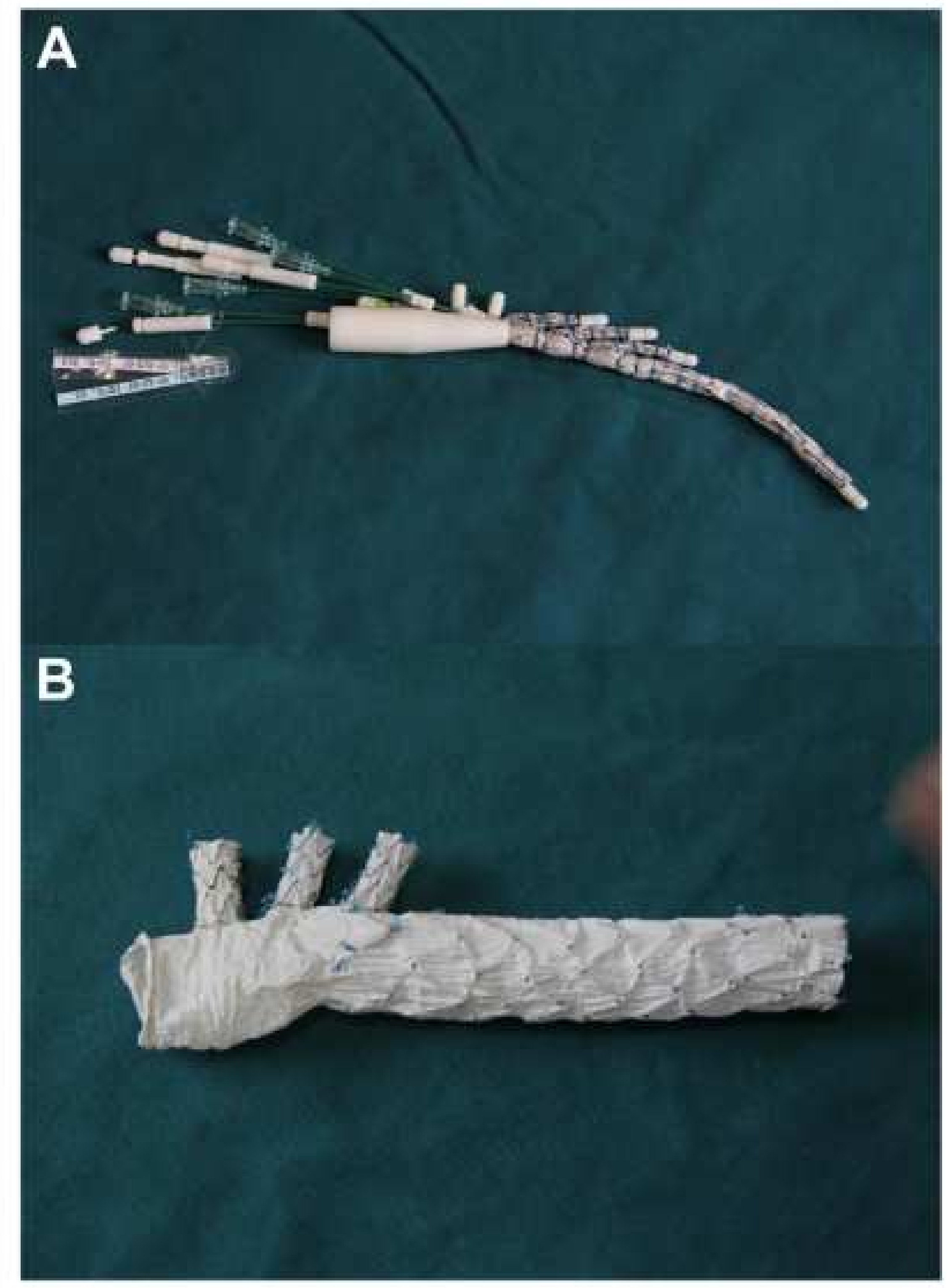

FIGURE 1 (A) The appearance of the triple-branched stent graft before it is released. (B) The triple-branched stent graft consisted of a Dacron-covered (Invista, Wichita, KS) self-expandable nitinol stent at the distal side, a main graft without a stent at the proximal side, and 3 sidearm stented grafts. The main graft and 3 sidearm grafts were individually mounted on 4 small catheters and restrained by 4 silk strings.

