Simplified Arch-first Technique in Aortic Arch Branches Replacement: Perfusion without Cardiopulmonary Bypass

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Abstract

Abstract Introduction: Surgery is the mainstay of treatment for aortic dissection which lesion affected the aortic arch. Conventional surgical methods usually use unilateral cerebral perfusion by cardiopulmonary bypass (CPB) to maintain the perfusion of the brain, and the reconstruction of arch branches must be performed under CPB. Unilateral cerebral perfusion with prolonged CPB may lead to complications of cerebral hypoperfusion. We propose a new technique that can accomplish aortic arch branches replacement without the use of cardiopulmonary bypass and maintain bilateral cerebral perfusion at all times. **Materials and Methods:** From January 2018 to July 2021, we performed the new technique in 23 patients. Furthermore, we performed a retrospective analysis with patients undergoing conventional surgery during the same period, comparing perioperative data and follow-up data between two groups. **Result:** The CPB time, deep hypothermic circulatory arrest time and aortic cross-clamping time of new technique group was significantly shorter than conventional group. Other perioperative data and follow-up data were not statistically different. **Discussion:** Simplified arch-first technique can significantly shorten CPB, aortic cross-clamping and deep hypothermic circulatory arrest time. The technique is theoretically safer because it can better protect the cerebral perfusion during the operation. The short-term efficacy of this technique is the same as that of conventional surgery, and it is more convenient for surgeons to operate. **Conclusions:** Compared with the conventional method, the simplified arch-first technique is non-inferior, friendly in operation and safer in theory, and is worthy of promotion. **Key words**: Aortic dissection; Arch-first; Cardiopulmonary bypass; Aortic arch reconstruction

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INTRODUCTION

Acute aortic dissection(AAD) is an emergency situation, with 2.5-6/100,000 incidence per year according to an Oxford Vascular study and a mortality of 50% within the first 48 hours if not operated[1,2]. It is generally accepted emergency surgery is the best way to resolve this problem[3]. Now, a standard surgical approach is Sun's procedure, namely graft replacement of the ascending aorta and aortic arch, and integrating frozen elephant trunk (FET) into the descending aorta[4].

Total arch replacement is complex and time-consuming, and long-time interruption of cerebral blood flow increases the risk of cerebral ischemia[5]. Conventional Sun's surgery is the same as most surgeries, generally needs cannulation through the right axillary artery and right atrium to establish cardiopulmonary bypass (CPB) first. Then the aortic root procedures are finished after the coronary circulation arrest is instituted. FET is implanted into the descending aorta, and the distal end of the four-branched vascular graft is anastomosed with the FET under the deep hypothermia with selective antegrade cerebral perfusion (SACP) and lower body circulatory arrest. Only after all those steps are completed, the left common carotid artery, left subclavian artery and brachiocephalic trunk can be anastomosed with the vascular graft. Since the reconstruction of distal aorta and arch is time-consuming, SACP time is required long enough in the classic surgery to ensure cerebral protection. In addition, the reconstruction of arch branches unavoidably takes up a big part of the time of CPB. All those conditions may lead to excessive associated operative complications.

We tried to establish autologous bypass through the femoral artery to carotid arteries without CPB and extra materials, which allows us to complete the reconstruction of the aortic arch branches without CPB and hypothermia. At the same time, we ensured bilateral cerebral perfusion throughout the whole operation, and the shortest left subclavian artery ischemia time.

MATERIALS AND METHODS

23 patients were treated with arch-first technique in Qilu Hospital of Shandong University from January 2018 to July 2021. One patient died during surgery due to severe ischemic cardiomyopathy, and the remaining 22 patients (Group A) completed the surgery. The 22 patients' mean age were 56.5(±9.3) years old, and 9 (40.91%) of them were male. All patients were diagnosed with acute type A aortic dissection (ATAAD) and the lesion affected the aortic arch. 2 (9.09%) patients were type B aortic dissection progressed into ATAAD after thoracic endovascular aortic repair (TEVAR). Besides, we also reviewed and collected clinical data from 25 other patients (Group B) as a historical control. Those patients only underwent conventional Sun's procedure by the same surgical group during the same period. There was no significant difference in the comorbidities of the two groups of patients. Patients' preoperative characteristics are listed in Table 1. All discharged patients were followed up by outpatient service, phone or WeChat. We performed CT on patients at 3 months 6, and 12 months as required by the guidelines[3,6]. This study was approved by Medical Ethics Committee of Qilu Hospital of Shandong University. Patient consent statement was waived due to no harm to patients.

