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Intraoperative Fenestration of Frozen Elephant Trunk (FET) and Total Arch Replacement for Aortic Dissection in Aberrant Subclavian Artery

Zhang Jing,[1] Zhefeng Kang,[2] Zejun Fei,[1] Yuanyuan Fan,[3] Yingqiang Guo,[2] Jun Shi[2]

[1]Department of Radiology, West China Hospital of Sichuan University, Chengdu, Sichuan Province, China;
[2]Department of Cardiovascular Surgery, West China Hospital of Sichuan University, Chengdu, Sichuan Province, China;
[3]West China School of Medicine, Sichuan University, Chengdu, Sichuan Province, China

ABSTRACT

Background: Total arch replacement (TAR) and the frozen elephant trunk (FET) routinely are performed to treat aortic dissection. When aortic dissection combines with the aberrant right subclavian artery (aRSA), routine TAR+FET will occlude the ostium of aRSA. But there is no consensus regarding the optimal surgical strategy to revascularize the aRSA. We seek an uncomplicated and less time-intensive way to reconstruct the aRSA.

Methods: From July 2020 to April 2022, six patients with aortic dissection and aRSA underwent TAR+FET and intraoperative fenestration on the descending trunk. The mean age of the patients was 51.7 (SD 16.2; range 30.0–72.0). TAR+FET was performed via a median sternotomy and under cardiopulmonary bypass (CPB) and moderate hypothermic circulatory arrest (HCA). A fenestra of descending trunk was made intraoperative.

Results: There was no operative death in hospital and follow up. The average aortic cross-clamp time, SACP time, and lower body circulatory arrest time was 138.8 (SD 22.5; range 103.0–156.0) min and 28.3 (SD 3.9; range 25.0–35.0) min. Bleeding, neurological deficit, visceral ischemia, injury to the spinal cord, or organ dysfunction was not observed. Follow-up CTA showed the blood flow of aRSA was patent in all patients.

Conclusion: TAR+FET and intraoperative fenestration on the descending trunk is an efficacious approach. It also reduces the difficulty of reconstruction the aRSA in aortic dissection patients.

INTRODUCTION

Aortic dissection has a reported incidence of 3.4 per 100000 person-years [Clouse]. It is always associated with high mortality without immediate surgical intervention [Frederick 1975]. When treating dissections involving arch and descending aorta, total arch replacement (TAR) and the frozen elephant trunk (FET) routinely were performed in our center. The sick aortic arch was replaced and three arch vessels (the innominate, left carotid, and left subclavian arteries) were anastomosed to a tetrafurcate graft, while a stented elephant trunk was implanted into the descending aorta [Sun 2013].

Most individuals (75%) have the "normal" aortic arch, with the innominate, left carotid, and left subclavian arteries arch vessels arising from proximal to distal. But a small group had a rare anatomical variant of the aortic arch called the aberrant right subclavian artery (aRSA) [Muller 2011; Frequency 2013; Dumfarth 2015]. It most often presents as the right subclavian artery (RSA) arising as a fourth vessel from the distal aortic arch or proximal descending aorta and follows either a retro-esophageal course or extends between the esophagus and trachea to the right arm [Konstantinou 2022]. When aortic dissection combines with the aRSA, the FET implanted in descending aorta will occlude the ostium of RSA, which may lead to complications of ischemia of the right vertebral artery, right upper extremity artery, and right internal thoracic artery [Toole 1975; Li 2021; Benhammamia 2019]. Thus, it requires revascularization of the subclavian artery but there is no consensus regarding optimal surgical strategy. The conventional approach involves anastomosing the distal extremities with an artificial vessel after ligation or suture the oral of aRSA [Kikuchi 2005; Li 2020]. But it will significantly increase surgical difficulty and operation time.

To make it more uncomplicated and less time-intensive, we had reported a method reconstructing the aRSA by fenestration intraoperatively while performing TAR and FET [Kang]. In this study, we retrospectively report on six patients with aortic dissection and aRSA, who underwent this new procedure in our center.