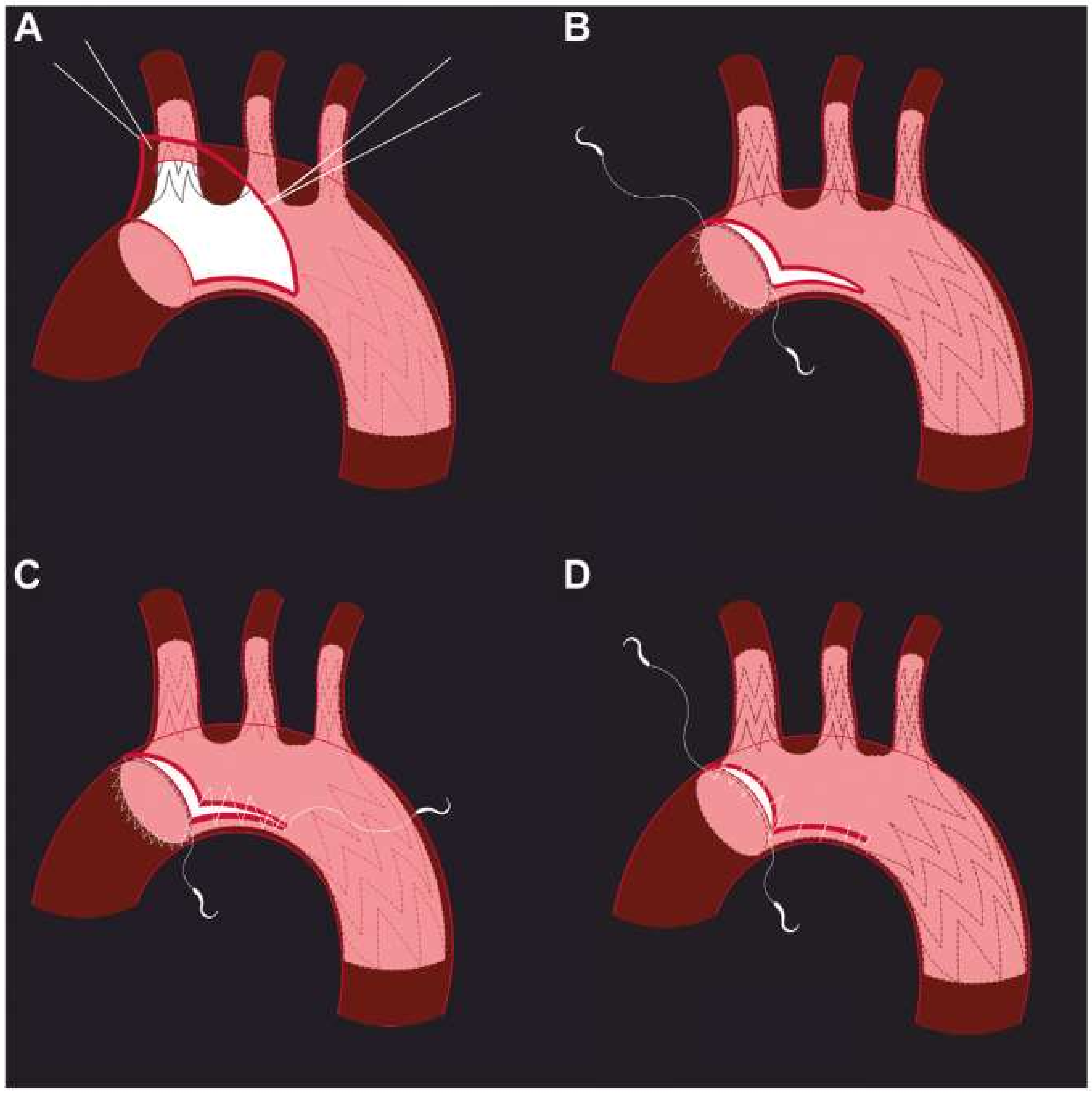

FIGURE 2 (A) A transverse incision at the front wall of the normal aorta close to the junction of the ascending aorta and aortic arch. The second incision was transected obliquely from the bottom of the first incision to the end of the arch, and most of the lesser curvature was incised. The distal portion of the main graft was inserted into the true lumen of the descending aorta, and each sidearm graft was positioned inside the corresponding aortic arch vessel. The grafts were deployed by withdrawing their restraining strings. (B) The back side of the proximal end of the main graft was attached to the back wall of the normal aorta using a continuous suture. (C) The transverse incision of the aortic arch was closed using a continuous suture attached to the main graft portion of the TBSG. (D) The front side of the first incision was closed, incorporating the proximal end of the main graft.

graft for bilateral ACP (flow rate, 10 mL · kg^{-1} · min^{-1}). The backside of the proximal end of the main graft was attached to the back wall of the normal aorta with a continuous suture (Figure 2B). The transverse incision of the aortic arch was then closed using a continuous suture attached to the main graft portion of the TBSG (Figure 2C). The front side of the first incision was closed after incorporating the proximal end of the main graft (Figure 2D). After the air was carefully flushed out, systemic perfusion was resumed, and the patient was rewarmed. If the arch vessel was seriously involved in the dissection and its diameter was greater than the corresponding implanted sidearm stent graft, aortic arch vessel banding at the base was performed. The length of the banding felt was 5%-10% shorter than the size of the corresponding sidearm stent graft.