All analyses were calculated using SPSS software (version 26.0, SPSS Inc, Chicago, IL). Continuous data were presented as the mean ± standard deviation (SD) or median (lower quartile -upper quartile). Student-t test or Mann-Whitney U test was used for continuous variables. Chi-squared test or Fisher's exact test was used for categorical variables. A P-value <0.05 was considered significant.

SURGICAL TECHNIQUE

Preoperative examination included computed tomographic angiography (CTA) of coronary artery, carotid artery, thoracic aorta, abdominal aorta, iliac artery and lower limb artery to determine the dissection. Transthoracic echocardiography was performed to determine the aortic root condition and other cardiac structural changes. The safety and effectiveness of cannulation was analyzed by CTA to determine whether the right subclavian artery, left common carotid artery and the femoral artery, iliac artery of the cannulated side were true lumens.

The operation used combined intravenous and inhalation general anesthesia. Central venous pressure, bilateral radial artery pressure, unilateral dorsal pedal artery pressure and nasopharyngeal temperature, rectal temperature were monitored during operation.

The patient was in a supine position and underwent a median thoracotomy, exposes the right subclavian artery, the branches of aortic arch and femoral artery. 1 mg of heparin per kilogram was given to heparinize. Cannulations through femoral artery, left common carotid artery, and right subclavian artery (or brachiocephalic artery if the right subclavian artery is involved in the dissection) were used to establish autologous bypass to maintain cerebral perfusion. The femoral artery was intubated with 18-24mm cannula, the right subclavian artery was intubated with 8-12mm cannula, and the left common carotid artery was intubated with 6-8mm cannula (Figure 1A). The innominate artery should be intubated with 10-14mm cannula if the right subclavian artery could not be intubated. The pipeline of autogenous circulation was modified from the arterial conduit of CPB. No additional material or instrument was required. The root of the arterial tube was clamped before CPB to ensure the sealing of autologous circulation.

Reconstruction of the arch branches could be performed after the completion of autologous bypass. The sequence of anastomosis to four-branched vascular graft was innominate artery, left common carotid artery and left subclavian artery. The arch branches were clamped and transected, then the proximal sides were sutured first to remove vascular clamps to expose surgical field (Figure 1B). The distal stumps were anastomosed with the limbs of vascular graft in turn. After the reconstruction of the branches, vascular clamps were taken away to de-air the vascular graft, then the both ends of the vascular graft were clamped. Oxygenated blood from the right subclavian artery (or innominate artery) retrograded into the vascular graft, and then, flowed into the left common carotid artery and the left subclavian artery.

Cannulation of the left common carotid artery could be removed (Figure 1C). It should be noted that radial artery and dorsal pedal artery blood pressure need to be closely monitored and maintained at relatively high levels to ensure cerebral perfusion during this period.

The next step was establishment of CPB through cannulation of the right atrial appendage. The left ventricle was vented through the right upper pulmonary vein. CPB supplied arterial blood to the lower and upper parts of the body through the femoral artery and right subclavian artery (or innominate artery) respectively. Patients with known connective tissue disease should have an aortic root replacement[7]. Others with aortic sinus injured by dissection should be treated with aortic root reconstruction (Wheat, Bentall procedure or reconstruction of sinus of Valsalva) during the cooling phase (Figure 2D). When the rectal temperature drops to 25°C, systemic circulation was arrested and SACP was initiated. In order to facilitate the anastomosis, the clamp of the distal end of vascular graft should be moved to a position near to the proximal side. The aortic arch was transected on the anterior wall and the FET was inserted into the true lumen of the descending aorta, and the distal vascular graft trunk was anastomosed with the proximal FET (Figure 2E). Then the perfusion of the systemic circulation was restored, SACP was discontinued, and rewarming started. After the above procedures were completed, there was sufficient time to check the leakage of each anastomosis, especially the position of distal vascular graft and proximal FET.

Finally, the proximal end of the four-branched vascular graft was anastomosed with the aortic root (Figure 2F).