MATERIALS AND METHODS

Patients: Between July 2020 and April 2022, six patients with aortic dissection and aRSA underwent the TAR+FET along with intraoperative fenestration on the descending trunk. The mean age of the patients was 51.7 (SD 16.2; range 30.0–72.0). Preoperative characteristics of the cohort

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Correspondence: Jun Shi, Department of Cardiovascular Surgery, West China Hospital of Sichuan University, No. 37, Guoxue Alley, Chengdu, Sichuan, P.R. China, 610041 (e-mail: shijun568@163.com).

Table 1. Patient characteristics

Variables	Value
Age(years) mean ± standard deviation	51.7±16.2 (range 30.0–72.0)
Height (cm)	164.2±11.4(range 156.0–186.0)
Weight (kg)	60.3±9.1(range 54.0–78.5)
Systolic pressure (mmHg)	134.3±21.0(range 101.0–165.0)
Diastolic pressure (mmHg)	62.2±15.6(range 40.0–80.0)
Organ ischemia	0 (0)
Neurological complications	0 (0)
History of cardiovascular surgery	0 (0)
Acute dissection	6 (100%)
Dissection involving aRSA	0 (0)

are listed in Table 1. (Table 1) All patients were diagnosed with aortic dissection involving the arch and descending aorta and confirmed the left-side arch with the aRSA by computed tomographic angiography (CTA) preoperatively. (Figure 1) The blood pressure of the right upper limb preoperatively was recorded. None of the patients were observed with complications related to organ ischemia caused by vessel dissection.

The hospital ethics committee of West China Hospital of Sichuan University granted approval of this study. Written informed consent was obtained from the patients for publication of this article and any accompanying images.

Surgical method: The indications of TAR using an FET for patients with aRSA include type A dissections involving the arch or arch vessels and descending aorta. For patients reconstructing aRSA with intraoperative fenestration, the aRSA should not be involved with dissection.

The main steps of TAR+FET was performed as previously reported [Sun 2013; Ma 2013]. Patients underwent the surgery via a median sternotomy and under moderate hypothermic circulatory arrest (HCA). Cardiopulmonary bypass (CPB) was set up via femoral cannulation. When the nasal temperature reached 25℃, the left subclavian artery (LSA), right common carotid artery (RCCA), and left common carotid artery (LCCA) were clamped and RCCA was cannulated for unilateral selective antegrade cerebral perfusion (SACP). The sick arch was then cut off and an FET (Cronus, MicroPort Medical, Shanghai, China) was deployed to the descending aorta. The size of the trunk was chosen 10% oversize than the diameter of descending aorta. After this stage, the unique steps of our method would be performed: 1) When the trunk had well expanded, approximately locating the oral of the fenestration by pushing the root of aRSA to the wall of the trunk, so that an embossment can be seen on the inner surface of the trunk, which is just at the opening of the aSCA; 2) We then would create a fenestra with a cauter on the located Dacron sleeve of the trunk and make sure the oral was fluent; and 3) Anastomosing the proximal FET and descending aorta to the tetrafurcate graft, separately clamping the proximal segment and four branches of the graft, so that the perfusion of the lower body and RSA can be resumed.

