Original Article

Frozen elephant trunk with modified *en bloc* arch reconstruction and left subclavian transposition for chronic type A dissection

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Background: Several methods of arch vessel reconstruction, such as *en bloc* (island) and branched graft techniques, have been proposed to treat aortic arch pathologies during total arch replacement (TAR). We seek to review our experience with modified en bloc technique and left subclavian (LSCA)-left carotid artery (LCCA) transposition in TAR and frozen elephant trunk (FET) procedure for chronic type A aortic dissection (CTAAD).

Methods: From September 2010 to September 2016, 35 consecutive patients with CTAAD underwent modified *en bloc* arch reconstruction with LSCA-LCCA transposition during TAR and FET procedure. Computed tomographic angiography (CTA) was performed during follow-up.

Results: In-hospital mortality was 5.7% (2/35). No neurological deficit or spinal cord injury occurred. Re-exploration for bleeding and continuous renal replacement therapy were required in 2 patients each (5.7%). Follow-up was complete in 100% for a mean duration of 4.1±1.8 years (range, 0.5–6.7 years). One patient experienced a transient stroke and thoracoabdominal aortic replacement was performed in 1. There were 2 late non-cardiac deaths. Survival was 87.9% (95% CI, 70.7–95.3%) at 6 years. At 6 years, the incidence was 3% for reoperation, 12% for late death, and 85% of patients were alive without reoperation. The anastomosis between the LSCA and LCCA was patent in 100%.

Conclusions: Acceptable early and mid-term outcomes were achieved for patients with chronic type A dissection using *en bloc* technique with LSCA-LCCA transposition during TAR and FET procedure. This technique may be an alternative approach to chronic type A dissection in selected patients.

Keywords: Chronic type A aortic dissection (CTAAD); total arch replacement (TAR); island technique; left subclavian artery transposition; frozen elephant trunk (FET)

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Introduction

Because of the high morbidity and mortality associated with acute type A dissection, only a small proportion of the patients with a delayed diagnosis and treatment survived into the chronic phase. However, chronic type A aortic dissection (CTAAD) is not uncommon in China owing to socio-economic reasons (1,2). In recent years, various approaches such as open surgical, hybrid (2-4) and endovascular repair (5,6) have been developed to treat CTAAD involving the aortic arch. Several techniques such as *en bloc* (island), branched graft (7,8) and branched stent

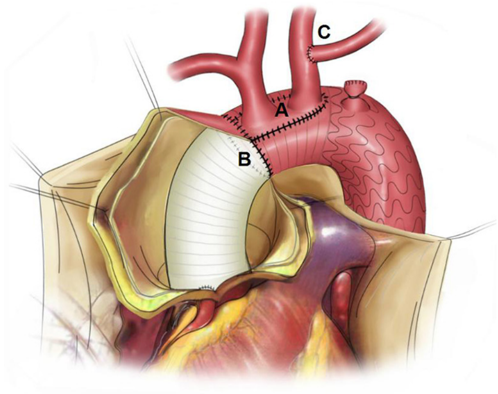

Figure 1 Schematic diagram of frozen elephant trunk with modified *en bloc* arch reconstruction and left subclavian transposition for chronic type A dissection. (A) The "island" containing the origins of the innominate artery and left common carotid artery was sutured to the trimmed stent-free Dacron graft of the frozen elephant trunk. (B) An end-to-end anastomosis was made between the rounded opening of the proximal aortic arch and distal ascending aortic graft. (C) The distal end of the left subclavian artery was transferred to the left common carotid artery in an end-to-side fashion. The anastomosis sequence was (A), (B) and (C).

graft (9) have been proposed for reconstruction of arch vessels during TAR. In our institution and other centers (1,4), total arch replacement (TAR) using a frozen elephant trunk (FET) is the procedure of choice to improve the long-term outcomes of patients with CTAAD. In the present study, we seek to review our experience with TAR and FET using a modified *en bloc* technique and left subclavian (LSCA)-left carotid artery (LCCA) transposition in patients with CTAAD during a 6-year period.

