A modified frozen elephant trunk technique for acute Stanford type A aortic dissection

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Abstract
Background Acute Stanford type A aortic dissection is a lethal event with a high mortality rate and requires emergency intervention. The goal of salvage surgery is to keep the patient alive by addressing the problems of severe aortic regurgitation, tamponade, primary tear and malperfusion of organs, and, if possible, to prevent the late dissection-related complications in the proximal and downstream aorta. No standard treatment or techniques have been determined for this disease. We aim to describe a modified elephant trunk technique for acute type A aortic dissection and report the short-term outcomes of this surgical technique.

Methods From February 2018 to August 2019, 16 patients who were diagnosed with acute Stanford type A aortic dissection underwent surgery with the modified frozen elephant trunk technique procedure at Xiamen Heart Centre (9 men; age, 59.21±11.67 years). All perioperative variables were recorded and analyzed. We measured the diameters of the ascending aorta, aortic arch and descending aorta on the bifurcation of the pulmonary and abdominal aortas and compared the diameters at admission, before discharge, and 3 months after discharge.

Results Fifteen patients (93.8%) had hypertension and poor blood control management. Operative mortality was 6.25%. The primary tears were located in the lesser curve of the aortic arch in 5 patients (31.3%), in the ascending aorta in 9 patients (56.3%), and no entry was found in 2 patients (12.5%). The dissection extended to the iliac artery in 14 patients (87.6%) and to the distal descending aorta in 2 patients (12.5%). The time of cardiopulmonary bypass (CPB), cross-clamping and cerebral perfusion were 215±40.5, 140.8±32.3, and 23±6 minutes, respectively. Aortic valve plasty was performed in 15 patients (93.8%). Additionally, the Bentall procedure and coronary artery repair were performed in 1 patient each (6.3%), respectively. The diameters at all levels were greater before discharge than those when admission to the hospital, except for the diameter of the aortic arch. After 3 months, the diameters at the aortic arch, descending aorta of the diaphragm, bifurcation of the pulmonary artery had increased, but the diameter at the bifurcation level of the common iliac artery had changed little. Only the diameter of the distal stent aorta had increased significantly.

Conclusion The modified frozen elephant trunk technique for acute Stanford type A aortic dissection is
safe and feasible, and it could be used for organ malperfusion as well. Short-term outcomes are encouraging, but long-term outcomes require further investigation.

Introduction
Acute Stanford type A dissection is a lethal event with a high mortality of 1% per hour for the first 48 hours; thus, it requires emergency surgery, except when patients have a serious condition like coronary and/or cerebral malperfusion[1]. There is controversy regarding how to treat this disease, especially when the aortic arch and descending aorta are involved (DeBakey type I and II) [2] [3] [4]. Early surgeons used a limited approach, such as ascending aortic or hemiarch replacement, which ignored the true lumen flow and pathologic disorders of the descending aorta[5]. Some papers indicate that the frozen elephant techniques have an acceptable mortality or morbidity risk for treating acute type A aortic dissection[1] [6] [7] [8]. To obliterate the false lumen and better manage the descending aorta for good remodeling, and also to simplify the procedure and avoid time-consuming hemostasis, here we introduced a new technique to achieve the goals mentioned above. The procedure incorporates a frozen elephant trunk that is fenestrated proximal to the stent graft to perfuse the supra-vessels above. Here, we describe this new technique for type A dissection and report the short-term outcomes.

Methods
From February 2018 to August 2019, 16 patients presenting with acute Stanford type A aortic dissections were admitted to the hospital. Medical records were retrospectively reviewed for pre-, intra-, and postoperative variables. The ethical committee of Xiamen Heart Centre approved for this retrospective study, and all patients provided informed consents. So that we could make an accurate diagnosis, patients underwent preoperative computed tomography angiography (CTA), transthoracic echocardiography, laboratory testing, electrocardiography, and blood gas analysis before surgery was initiated. All patients in this study underwent treatment using our modified technique.

All perioperative variables were recorded and analyzed. We measured the diameters of the ascending aorta, aortic arch, and descending aorta at the bifurcation of the pulmonary and abdominal aortas and compared the diameters at admission, before discharge, and 3 months after discharge.