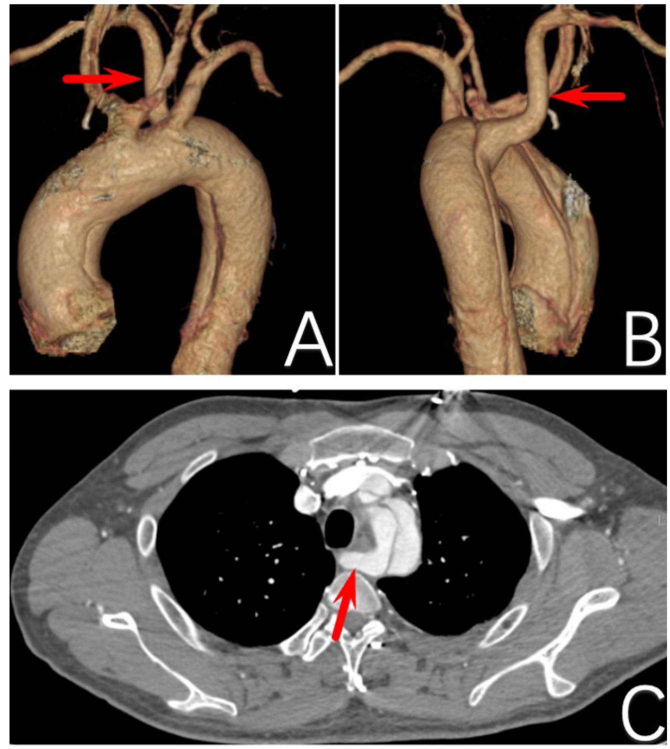

Figure 1. Computed tomographic angiography showed a type A dissection involving the arch and descending aorta. The aberrant right subclavian artery is shown on the arch (A and B, arrowhead) and its ostium on descending aorta (C, arrowhead).

It is important to ensure the fenestration completed gradually, we first made a small hole on the trunk and inserted a bougie through the hole into the right aSCA to check whether it is the correct location. Then, the fenestra was enlarged until its size matched or slightly smaller than the opening of the right aSCA. An aspirator was inserted into the right subclavian artery through the fenestra to identify the patency of the vessel. (Figure 2) When the perfusion was resumed, right arterial blood pressure should be monitored to identify the fluency of the fenestration.

After resuming the body perfusion and revascularization of the aRSA, the uncannulated LCCA was first anastomosed to minimize the cerebral ischemia time, after which the rewarming began. The bilateral cerebral arteries and right subclavian artery perfusion were continued at this time. The tetrafurcate graft was sutured to the ascending aorta next. Afterward, the RCCA and LSA separately were anastomosed to the two branches of the tetrafurcate graft.

Patient follow up: Operative mortality was defined as any death occurring within 30 days of surgery or before final discharge from the surgery. Reoperation was defined as any surgical procedure related to the primary surgery (severe endoleak, anastomotic leak, occlusion of macrovascular and dissection progression). All patients had an aortic CTA at

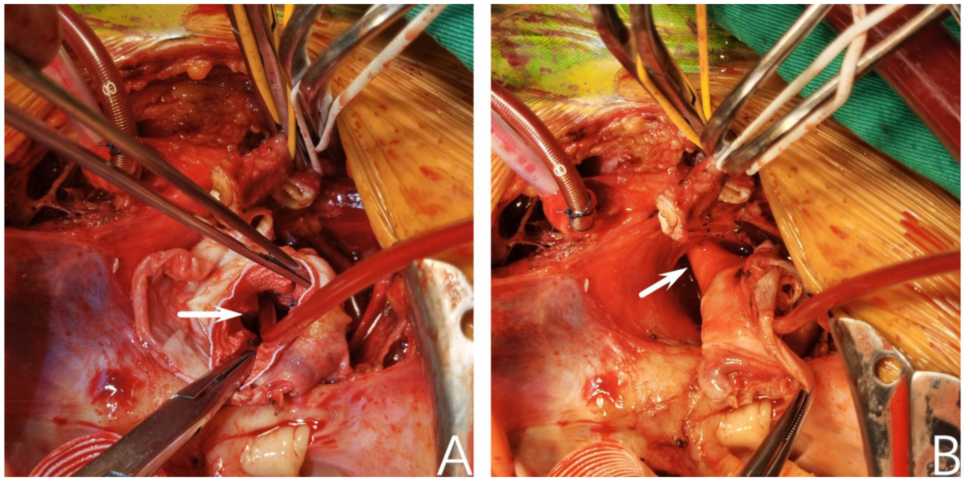

Figure 2. An aspirator was inserted into the right subclavian artery through the fenestra to identify the patency of the vessel (A, arrowhead). The root of the right subclavian artery is shown behind the descending aorta (B, arrowhead).