Methods

Patients

Between September 2010 and September 2016, 35 consecutive patients with CTAAD underwent surgical repair using *en bloc* technique with LSCA-LCCA transposition during the TAR and FET procedure under hypothermic circulatory arrest with selective antegrade cerebral perfusion (SACP). Mean age was 48.5±10.4 years (range, 28–70 years) and 29 were male (82.9%). Chronic aortic dissection was defined as a duration of >14 days from onset of symptoms to surgery (10). In this cohort, the median duration from symptom onset to surgery was 1.2 months (range, 0.5–84.0 months). Diagnosis was confirmed preoperatively by computed tomographic angiography (CTA) and echocardiography in all the patients.

Surgical technique

Our surgical technique of FET was previously described in detail (1,2,11). Briefly, right axillary artery cannulation was used for cardiopulmonary bypass (CPB) and SACP, heart was arrested with perfusion of cold blood cardioplegic solution, and unilateral SACP under hypothermic circulatory arrest at 25 ℃ was utilized with a flow rate of approximately 5–10 $mL \cdot kg^{-1} \cdot min^{-1}$. The procedure involved deployment of a FET (10 cm long and 24–30 mm in diameter), Cronus® (MicroPort Medical, Shanghai, China) in the true lumen between the origins of the LCCA and LSCA. Aortic valve or root procedures and concomitant operations were performed during the cooling phase.

The anterior wall of the aortic arch was incised longitudinally up to the origin of the LCCA, and the incision was about 5 mm distal to the origin of the innominate artery (IA) and LCCA. No dissection of the arch vessels was confirmed intraoperatively. After deployment of FET, the stent-free sewing edge (3 cm long Dacron graft) of the FET was straightened and trimmed to fit within native aortic wall containing the origins of the IA and LCCA. Next, the trimmed sewing edge was sutured to the native aortic wall near the origins of the IA and LCCA, as described in detail previously (12). Thus, the residual aortic arch wall and sewing edge formed a circular opening. Then, an end-to-end anastomosis was made between the rounded opening of the proximal aortic arch and distal ascending aortic graft. Subsequently, the flow rate was resumed to normal.

During the rewarming phase, the LSCA was clamped and transected 5–10 mm distal to its origin. The proximal stump of the LSCA was sewed with a running suture, and the distal end of the LSCA was anastomosed to the LCCA in an end-to-side fashion, as described previously (12,13). For patients with an ILVA, ILVA-LCCA transposition was performed in a similar way. These steps could be undertaken during the cooling phase if there was sufficient time. *Figure 1* shows a schematic diagram of the modified procedure.

Table 1 Preoperative clinical profiles

Variables	Value (n=35) (%)
Age (years)	48.5±10.4
Male	29 (82.9)
Marfan syndrome	3 (8.6)
Hypertension	27 (77.1)
Diabetes	4 (11.4)
Smoking	20 (57.1)
Renal dysfunction	3 (8.6)
Coronary artery disease	5 (14.3)
Left ventricular dysfunction	4 (11.4)
History of stroke	2 (5.7)
Aortic regurgitation	12 (34.3)
Mitral regurgitation	2 (5.7)
Cardiac tamponade*	1 (2.9)
Lower extremity ischemia	1 (2.9)
Isolated left vertebral artery	2 (5.7)
Thoracoabdominal aortic aneurysm (extent V)	1 (2.9)
Previous cardiovascular surgery	4 (11.4)
Previous thoracic endovascular aortic repair	4 (11.4)

*, compression of the heart due to accumulation of blood and clots in the pericardium as a result of effusion or rupture of the ascending aorta.

Patient follow-up

Operative survivors were followed up by clinic visits, telephone interviews, letters or emails. Complications such as neurologic and other morbidities were recorded. CTA was performed before discharge, at 3 and 6 months, 1 year and annually to evaluate thrombosis and obliteration of the false lumen, expansion of the true lumen, arch vessels patency, endoleak and other aortic complications.

Statistical analysis

Statistical analysis was performed using SPSS for Windows 19.0 (SPSS Inc., Chicago, IL, USA) and GraphPad Prism for Windows 6.0 (GraphPad, La Jolla, CA, USA). Continuous variables were expressed as mean ± standard deviation (range); for variables not normally distributed, the median value was determined. Categorical variables are presented as number (percentage). Survival was estimated using the Kaplan-Meier method. Competing risks of death and reoperation were analyzed with the Fine and Gray proportional hazards model. All statistical tests were 2-sided and a P value of <0.05 was considered statistically significant.