DATA COLLECTION AND FOLLOW-UP. Patients were told to receive mono-antiplatelet therapy for the first 3 months postoperatively. The patients were followed up prospectively with computed tomography angiography before hospital discharge, 3 months postoperatively, and annually thereafter. All survivors were contacted via direct interviews in our outpatient department or via telephone. We retrospectively reviewed all clinical data. Categorical variables are presented as number and percentage. Continuous variables are expressed as mean ± SD. Data were analyzed using SPSS 22.0 (IBM, Armonk, NY). Continuous variables were analyzed using a *t* test,

TABLE 1 Characteristics of Patients With Non-A–Non-B Aortic Dissection Receiving TBSG Implantation (n = 50)

Variable	Value
Age, y	50.0 ± 8.4 (33-66)
Sex	
Male	40 (80)
Female	10 (20)
Body mass index, kg/m^2	27.1 ± 5.5 (20.8-35.2)
Body surface area, m^2	1.9 ± 0.26 (1.6-2.4)
Comorbidities	
Hypertension	42 (84)
Marfan syndrome	3 (6)
Diabetes mellitus	4 (8)
Coronary artery disease	2 (4)
Previous stroke	3 (6)
Chronic renal dysfunction[a]	4 (8)
Organ malperfusion	12 (24)
Cerebral malperfusion	4 (8)
Coronary malperfusion	0
Renal malperfusion	4 (8)
Visceral malperfusion	1 (2)
Extremity malperfusion	3 (6)
Aortic valve regurgitation	
Severe	2 (4)
Moderate or less	48 (96)

[a]Defined as preoperative creatinine greater than 1.5 mg/dL. Values are presented as n (%) or mean ± SD (range). TBSG, triple-branched stent graft.

as appropriate. Calculated *P* values of less than .05 were considered significant.