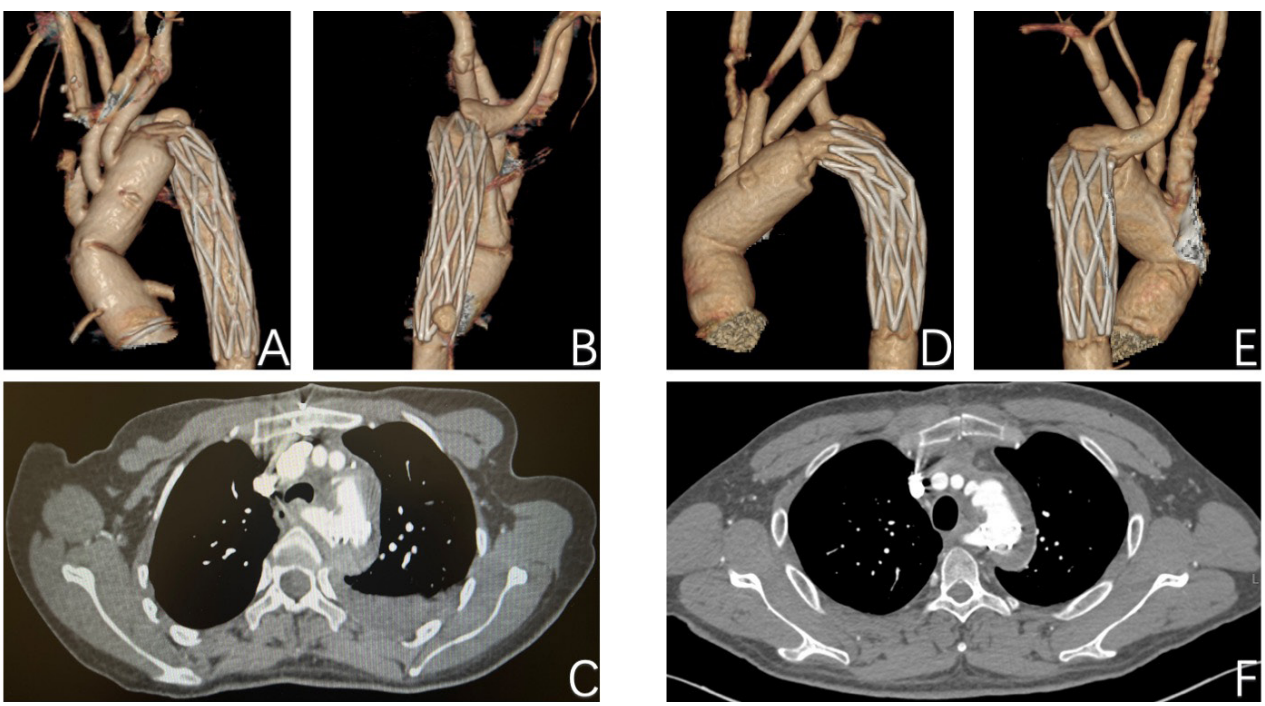

Figure 3. Computed tomographic angiography showed the right subclavian artery was patent at discharge in two different patients (A-C, D-F). And the false lumen was well closed.

discharge and were recommended to have aortic CTA at three months, and annually thereafter to assess the patency of the aRSA and residual dissection and complications (endoleak, anastomotic leak and occlusion). The blood pressure of bilateral upper limbs was recommended to be recorded at least three times a day and would be checked at every follow up.

Statistical analysis was performed using SPSS 22.0. Continuous variables were expressed as mean, followed by standard deviation (SD) and range, and categorical variables as number (percentages).