Results

Preoperative data

Comorbidities included hypertension in 27 patients (77.1%) and Marfan syndrome in 3 (8.6%). Preoperative renal dysfunction (serum creatinine level >1.5 mg/dL) was present in 3 patients (8.6%), left ventricular dysfunction (left ventricular ejection fraction <50%) in 4 (11.4%), and lower extremity ischemia in 1 (2.9%). Four patients (11.4%) had previous cardiac surgery, including Bentall procedure for type A dissection, aortic valve replacement, aortic and mitral valve replacement, and coronary artery bypass grafting (CABG) in 1 each. Four patients (11.4%) had previous thoracic endovascular aortic repair for type B dissection, 3 of them were retrograde type A dissection and 1 was a new type A dissection. An isolated left vertebral artery (ILVA) was noted in 2 patients (5.7%). *Table 1* shows the preoperative characteristics of patients with CTAAD.

There was no dissection or aneurysm of the IA, LCCA, or distal LSCA among these patients. The primary tear was located in the ascending aorta in 21 patients (60.0%), transverse arch in 9 (25.7%), and proximal descending aorta in 5 (14.3%). Dissection extended to the distal aortic arch in 2 patients (5.7%), descending thoracic aorta in 4 (11.4%), abdominal aorta in 8 (22.9%) and iliac artery in 21 (60.0%), respectively. One patient had a Crawford extent V thoracoabdominal aortic aneurysm.

Surgical data

All patients underwent the procedure successfully. The average times of CPB, aortic cross-clamp, and SACP were 176±47 minutes (range, 111–268 minutes), 89±30 minutes (range, 49–189 minutes), and 29±6 minutes (range, 15–38 minutes), respectively; the mean operative time was 6.6±1.0 hours (range, 5.0–9.0 hours). The median amount of intraoperative blood transfusion was 4 units (range, 0–12 units) and fresh frozen plasma transfusion was 400 mL (range, 0–1,600 mL), respectively. Concomitant procedures are listed in *Table 2*.

Table 2 Concomitant procedures

Procedure	Value (n=35) (%)
Bentall procedure	12 (34.3)
Aortic valve repair	1 (2.9)
Mitral valve repair	1 (2.9)
Coronary artery bypass grafting	2 (5.7)
Ascending aorta-femoral artery bypass	1 (2.9)
Isolated left vertebral-left carotid artery transposition	2 (5.7)

Operative morbidity and mortality

There were 2 in-hospital deaths (5.7%). One patient who underwent surgery 6 years after the initial diagnosis suffered ischemia in viscera organs and died of multiple-organ failure at postoperative 10 days; the other patient with a prior CABG underwent concomitant redo CABG and died of heart failure 9 days postoperatively. No neurological deficit or spinal cord ischemia occurred.

Re-exploration for bleeding was required in two patients (5.7%). Continuous renal replacement therapy was required temporarily in two patients with preoperative renal dysfunction (5.7%). Poor wound healing occurred in one patient (2.9%). All patients recovered uneventfully and were discharged from the hospital in a stable condition.

Follow-up

By March 2018, follow-up was complete in 100% (33/33) for a mean duration of 4.1±1.8 years (range, 0.5–6.7 years). One patient sustained a transient stroke and recovered after medication administration. One patient with Crawford extent V thoracoabdominal aortic aneurysm (6.5 cm in diameter) underwent planned thoracoabdominal aortic replacement 3 months after the TAR + FET procedure, and his postoperative course was uneventful. No cases of visceral malperfusion was observed during the follow-up period.

Follow-up CTA was available in 87.9% of patients (29/33). Persistent anastomotic leak of the aortic arch was observed in one patient (3.4%), but without false lumen expansion or pseudoaneurysm formation to the latest follow-up extending to 2 years. No stenosis or aneurysm of the anastomosis between the LSCA and LCCA was detected (*Figure 2*). Complete thrombosis, partial thrombosis and the false lumen patency around the FET were seen in 89.7% (26/29), 6.9% (2/29) and 3.4% (1/29), respectively. Complete thrombosis at the diaphragmatic level occurred in 62.1% (18/29) of patients (*Figure 3*).