Procedure
All cases were performed with the patients under general anesthesia. Three atrial pressure lines (2 radial and 1 pedal) and a transesophageal echocardiographic monitoring probe were inserted. Cerebral activity was monitored by noninvasive detection of cerebral oxygen saturation monitoring. Perioperative cerebrospinal fluid drainage was not routinely used. After median sternotomy, the 3 brachiocephalic arteries were dissected carefully and prepared, cardiopulmonary bypass was then initiated via femoral artery and right atrium cannulation. Left ventricular drainage was finished by placing a tube in the right superior pulmonary vein, and then cooling was begun. During the cooling phase, the ascending aorta was clamped proximal to the innominate artery and incised above the sinotubular junction. Histidine-tryptophan-ketoglutarate cardioplegia solution was infused antegrade to the left and right coronary artery sinuses. The proximal aorta was transected, the fresh clot was removed, and the aortic valve was repaired. After that, the proximal stump was trimmed with Teflon strips to reconstruct the dissected root. Circulatory arrest was started, and unilateral cerebral perfusion via the innominate artery cannulation [9] [10] was initiated at a rate of 5–10 mL/kg/min at a rectal temperature of 25 °C after valve-sparing was accomplished. The aortic arch was opened and transected at the innominate artery level to determine whether there was any tear in the aortic arch. The diameter of the arch was measured to confirm an appropriate stent graft size, and the length was 10 to 15 cm depending on the patient’s height and body habitus. A WeiChuang (Cronus; Microport Medical Co, Ltd, Shanghai, China) stent was inserted into the true lumen of the arch, released to a level that covered the three brachiocephalic vessels, and resected to create a fenestration around the orifices of the brachiocephalic vessels. Then, it was circumferentially sutured to the low margin of the left subclavian artery orifice using continuous mattress sutures of 4 – 0 Prolene, ensuring that all the layers of the graft wall and aortic arch were penetrated. The stent graft at the base of the fenestration was sutured to the base of the branch artery as well, using interrupted sutures with 3 – 0 Prolene(Fig. 1). Finally, after the fixation of the fenestrated stent with a Dacron patch, the reinforced distal stump was anastomosed to the vascular graft. Meanwhile, a silicone Foley catheter with an aqueous capsule was inserted into the descending aorta to occlude blood flow from femoral cannulation. After the last anastomosis, the heart started beating after removal of the clamp with
carefully de-airing. Patients were gradually weaned off of cardiopulmonary bypass during the remaining surgical procedures, such as hemostasis and closure of the incision.

Follow-up

CTA was performed when patients were admitted, before discharge, and 3 months after discharge, using 3-dimensional reconstruction software to measure the diameters of the ascending aorta, true lumen and false lumen of the aortic arch, and the descending aorta at its widest point. Changes in the diameters of the different sites were recorded and analyzed.

Statistical analysis

Standard descriptive statistical analyses were used. Continuous variables are shown as the means with standard deviations or as medians with ranges (because of the small sample size), and categoric variables are presented as percentages. Data analysis were analyzed using SPSS version 20.0 (IBM Corporation, Armonk, NY). P values < 0.05 were considered significant.

Results

Preoperative, intraoperative and postoperative variables are shown in Table 1 and Table 2.

| Table 1
| Preoperative Clinical characteristics |
|--------------------------------------|
| Characteristic                      | n(%)          |
| Age                                 | 56.1 ± 7.6    |
| Patients                            | 16            |
| Male/female                         | 9(56.3)/7(43.8) |
| Comorbidities                       |               |
| Hypertension                        | 15(93.8)      |
| Chronic kidney disease              | 1(6.3)        |
| Diabetes melitus                    | 3(18.8)       |
| Primary entry                       |               |
| Ascending aorta                     | 9(56.3)       |
| Arch                                | 5(31.3)       |
| No entry found                      | 2(12.5)       |
| Malperfusion                        |               |
| Coronary                            | 1(6.25)       |
| Leg                                 | 2(12.5)       |
| Cerebral                            | 2(12.5)       |
Changes in the diameters of the aorta, aortic arch, descending aorta at the diaphragm, and at the bifurcation of the common iliac artery are shown in Table 3. The diameters of the ascending aorta changed less than did those of the other arteries, because we replaced the ascending aorta with a Dacron tube. The diameters at all levels were larger before discharge than on admission to the
hospital, except the aortic arch. After 3 months, the diameters of the aortic arch and the descending aorta at the level of the diaphragm and bifurcation of the pulmonary artery level increased, but there was little change at the level of the bifurcation of the common iliac artery. Only the diameter of the distal stent aorta increased significantly (Fig. 2). Three-dimensional reconstructions of different level of the aorta are shown in Fig. 3.