RESULTS

PATIENT CHARACTERISTICS. The mean patient age was 50.0 ± 8.4 (range: 33-66) years. Forty patients (80%) were male. No patient had undergone a prior cardiac operation. Preoperative comorbidities included hypertension (84%), chronic renal dysfunction (8%), diabetes mellitus (8%), stroke (6%), and coronary artery disease (4%). Gastrointestinal hemorrhage was not observed in any patient. Viable arch entry was found in 24 patients (48%), and descending thoracic aorta entry was found in 26 patients (52%). The entry was predominantly located near the origin of the left subclavian artery. The dissection involved zone 2 in 32 patients (64%), zone 1 in 12 (24%), and zone 0 in 6 (12%). The dissection extended into the abdominal aorta in 16 cases (32%) and to the iliac artery in 34 cases (48%). No patient had an isolated left vertebral artery. Preoperative organ ischemia associated with AD included cerebral malperfusion (n = 4), renal ischemia (n = 4), lower limb ischemia (n = 3), and visceral ischemia (n = 1). Ultrasound showed that 2 patients had severe aortic valve regurgitation; the remaining patients had moderate or less than moderate aortic valve regurgitation. Preoperative patient data are shown in Table 1. The average interval between the onset of symptoms to the operation was 25.0 ± 46.8 (range: 4-180) hours.

SURGICAL DATA. The mean duration of CPB, aortic cross-clamping, and ACP was 124.8 ± 14.9 (range: 90-150) min, 32.6 ± 15.7 (range: 22-70) min, and 12.2 ± 2.7 (range: 9-17) minutes, respectively. During cooling, 2 patients received concomitant aortic valve replacement, and two patients received concomitant coronary artery bypass grafting.

EARLY MORBIDITY AND MORTALITY. The mean total volume of drainage was 389.3 ± 160.8 mL. No patient required additional surgical treatment to correct excessive postprocedural bleeding. No cases of in-hospital death, 30-day death, tracheostomy, new onset stroke, paraplegia, gastrointestinal hemorrhage, sepsis, or multiple organ dysfunction syndrome occurred. The mean duration of mechanical ventilation, intensive care unit stay, and hospital stay was 25.6 ± 25.3 (range: 7-123) hours, 88.0 ± 59.1 (range: 12-229) hours, and 17.2 ± 7.5 (range: 9-30) days, respectively. Ventilator support for greater than 4 days was required in 2 patients. Twelve (24%) patients developed pneumonia. Pericardial and pleural effusions were found in 2 and 4 patients, respectively; all cases recovered after drainage. Six patients exhibited acute kidney injury. Eight patients (including 4 patients with chronic renal dysfunction and 2 patients with preoperative renal malperfusion) required continuous renal replacement therapy due to renal failure. Transient cerebral injury was observed in 6 patients. After TBSG implantation, lower limb and visceral ischemia were ameliorated in all patients. All patients recovered and were discharged (Table 2).

TABLE 2 Early Morbidity and Mortality of Patients Receiving TBSG Implantation

Variable	Value
In-hospital morbidity	
Pneumonia	12 (24)
Pericardial effusion	2 (4)
Pleural effusion	4 (8)
Acute kidney injury [a]	6 (12)
Cerebral injury	4 (8)
Transient cerebral injury	6 (12)
Stroke	0
Gastrointestinal hemorrhage	0
Sepsis	0
Multiple organ dysfunction syndrome	0
30-day death	0

[a]Defined as 50% rise in baseline creatinine or new need for dialysis. Values are presented as n (%). TBSG, triple-branched stent graft.

FOLLOW-UP. We were unable to follow up with 2 patients. All other survivors were followed up for the remainder of this study. The average of follow-up period

TABLE 3 The Morphology of the Aorta at the Time of Preoperative and Last Follow-Up

Morphology	Preoperative, mm	Last follow-up, mm	*P* Value
Middle ascending aorta	27.2 ± 3.2 (207-32.2)	27.1 ± 2.4 (24.4-34.4)	.952
Aortic arch	37.7 ± 10.1 (27.5-49.6)	27.9 ± 5.4 (25-34.3)	.010
False lumen of aortic arch	13.2 ± 5.2 (5.4-22.5)	1.6 ± 2.6 (0-7.2)	< .001
DTA at the level of the pulmonary bifurcation	36.1 ± 4.6 (28.2-48.5)	33.2 ± 4.0 (26-40.7)	< .001
False lumen of DTA at the level of the pulmonary bifurcation	18.4 ± 5.0 (10.3-28.5)	4.7 ± 3.8 (0-12)	< .001

Values are presented as mean ± SD (range). DTA, descending thoracic aorta.