RESULTS

Operative data: All six patients were diagnosed with type A dissection involving the arch and descending aorta. All patients underwent TAR+FET and intraoperative fenestration of aRSA. Four patients had Bentall performed for ascending aorta dissection and the others underwent ascending aorta replacement. The average aortic cross-clamp time, SACP time, and lower body circulatory arrest time was 138.8 (SD 22.5; range 103.0–156.0) min and 28.3 (SD 3.9; range

25.0–35.0) min, respectively. There was no major bleeding event that occurred in operation. The mean arterial pressure (MAP) of the right and left radial artery was 43.3 (SD 14.4; range 27.0–65.0) mmHg and 50.7 (SD 12.4; range 30.0–65.0) mmHg. Patients routinely were transferred to the intensive care unit (ICU) after surgery. Average extubation time of patients was within 24 hours after surgery. Mean drainage volume within 24 hours was 486.8 (SD 112.7; range 303.0–600.0) ml. No reoperation occurred.

Mortality and complications: There was no operative death in the hospital and at follow up. All patients were discharged from the hospital. Neurological deficit, visceral ischemia, or injury to the spinal cord was not observed. There was no organ dysfunction that needed dialysis or artificial liver treatment. The systolic and diastolic pressure of the right and left upper limb at six months after surgery was 118.6 (SD 15.8; range 98.0–138.0)/81.7 (SD 9.1 range 67.0–90.0) mmHg, 114.7 (SD 13.8; range 97.0–130.0)/ 78.2 (SD 7.7; range 65.0–87.0) mmHg.

Radiological follow up: All patients received an aortic CTA at discharge and at three months after surgery. (Figure 3) Obliteration and thrombosis of the false lumen, expansion of the true lumen was observed across the segment of FET in 100% patients at three months. The blood flow of aRSA was patent among all patients at discharge and three months after surgery. There was no obstruction or stenosis was observed in the aRSA and no severe endoleak around the oral of the fenestration at three months follow up.

DISCUSSION

Most aortic dissection involving the arch and descending aorta can be treated well by TAR+FET procedure [Sun 2013; Ma 2013]. The sick arch surgically is removed under moderate HCA and SACP, and a frozen stent is implanted in the descending aorta. After anastomosing the proximal descending aorta, the perfusion can be resumed, then the LCCA, brachiocephalic trunk, LSA and ascending aorta can be anastomosed, respectively. This procedure could guarantee a good cerebral perfusion during the HCA, and the frozen trunk deployed in the descending aorta will cover tears of dissection to accelerate the false lumen obliteration and thrombosis. Favorable prognosis with less complications of this procedure also has been confirmed with clinical study [Ma 2013].

Aberrant right subclavian artery is a rare congenital vascular malformation [Muller 2011]. Blood flow through the aRSA via its opening at the descending aorta into the right vertebral artery, axillary artery, and internal mammary artery to perfume the posterior circulation, right upper limb, and chest wall. When a patient with aRSA undergoes the TAR+FET procedure, the frozen trunk deployed into the descending aorta will cover the oral of the aRSA, thereby blocking its blood flow. It emerges with a high possibility of neurological complications, such as paraplegia or dysfunction of the right upper limb caused by ischemia [Li 2021; Patel 2021; Khoury 2021]. Therefore, revascularization of aRSA is necessary to avoid postoperative complications.