| Site of aorta                      | Preoperative(mm) | Before discharge(mm) | 3 months after discharge | P-value |
|-----------------------------------|------------------|----------------------|--------------------------|---------|
| Ascending aorta (mean ± SD)       | 43 ± 3.5         | 28.3 ± 3.1           | 28.4 ± 2.7               | 0.14    |
| Aortic arch (mean ± SD)           | 34.4 ± 4.0       | 30.1 ± 4.1           | 31.2 ± 3.8               | 0.07    |
| Descending aorta                  |                  |                      |                          |         |
| Bifurcation of the pulmonary artery | 29.1 ± 3.5     | 33.5 ± 4.8           | 34.2 ± 4.2               | 0.13    |
| Distal stent                      | 29.1 ± 0.4       | 31.9 ± 2.6           | 32.3 ± 3.2               | 0.01    |
| Diaphragm                         | 29.1 ± 0.4       | 30.9 ± 0.4           | 31.2 ± 1.2               | 0.42    |
| Bifurcation of the common iliac artery | 18.5 ± 0.3 | 2.01 ± 0.3           | 2.01 ± 0.3               | 0.66    |

The additional file is a video called "Fenestrated Technique".

**Discussion**

Acute aortic dissection is a lethal condition that requires emergency surgery to prevent patients from dying of rupture, tamponade and severe aortic valve regurgitation. Additionally, if necessary, surgery is required to correct of the dissected aortic root, coronary ostia and distal malperfusion including cerebral and visceral malperfusion. With improvements in surgical techniques, anaesthesia and perioperative care, the majority of patients have been salvaged, but the condition is still associated with high morbidity and mortality. However, the ideal surgery for acute type A dissections is controversial. Some surgeons suggest an ascending aorta replacement with the proximal arch replacement and aortic root repair as well. Ando et al. recommended total arch replacement with an elephant trunk to obtain a stronger distal anastomosis and facilitate descending aortic operations [5]. If it is not possible to completely stabilize the dissected membrane or obliterate the false lumen, some surgeons propose total aortic arch replacement with a frozen elephant trunk technique to prevent its dilatation[4]. The exponentially increasing use of stents for the descending aorta, together with encouraging outcomes of the INSTEAD XL trial [12], have incited a prevalent trend toward
antegrade stent placement with contaminant with the replacement of the proximal aorta during the repair of an acute type A aortic dissection[3] [13]. Many studies have reported that aortic arch replacement with the frozen elephant trunk technique can result in excellent aortic remodeling of the downstream aorta and can improve the long-term outcomes of acute aortic dissection. Some analyses have also found that the frozen elephant trunk technique for aortic arch dissection did not result in unacceptable rates of mortality and morbidity risks [1]. Furthermore, the branched graft technique and the en bloc technique can be used during surgical treatment of the aortic arch diseases, including aortic dissection[14]. Additionally, the Y-Graft technique and aortic arch debranching are also used by surgeons as aortic therapy[15]. Finally, a prophylactic aortic arch debranching technique has also been reported[4]. However, because of the unclear long-term follow-up outcomes and low numbers of patients, none of these techniques has emerged as the standard for surgical repair.

In China, total arch replacement using a 4-branched graft with implantation of a special stented graft in the descending aorta (Sun’s procedure) is widely recognized and commended for favorable and safe outcomes and the feasibility of reoperation of the residual descending aorta[16]. However, Sun’s procedure entails careful dissection, 3 anastomoses of the 3 brachiocephalic vessels, and serious hemostasis which requires too much time to complete. Thus, the main counter-argument is that greater technical complexity, longer operative times, and extended hypothermic circulatory arrest times may increase patient mortality and morbidity.

To address the limitations of Sun’s procedure and to simplify the procedure, we developed a modified frozen elephant trunk technique for acute Stanford type A dissection, using WeiChuang(Cronus; Microport Medical Co, Ltd, Shanghai, China) stent fenestration in the arch(exposing the orifices of the 3 branchiocephalic vessels) and circumferentially fixing the stent with the lesser curvature to prevent a source of endoleak. Compared with the most utilized procedures, our technique does not involve dissection of the left subclavian artery which can be hard to visualize clearly, replacement of the 3 branchiocephalic vessels, or distal end-to-end anastomosis, thereby reducing cardiopulmonary bypass time and clamp time. Most importantly, even though we currently have limited experience with it, our technique involves eliminating the tear in the ascending aorta, thrombosing the false lumen, excellent
remodeling of the downstream aorta improving the distal malperfusion and simplifying the overall procedure as well.