was 37.4 ± 17.6 (range: 12-78) months. One patient had a stroke 5 months after discharge; he recovered without severe sequelae. Two patients required secondary interventional therapy for residual dissection below the level of the TBSG. No other patients required reintervention. Computed tomography angiography was performed in 48 patients during follow-up. All implanted TBSGs had good positioning and all sidearm stent grafts were fully patent. No retrograde AD, new intimal tears created by the edge of the stent graft, or type I endoleaks were detected. All distal ends of the main grafts were located in the true lumen of the descending aorta above the T8 level. The last postoperative scans showed complete thrombus formation of the false lumen around the TBSG in 46 patients (95.8%), at the diaphragmatic level in 32 patients (66.7%), and at the superior mesenteric arterial level in 6 patients (12.5%). No significant changes were found at the level of middle ascending aorta. However, the diameter of aortic arch and its false lumen, and the diameter of the descending thoracic aorta and its false lumen at the level of the pulmonary bifurcation had significantly decreased at the time of last follow-up (Table 3). Although residual dissection in the abdominal aorta remained in most patients, no significant abdominal aortic enlargement was observed compared with preoperative scans.

COMMENT

Non-A-non-B dissection is not uncommon in AD patients;[2] however, its optimal management remains controversial. Supraaortic vessel debranching followed by thoracic endovascular aortic repair is a favorable treatment for non-A-non-B dissection. The hybrid technique is considered minimally invasive because it avoids aortic cross-clamping and hypothermic circulatory arrest; however, postoperative mortality (incidence: 0%-15%) and complications, including retrograde dissection, stroke (incidence: 0-11%), and endoleak remain high due to variations in the anatomical configuration of the aortic arch (angulation) and great vessels (angulation and position).[11,25-27]

Joo and colleagues[28] reported late complications following hybrid aortic arch repair in 65 patients, with an in-hospital mortality rate of 6%. Late complications were observed in 25 patients (42%), including delayed type I endoleak (n = 8), sudden death (n = 4), distal stent-induced new entry (n = 3), stent migration (n = 3), retrograde dissection (n = 2), aortopulmonary fistula (n = 2), aortoesophageal fistula (n = 1), stent fracture (n = 1), and infection (n = 1). Six patients (10%) underwent late open conversion. Regardless of zone type, the incidence of late complications was relatively high.

Total endovascular repair methods, including parallel grafting, fenestration, and branched stent grafting, have low mortality and morbidity rates. However, these techniques still have some limitations and complications. Endovascular repair requires a stable proximal landing zone within a surgical graft or a native ascending aorta with a diameter ≤38 mm.[29] The proximal sealing zone should preferably be ≥30 mm in length, measured at the inner curvature, be free of excess calcification and thrombus formation, and have an angulation >60°.[1] The parallel graft technique carries a high incidence of endoleak due to guttering associated with poor conformability between the main stent-graft and any parallel stents, reportedly up to 22%.[15] The fenestration technique was reported to have good short-term outcomes with less mortality and good patency of branch grafts;[16,17] however, the risks of retrograde type A AD and stroke remain and long-term data are scarce. The branched stent graft technique has been increasingly used.[30,31] A single-branched stent graft reportedly has good outcomes for type B AD involving the left subclavian artery. However, the finished product may not be suitable for dissection involving the region from the left common carotid artery to zone 0. Custom-made grafting suiting the various arch and supra-arched vessels requires 6-8 weeks of preparation.

The TBSG technique was first applied to treat acute type A AD in 2008. The incidence of neurologic injury, endoleak, and mortality are lower in this study than those reported in the literature.[19-24] Cerebral disorder is a major complication of arch repair. The promising results of this study may be due to 3 reasons. First, the

open arch technique facilitates TBSG implantation. All arch vessel orifices and the true lumen of the descending aorta could be easily identified through the arch incision, resulting in faster and safer TBSG implantation. Only 1 or 2 anastomoses were required using this TBSG technique, reducing circulatory arrest time. Second, we applied bilateral cerebral perfusion, which provided more physiologic and effective cerebral protection during hypothermic circulatory arrest. Third, our patients were relatively young, and the atherosclerotic changes in the aortic wall were not severe.