Figure 2 Three-dimensional computed tomographic reconstruction of chronic type A dissection 1 year after surgery using *en bloc* technique with left subclavian artery (LSCA)-left common carotid artery (LCCA) transposition and frozen elephant trunk (FET). (A) The LCCA, (B) the LSCA, and (C) the Cronus FET. The LSCA was anastomosed to the LCCA in an end-to-side fashion (white arrow), with patent anastomoses. The false lumen disappeared and the true lumen returned to normal around the FET.

Survival

Two patients died during follow-up. One patient died of unknown reason at 6 months after ascending aorta replacement + TAR + FET + CABG; the other died of over-anticoagulation at 34 months after Bentall + TAR + FET + mitral valve repair. Overall survival was 91.4% (95% CI, 75.7–97.2%), 87.9% (95% CI, 70.7–95.3%) and 87.9% (95% CI, 70.7–95.3%) at 1, 3 and 6 years, respectively (*Figure 4*). In competing risks analysis, the incidence was 3% for reoperation at 6 years, 12% for late death, and 85% of

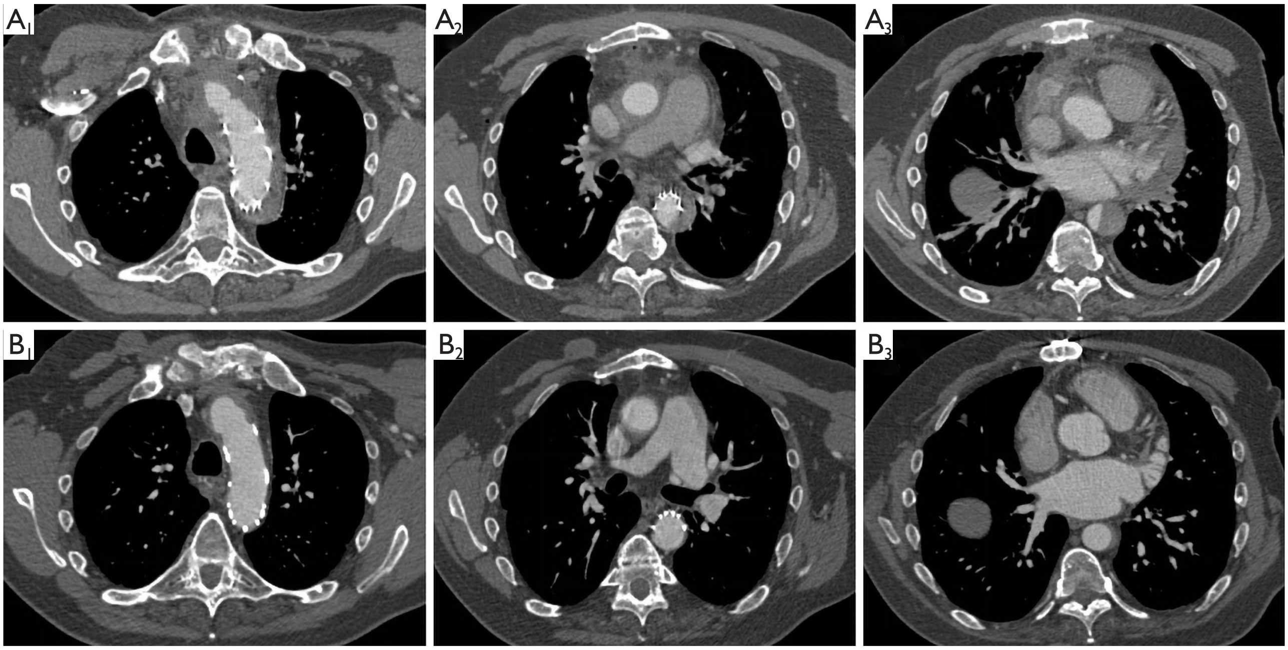

Figure 3 Computed tomographic angiography of a patient with chronic type A dissection 2 weeks (A1–A3) and 1 year (B1–B3) after surgery. The false lumen was obliterated with thrombus and the true lumen returned to normal at different levels. A1 and B1, around the frozen elephant trunk (FET); A2 and B2, at the distal end of FET; A3 and B3, extending to the diaphragmatic hiatus.