Our technique has achieved good results, some possible reasons are as follows: (1) the proximal frozen elephant trunk was located in the arch between the innominate artery and left coronary artery with limited sacrifices of intercostal arteries, avoiding extensive coverage of the descending artery that can be a risk factor for paraplegia. Flores and colleagues demonstrated that extensive coverage of the descending aorta with the graft region of the frozen elephant trunk prosthesis, represents a strong risk factor for spinal cord ischemia in patients undergoing frozen elephant trunk surgery; (2) the simplified procedure requires less time because we avoid judicious dissection and anastomosis of the 3 arteries of the arch; (3) we use a special stent graft that is convenient for future thoracoabdominal aorta replacement in the future; (4) the frozen elephant trunk technique can enlarge the true lumen and offers promising false lumen thrombosis and remodeling; and (5) during the primary cases, we found that the margin of the left subclavian artery is generally the source of an type I endoleak, so we used circumferential anastomosis at the level of the left subclavian artery to prevent endoleaks.

Spinal cord ischemia is a serious complication that can occur perioperatively. A length of 10 cm for frozen elephant trunk graft is acceptable, as most cardiac surgeons believe its primary purpose is to stabilize the dissecting membrane and open true lumen expansion downstream [17]. However, Eric E. Roselli stated that a 10-cm frozen elephant trunk does not offer adequate length to cover the curve of the arch entirely, and a 15-cm device was the most appropriate because 20-cm devices have a tremendous risk of spinal cord injury [13]. In our patients, we advocate 12 cm frozen elephant trunk device, which can greatly decrease the risk of paraplegia. Selecting a distal landing zone above the T7 level seems to decrease the spinal cord ischemia greatly [7]. Davide Pacini claims that spinal cord injury occurs more often in patients with a patent false lumen during follow-up than in those without it[8]. Unfortunately and conversely, one patient developed paraplegia before discharge because he had organ malperfusion, and CTA indicated extensive thick thromboses in the false lumen which might have been be a risk factor for his paraplegia.
According to European guidelines, recommendations for type A intramural hematoma are the same as those for the treatment for type A aortic dissection. There is a case report describing the use of the frozen elephant trunk to treat the disease, but the patient received subsequent endovascular surgery 8 months after his discharge[18]. There are 2 patients (12.5%) who underwent surgery with our technique who have persistent back pain, which was diagnosed as intramural hematoma and they achieved good outcomes, suggesting satisfactory outcomes for this technique.

Additionally, there have been some reports of several new techniques to treat acute Stanford type A aortic dissection[19] [20]. In contrast to those other procedures, we do not use a special tailor-made stent graft which composed of a 3-mm stent-free vascular graft at the proximal end and a self-expandable stent, tailor-made grafts may be very expensive in China. Finally, we also achieved the same good results. It is important to note that not all cases of type A aortic dissection are appropriate for this technique. Good candidates for our technique include: (1) primary tear locate in the ascending or descending aorta and the less curve of the aortic arch; (2) the primary tear is not located between the supra-vessels. If our technique is used in cases other than these, the false lumen will be patient, aortic arch will dilate, and a type I endoleak will occur.

Limitations
This study was a retrospective study with a small sample size and no control group from a single center. The follow-up period was not overly long, and our results mainly describe short-term outcomes before discharge and 3 months after discharge.

Conclusion
Our modified frozen elephant trunk technique for acute Stanford type A aortic dissection is safe and feasible. Short-term outcomes are encouraging, but long-term outcomes including remodeling of the descending aorta need further investigation.

Abbreviations
CPB: Cardiopulmonary bypass; CTA: computed tomography angiography.

Declarations

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Availability of data and materials

The datasets generated or analyzed during the current study are included in this published article.

Authors’ contributions

Shibo Song was a major contributor in writing the manuscript. Poyuan Hu, Xijie Wu, Yong Sun and Haifeng Qiang contributed to conception and design. Shihao Cai drafted tables. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This study was approved by the ethical committee of Xiamen Cardiovascular Hospital of Xiamen University.

Consent for publication

All patients gave written formal consent to participate.

Competing interests

The authors declare that they have no competing interests.

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Figures
Figure 1

A: The illustration of a “fenestrated” frozen elephant trunk for Stanford A dissection; B: The red arrow and the black arrow indicate continuous suture and circumferential suture to prevent endoleak; The blue arrow indicates continuous mattress suture. C: The illustration of the “fenestration”.
Figure 2

CTA about the aorta at different level at admission and before discharge and 3 months after discharge. The upper four pictures stands for aorta at the bifurcation of the pulmonary artery, aortic arch, diaphragm and bifurcation of the common iliac artery when admitted in hospital (A-D). The middle and final four pictures stands for aorta at the bifurcation of the pulmonary artery, aortic arch, diaphragm and bifurcation of the common iliac artery when before discharge (E-H) and 3 months after discharge (I-L).
Figure 3

Three-dimensional reconstruction of the aorta at admission before discharge and 3 months after discharge (A-C).

Supplementary Files
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fenestration.mp4