RESULTS

The average time of autologous bypass in Group A was 35.2 +- 8.0 min. As expected, the CPB time of arch-first technique was significantly shorter than Group B (223.5 +- 45.2 min versus 254.2 +- 57.2 min, p = 0.049). Meanwhile, deep hypothermic circulatory arrest time and aortic cross-clamping time also decreased markedly. Other measures, such as concomitant surgery, ICU stay time, ventilator support time and postoperative complications were not statistically different. Intraoperative and postoperative data are listed in Table 2 and Table 3 respectively.

Two patients in Group A died during hospitalization. Both of them were due to postoperative massive cerebral infarction, one of whom had renal failure. Three patients in group B died in hospital. Causes of death included extensive cerebral infarction, severe heart failure, ischemic necrosis of abdominal organs, and severe renal failure and electrolyte imbalance due to severe ischemic necrosis of lower extremities. There was no significant difference in mortality between the two groups (p =1.000).

The remaining patients were discharged successfully. Every patient underwent CTA and was found that the autologous arterial blood flowed smoothly, the true lumen was enlarged compared to pre-operation, and thrombosis had formed and started to reabsorption in the false lumen. The preoperative and postoperative CTA of the patient can be seen in Figure 3. There were no complications such as death, internal leakage, spinal cord ischemia, and stroke in discharged patients.

5 DISCUSSIONS

Circulatory management is essential in aortic arch surgery. Total aortic arch replacement surgery may cause many complications (such as the cerebral or renal ischemia), the main reason is attributed to insufficient perfusion and severity is positively correlated with ischemia time[5]. The conventional Sun's surgical method uses unilateral cerebral perfusion by CPB to maintain the perfusion of the brain, and the reconstruction of arch branches must be performed under CPB[4]. Although the other arch-first technique before us ensured the cerebral perfusion or reduced time, they were still performed under CPB[8–11].

Excessively long CPB and hypothermia also may lead to more complications, such as the disturbances of the coagulation system and stroke[12–15]. In addition, unilateral perfusion must rely on collateral circulation of the brain. Although the ophthalmic and leptomeningeal arteries also provide partial perfusion, the main source of perfusion is the circle of Willis[16]. But the anomalies of the circle of Willis are frequent, Merkkola et al. reported that 22% of the anterior communicating arteries and 46% of the left posterior communicating arteries were missing[17].

The simplified arch-first technique could solve some of problems. The most remarkable advantage is it shortens the time of CPB and part of the circulatory arrest time because the reconstruction of the aortic arch branches is under the autologous bypass, which may reduce the lower body circulatory arrest relevant and CPB related complications. Meanwhile, cerebrum blood is supplied by bilateral cerebral perfusion during the whole operation even at the anastomosis of the left common carotid artery, which avoids cerebral ischemia caused by incomplete circle of Willis. In addition, triple aortic arch branches perfusion could reduce spinal cord injury compared to unilateral cerebral perfusion[18]. The left subclavian artery is temporarily cross-clamped only during anastomosis, the perfusion of left vertebral artery is continuous at other times, which may minimize the possibility of neurologic complications.

In addition, due to the reconstruction of the arch branches is done under the whole brain perfusion, the surgeon has sufficient time to complete procedures without the limitation of CPB and low body circulatory arrest. Since the distal and proximal ends of the vascular graft trunk are not anastomosed, the graft can be moved freely and the vision of the surgical field is clearer, which is conducive to operation and hemostasis. Therefore, simplified arch-first technique is a very friendly innovation to surgeon.

The disadvantages of this technique include increased complexity of cannulation and may obscuring the operative field. Meanwhile, this technique has higher requirements for trimming the length of the four-branched vascular graft. If the vascular graft is too long, it will be twisted and the lumen will be narrowed. On the other hand, it will cause the anastomotic stoma to be too tight and incontrollable bleeding if the graft is too short. Hence, the spatial imagination of the surgeon is required. It is necessary to carefully read the CT before surgery and repeatedly study the three-dimensional spatial images of thoracic, heart and aorta to preliminarily estimate and measure the site of vessel reconstruction and the length of the vascular graft, which is critical for the trim and placement of the graft during surgery.

CONCLUSIONS

Simplified arch-first technique can significantly shorten CPB, aortic cross-clamping and deep hypothermic circulatory arrest time. Although unproven, this technique could theoretically provide better cerebral perfusion. Simplified arch-first technique has good clinical and short-term follow-up outcomes, and it is non-inferior to conventional aortic dissection surgery. It can be predicted that this operator-friendly technique is expected to provide new improvements and development directions for the surgical options of aortic arch replacement.