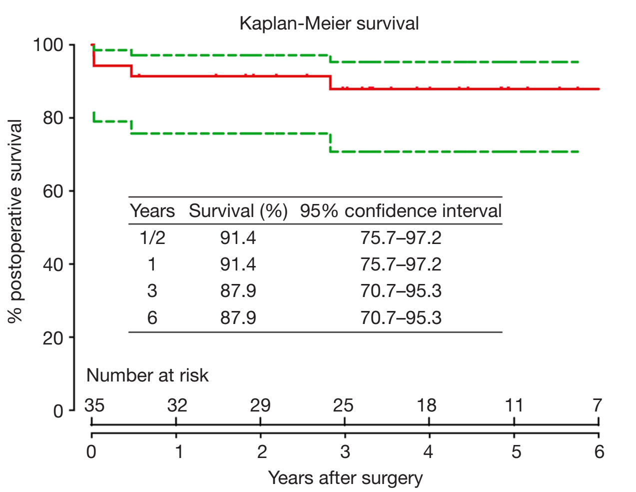

Figure 4 Kaplan-Meier survival (red line) and its 95% confidence interval (green lines).

patients were alive without reoperation (*Figure 5*).

Discussion

Acute type A aortic dissection is a lethal emergency associated with high mortality. Pathologic studies have shown that the aortic wall of the chronic dissection is relatively stable owing to increased thickness and stiffness of intimal flaps during the remodeling process (14,15). Hence, the mortality associated with type A dissection is significantly lower in the chronic phase (10). Currently, surgical management similar to that for acute type A dissection is accepted first-line treatment for CTAAD, with better outcomes than that for patients who undergo surgery in the acute phase (5,16). Various surgical techniques have been introduced to treat aortic arch pathologies of CTAAD (1,2,4,11,16), yet the optimal method is controversial. In recent years, the FET technique has offered a new alternative therapy for chronic and acute dissections. Several meta-analyses have revealed that the TAR and FET technique is associated with a lower prevalence of mortality, and reduces false lumen patency, and the need for reintervention compared with conventional arch procedures (17,18). In multicenter studies, respectable results have been achieved for CTAAD using the TAR and FET approach (1,3,4,19).

However, TAR remains a challenging surgical procedure and bleeding from the anastomoses remains a dreadful complication. Over the years, various techniques, such as

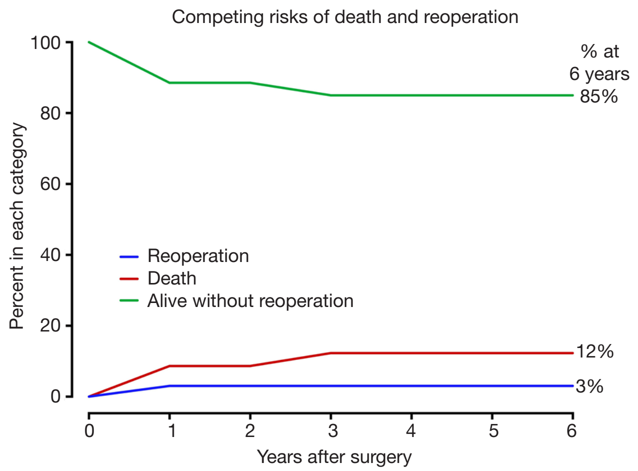

Figure 5 Competing risks of late death and reoperation.

the *en bloc* (island), branched graft (7,8), branched stent graft (9,20), and supra-aortic debranching (21,22), have been introduced to simplify the anastomoses and hemostasis during TAR. However, for the reimplantation of the arch vessels, the *en bloc* and branched graft are the most commonly used methods (7,8).

The classical *en bloc* technique needs only one anastomosis for the arch vessels and has the advantage of long-term patency by preserving the native arch vessels. However, this technique requires all the anastomoses to be completed before reperfusion can be resumed, which can prolong the cerebral and low body ischemia times. Meanwhile, the distal anastomosis in zone III (distal to the LSCA) and the hemostasis of the posterior part of the "island" are technically difficult because of the deep surgical field, which may increase the risk of anastomotic leaks. Moreover, there is a potential risk of aneurysmal dilation of the "island" containing a large piece of residual aortic wall.