The normal strategy of aRSA revascularization is fully freeing this vessel, suturing or ligating the root, and then anastomosing the distal extremity to a branch of tetrafurcate graft [Kikuchi 2005; Li 2020; Zhu 2016]. But this method undoubtedly increases the difficulty of surgery. First, the aRSA usually opens at the dorsal side of the proximal segment of the descending aorta and follows either a retroesophageal course or extends between the esophagus and trachea to the right arm [Konstantinou 2022]. There are laryngeal nerve, thoracic duct, and esophagus in this area [Esposito 1999]. Freeing the aRSA probably damages these structures. And it has the possibility to lead the rupture of dissection because of repeated traction during manipulation. Moreover, SACP can directly perfuse the RCCA and RSA through the brachiocephalic trunk in patients with normal arch, but in patients with aRSA, the right subclavian artery does not share common origin with the RCCA. So only unilateral SACP of the RCCA can be achieved during the HCA. When the circulation resumes, the LCCA needs to be anastomosed first to ensure bilateral cerebral perfusion and then anastomosing the left or right subclavian artery [Li 2020]. Therefore, the ischemic time of the vertebral artery will be relatively prolonged, which may increase the incidence of ischemia-related complications of the basilar artery and posterior circulation in the early postoperative period.

In order to reduce the difficulty and time of operation, we used a previously reported surgical method to reconstruct the blood flow of aRSA through intraoperative fenestration on frozen stent [Kang]. Blood can directly flow into the aRSA through fenestra on descending aorta. The advantage is that this procedure does not need to suture or ligate the root of aRSA, which avoids the anatomical dissociation of the deep tissue in the posterior mediastinum and can reduce the complications caused by the injury of surrounding tissues include nerves, vessels, or lymphatic vessels. On the other hand, the fenestra on the descending aorta can restore the perfusion of the RSA immediately after the recovery of circulation. Compared with the normal operation method that needs to anastomose the left/right subclavian artery alone, it reduces the time of vertebral artery ischemia and plays a protective role in intraoperative brain protection. Our results also show that fenestration of the descending aortic stent does not significantly increase the HCA time. Compared with the ligation or suture of the root of the aRSA under circulatory arrest, the fenestration manner also is easier to operate and faster. By changing the revascularization of aRSA, the whole operation process was simplified, and the trauma of operation and time of HCA and CPB was reduced. Among the six patients we followed up, there was no death during the perioperative period and at one-year follow up. There also was no organ dysfunction caused by HCA or CPB and no neurological complications, including paraplegia.

Inevitably, there are some potential risks existing in this method, although it was not apparent to our six patients. The position and size are essential to the effect of fenestration. Inappropriate position or small size of fenestra may lead to obstruction of aRSA, which usually entails RCCA-to-aRSA bypass or interventional fenestration and placement of a chimney stent. Furthermore, the bypass is unable to provide physiological blood flow and prone to graft occlusion in the long term. It also is susceptible to subclavian steal syndrome and may lead to carotid artery ischemia [Toole 1975; Li 2020; Boening 1999]. Otherwise, inappropriate position or excessive size may lead to endoleak around the fenestra. In the case of severe endoleak, another open chest surgery may be required [Charalambous 2021; Ameli-Renani 2020]. To prevent obstruction and endoleak, accurate estimation of the size and position of the fenestra is important. We used a soft attractor to assist with evaluation of the fenestra position. As for the size of the fenestra, we believe it would be better to not exceed the diameter of the aRSA ostium. In addition, the oversize choice of frozen trunk may provide greater axial force to the descending aorta, so it can fit closely to reduce endoleak. We speculate the diameter and location of the aRSA opening itself also may have some association with postoperative endoleak, especially when the opening is in the false lumen. But there is still a lack of relevant data.

There are additional ways in practice, such as directly blocking the aRSA and then performing RCCA-to-aRSA bypass or endovascular repair [Konstantinou 2022; Ding 2018; Li 2021]. But these methods may increase complications secondary to ischemia or right vertebral steal syndrome, and inevitably may increase difficulties and the need for a secondary surgery. Additional studies are required to confirm optimal strategy.

CONCLUSION

TAR+FET and intraoperative fenestration on the descending trunk is a safe and efficacious approach to treat aortic dissection combined with the aberrant right subclavian artery. Intraoperative fenestration on the descending trunk can reconstruct the aRSA well and reduce time and difficulty. However, more data and long-term follow up is required.

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