Ischemic spinal cord injury induced by the stented elephant trunk has been previously reported.[32,33] The stented elephant trunk may occlude the intercostal arteries, possibly perpetuating spinal cord injury.[33] No postoperative paraplegia was observed in this study; there are 2 potential reasons for this. First, the length of the distal stented trunk was 100 mm, which did not extend beyond the T8 level. Second, the CPB time, ACP, and lower body arrest time were shorter than those reported previously.

No patient developed an endoleak. Potential reasons for this are as follows. First, the stented elephant trunk diameter was 10%-20% larger than the diameter of the proximal descending aorta, which effectively prevented retrograde flow from the descending aorta. Second, the main graft portion was anastomosed to the native arch, acting as the neointima of the arch. Third, the proximal end of the main tube graft was directly anastomosed to the normal aorta, or, in cases where the ascending aorta was involved, to the Dacron (Invista, Wichita, KS) tube graft replacing the ascending aorta. Therefore, an endoleak from the proximal end of the main tube graft was completely avoided. The main TBSG tube was designed without a stent considering the different directions of the arch vessels, the various distances between 2 neighboring arch vessels, and the different tortuosity and diameter of the arch. Banding at the bases of the arch vessels was routinely applied when the sidearm stent graft was smaller than the corresponding arch vessel, effectively preventing retrograde endoleaks from the arch vessels. Finally, the base of the brachiocephalic vessel was closed with a suture to avoid TBSG migration.

In traditional total arch replacement, performing distal anastomosis and hemostasis is difficult because of the deep surgical field. Moreover, operation on the descending aorta and left subclavian artery can induce phrenic and recurrent laryngeal nerve injury. The distal anastomosis is located at the proximal arch in the TBSG technique; therefore, performing anastomosis and hemostasis is easier. Anastomosis of the arch vessels was omitted. Thus, manipulation of the left subclavian artery or descending aorta did not occur, resulting in a lower CPB time and fewer complications, such as bleeding and phrenic and recurrent laryngeal nerve injury. In this study, CPB time, aortic cross-clamp time, ACP time, and postoperative early mortality and morbidity were lower than reported for the traditional arch replacement. This result supports the theory that open TBSG could reduce the risks and technical difficulties of arch repair.

In this study, only 2 patients required reintervention due to residual abdominal AD during follow-up. The rate of complete thrombus formation in the false lumen around the TBSG was 95.8%. These results demonstrate that TBSG provided excellent aortic arch repair. The distal part of the TBSG acted as the stented elephant trunk, which closed the tear located in the descending aorta and provoked thrombosis in the false lumen of the downstream descending aorta. This thrombosis in the false lumen resulted in preventing secondary enlargement, contributing to better long-term outcomes.

LIMITATIONS. The present study was a retrospective, single-center, nonrandomized study. Furthermore, we could not compare results of the traditional procedure from the same center. Multicenter research is required. Moreover, the population in this study was relatively young, which may contribute to the excellent results.

CONCLUSIONS. TBSG implantation for acute non-A-non-B AD achieved a low incidence of mortality and morbidity, with good remodeling of the dissected aortic wall observed during follow-up. Thus, the early outcomes of this technique were satisfactory.

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Triple-Branched Stent Graft for Acute Non-A, Non-B Dissection: An Interesting Step, But Is It Forward?

INVITED COMMENTARY:

Non-A, non-B dissection refers to arch involvement either by the most proximal tear or by retrograde extension into the arch. Debates continue to evolve about whether this is an actual entity deserving of its own nomenclature and even management. In this issue of *The Annals of Thoracic Surgery*, Li and colleagues[1] propose a new method for repair of these dissections by open surgical deployment of a triple-branched stent graft (TBSG) and present their outcomes in 50 patients. In this method, the aorta is incised transversely at the junction of the ascending aorta and aortic arch and obliquely from the bottom of this incision to the end of the arch. Subsequently, the TBSG is inserted into the true lumen of the descending aorta, with