In recent years, the branched graft technique has been applied widely during TAR in most aortic arch pathologies, and it has several advantages with respect to *en bloc* technique (8). Over the years, we have performed TAR using a 4-branched graft with the Cronus FET (the Sun procedure) for patients with complex chronic or acute type A dissection involving the arch or proximal descending aorta (23). The indications for this surgical procedure have been described in our previous studies, and favorable outcomes have been obtained in chronic patients (1,2,11). However, as many as 5 anastomoses need to be sutured during TAR in this procedure, which may prolong the hemostasis and operative times.

In addition, Shimamura *et al.* (20) and Chen *et al.* (9) have developed open double- or triple-branched stent graft for TAR in patients with type A dissection. Satisfactory short-term results have been achieved with these methods, but the postoperative migration and kinking of the branched graft may lead to endoleak or stroke (24). The supra-aortic debranching technique is also a promising alternative with the advantage of avoiding circulatory arrest (21,25). However, literature show that it is associated with a high rate of endoleak, stroke, and mortality (22,26). Other methods, such as trifurcated graft (27) and Y-graft (28), have been introduced, but their long-term outcomes for type A dissection remain known.

To address these issues, we have modified the *en bloc* technique for TAR and FET in type A dissection repair. In our modification, the "island" (residual aortic arch aortic wall containing only the IA and the LCCA origins) was trimmed into a very small piece, and all the native arch vessels were preserved via LSCA-LCCA transposition during TAR. The selection criteria of this technique in total arch repair for patients with type A dissection include: (I) the IA, LCCA and distal LSCA (at most 1 cm distal to its origin) are not involved by dissection, aneurysm; (II) the "island" is free from atherosclerotic and aneurysmal lesions; (III) adequacy of the circle of Willis (12).

Acceptable surgical results were obtained using this surgical procedure in the present study. The 5.7% in-hospital mortality was comparable to that of TAR using branched graft or classical *en bloc* technique. The SACP time was not significantly increased compared to conventional surgical procedure performed over the same period in our center (1), and no perioperative neurological deficits occurred. The short- and mid-term outcomes were favorable. Overall survival was 87.9% at 3 and 6 years, respectively. At 6 years, the incidence was 3% for reoperation, 12% for late death, and 85% of patients were alive without reoperation. The rate of false lumen thrombosis was comparable to previous FET series (2,4,12). Persistent anastomotic leak of the aortic arch was rarely observed (3.4%), which we think could be avoided by improving the suturing technique. Moreover, our technique has achieved excellent patency (100%) of the anastomosis between the LCCA and LSCA as confirmed by follow-up CTA.

Our modified *en bloc* technique has several advantages over the classical *en bloc* or branched graft technique. First, moving the distal anastomosis of the aortic arch to zone II (between the LCCA and LSCA) reduces technical complexity by simplifying anastomosis and hemostasis. Second, the small "island" is helpful in reducing the risk of aneurysmal dilatation. Third, different from artificial grafts that have the potential risk of stenosis or occlusion (29,30), all three native arch vessels are preserved by addition of the LSCA-LCCA transposition in this technique, which improves long-term patency. Fourth, only 3 anastomoses were needed during TAR. Furthermore, edema of the aortic wall diminished in most patients with CTAAD, making it firm enough to allow for strong traction of the sutures. Therefore, this surgical technique is more suitable for patients with chronic type A dissection with normal aortic tissues surrounding the IA and LCCA.

Study limitations

This study is limited by its retrospective nature, small sample size, lack of a control group and the relatively short duration of follow-up. Further studies in a large series, preferably in multiple centers, for longer durations are warranted to examine the long-term efficacy of this modified technique.

Conclusions

This modified *en bloc* technique with LSCA-LCCA transposition during TAR and FET procedure was safe and feasible and has achieve favorable mid- to long-term clinical and imaging results in patients with chronic type A dissection. It may be an alternate approach to chronic type A dissection in selected patients.

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Footnote

Conflict of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: This study was approved by the Institutional Review Board of Beijing Anzhen Hospital of Capital Medical University (No. 2016016X).

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