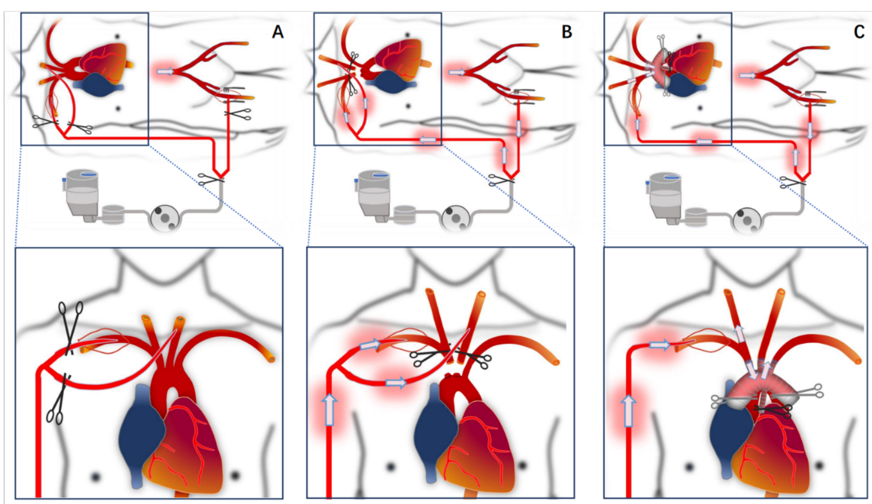

Figure 1 **A** , Intubate cannulations of femoral artery, right subclavian artery and left common carotid. **B** , Clamp innominate artery and left common carotid artery, start autologous bypass. Transect the branches and suture the proximal sides. **C** , Anastomose the branches in turn, remove cannulation of the left common carotid artery after anastomoses.

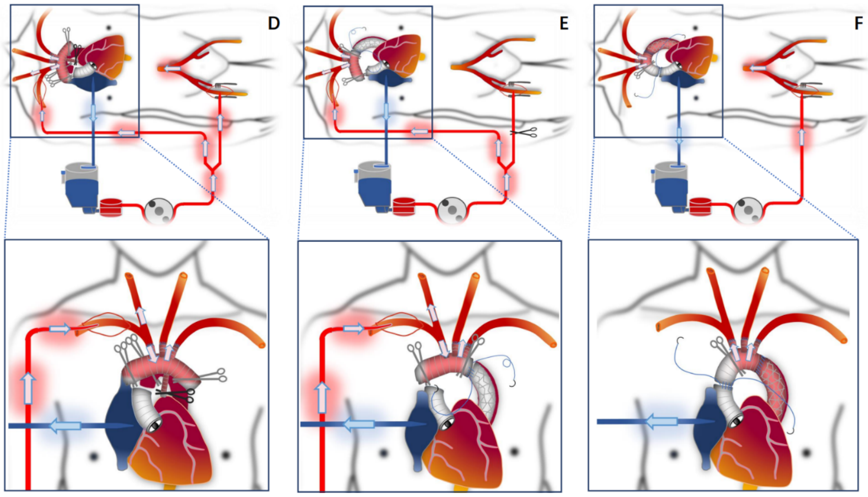

Figure 2 D , Intubate venous cannulation in the right atrial appendage, start cardiopulmonary bypass, complete aortic root reconstruction (take the Bentall procedure as an example). **E** , Insert frozen elephant trunk (FET) into descending aorta, anastomose the distal vascular graft trunk was with the proximal FET. **F** , Anastomose the proximal end of the four-branched vascular graft with the aortic root.

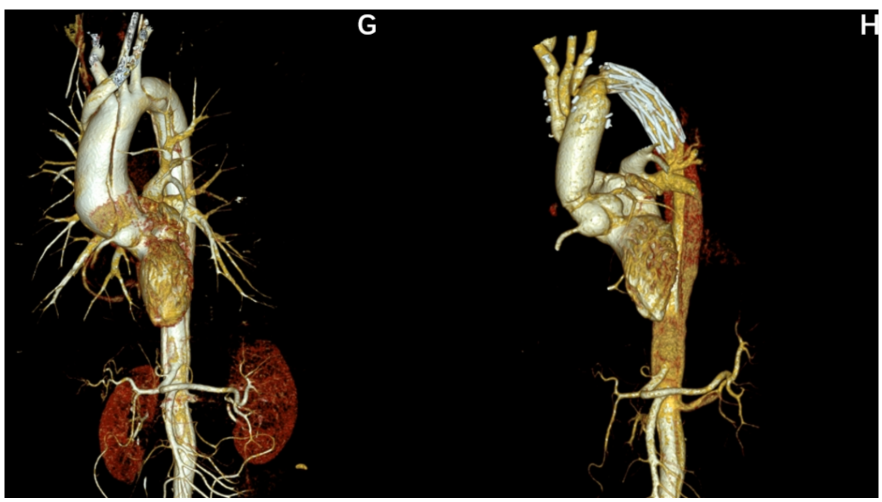

Figure 3 G , a 67-year-old male patient's preoperative computed tomographic angiography (CTA), the dissection involved the aortic root and whole aorta. **H** , 3-month postoperative CTA with simplified arch-first technique.

Preoperative data	Group A(n=22)	Group B(n=25)	*P*
Mean age (±SD), y	56.5 (±9.3)	54.0 (±13.4)	0.473
Male gender, n(%)	9 (40.91%)	16 (64.00%)	0.113
Hypertension, n(%)	18 (81.82%)	22 (88%)	0.690
Marfan syndrome, n(%)	2 (9.09%)	1 (4.00%)	0.593
Coronary artery disease, n(%)	4 (18.18%)	5 (20.00%)	1.000
Left heart failure, n(%)	2 (9.09%)	3 (12.00%)	1.000
COPD, n(%)	3 (13.64%)	3 (12.00%)	1.000

Preoperative data	Group A(n=22)	Group B(n=25)	*P*
Renal failure, n (%)	2 (9.09%)	1 (4.00%)	0.593
Lower extremity ischemia, n (%)	1 (4.55%)	1 (4.00%)	1.000
Cerebral ischemia, n (%)	4 (18.18%)	2 (8.00%)	0.398
Dissection involved aortic root, n (%)	5 (22.73%)	8 (32.00%)	0.478
After TEVAR, n (%)	2 (9.09%)	1 (4.00%)	0.593

TABLE 1 Preoperative data

COPD, chronic obstructive pulmonary disease TEVAR, thoracic endovascular aortic repair

TABLE 2 Intraoperative data

Intraoperative data	Group A(n=22)	Group B(n=25)	*P*
Concomitant procedures			
Bentall procedure, n(%)	2 (9.09%)	3 (12.00%)	1.000
Wheat procedure, n(%)	2 (9.09%)	1 (4.00%)	0.593
Reconstruction of the sinus of Valsalva, n(%)	1 (4.55%)	5 (20.00%)	0.194
Coronary artery bypass graft, n(%)	4 (18.18%)	2 (8.00%)	0.398
Surgical data			
Autologous bypass time (±SD), min	35.2 (±8.0)	—	—
Hypothermic circulatory arrest time (±SD), min	25.0 (±3.5)	28.4 (±5.2)	0.013*
CPB time (±SD), min	223.5 (±45.2)	254.2(±57.2)	0.049*
Aortic cross-clamping time (±SD), min	122.4(±27.8)	138.6(±20.3)	0.026*

CPB, cardiopulmonary bypass

TABLE 3 Postoperative data

Postoperative data	Group A(n=22)	Group B(n=25)	*P*
ICU median stay (IQR), d	6 (4-7)	8 (4-9.25)	0.334
Ventilator support $>$ 96 h, n (%)	7 (31.82%)	8 (32.00%)	0.989
Reoperation for bleeding, n (%)	1 (4.55%)	1 (4.00%)	1.000
Stroke, n (%)	2 (9.09%)	4 (16.00%)	0.670
Dialysis, n (%)	4 (18.18%)	5 (20.00%)	1.000
In-hospital death, n (%)	2 (9.09%)	3 (12.00%)	1.000

Author contributions:

Qi Wang: Concept/design, Statistics, Data analysis/interpretation, Drafting article

Han Song: Concept/design, Statistics, Data analysis/interpretation

Zhenhua Wang: Statistics, Data collection

Duoliang Wei: Statistics, Data collection

Kai Xu: Data collection

Bowen Li: Data collection

Jun Zhang: Concept/design, Critical revision of article

Xin Zhao: Concept/design, Critical revision of article, Approval of article, Funding secured by

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