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Article

Early Experience With the Application of Triple-Branch Perfusion Intubation in DeBakey Type I Aortic Dissection

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Abstract

Introduction: To investigate the clinical efficacy of perfusion intubation through the three branches of the aortic arch compared with the axillary artery in patients with DeBakey type I aortic dissection. **Methods:** A total of 63 patients with DeBakey type I aortic dissection who underwent open surgery from September 2023 to December 2024 were included and divided into two groups based on the cerebral perfusion method used. The three-branch perfusion group (Group B, 31 cases) received perfusion through the three branches of the aortic arch, while the axillary artery perfusion group (Group A, 32 cases) received perfusion via the right axillary artery. Preoperative, intraoperative, and postoperative clinical data were collected for both groups, and clinical efficacy was compared using *t*-tests and chi-square tests. **Results:** The experimental group had a shorter postoperative awakening time -, fewer cases of permanent neurological dysfunction (PND), lower mortality and reduced serum creatinine levels than the control group; these differences were statistically significant ($p < 0.05$). Notably, the lowest nasopharyngeal temperature was significantly higher in the experimental group than in the control group (24.90 ± 1.45 vs. 24.02 ± 2.17; $p = 0.014$). There were no significant differences between the two groups in cardiopulmonary bypass time, selective cerebral perfusion time, lower body circulatory arrest time, endotracheal intubation time, postoperative intensive care unit (ICU) stay, hospital stay, temporary neurological dysfunction, paraplegia, reoperation, hypoxemia and gastrointestinal bleeding ($p > 0.05$). **Conclusions:** Compared with traditional axillary artery intubation, perfusion intubation through the three branches of the aortic arch is as safe and effective, and is superior in terms of postoperative awakening time and incidence of PND. Moreover, perfusion intubation provides a stronger cerebral protection and can serve as a new cerebral perfusion strategy.

Keywords: DeBakey type I aortic dissection; perfusion of the superior three branches of the aortic arch; right axillary artery perfusion; perfusion strategy; brain protection

1. Introduction

DeBakey type I aortic dissection is a cardiovascular disease characterized by rapid onset, rapid progression, critical condition, high surgical mortality, and frequent postoperative complications. DeBakey type I aortic dissection is also one of the most challenging cardiovascular diseases in adult cardiac surgery [1,2]. In patients managed non-surgically, the mortality rate can reach 50% within the first 48 hours. Despite continuous improvements in surgical techniques, anesthesia, and intensive care, perioperative mortality (25%) and neurologic complications (18%) remain high [3]. However, surgery can reduce the 1-month mortality rate from 90% to 30%. Presently, the primary treatment for DeBakey type I aortic dissection is surgery. During deep hypothermic circulatory arrest (DHCA), ascending aortic replacement, total aortic arch replacement, and implantation of a descending aortic sinus stent graft constitute a classic surgical approach for treating these patients, and the associated efficacy has been widely recognized by experts worldwide. Although surgical techniques for DeBakey type I aortic dissection have greatly improved, surgical mortality and complication rates remain high [4,5]. Furthermore, neurological dysfunction is the most common postoperative complication, with a reported incidence of 5.5%–33.3%. Therefore, novel intraoperative brain protection strategies are needed to reduce the incidence of neurological dysfunction and improve the long-term prognosis of patients [6].

2. Materials and Methods

2.1 Study Design and Data Collection

This was a single-center retrospective cohort study conducted at the First Affiliated Hospital of the University of South China. We included consecutive patients diagnosed with DeBakey type I aortic dissection who underwent Sun's procedure between September 2023 and December 2024. Clinical data were retrospectively collected from the

institutional electronic medical record system. The following variables were extracted:

(1) Preoperative variables: age, sex, smoking history, history of hypertension, coronary artery disease, renal insufficiency, and peripheral vascular disease. Laboratory parameters included hemoglobin, activated partial thromboplastin time (APTT), prothrombin time (PT), international normalized ratio (INR), creatine kinase (CK), creatine kinase-MB (CK-MB), cardiac troponin, B-type natriuretic peptide (BNP), alanine aminotransferase (ALT), aspartate aminotransferase (AST), blood urea nitrogen, serum creatinine, and creatinine clearance.

(2) Intraoperative variables: lowest nasopharyngeal temperature, cardiopulmonary bypass time, cooling time, selective cerebral perfusion time, lower body circulatory arrest time, aortic cross-clamp time, rewarming time, and total operation time.

(3) Postoperative variables: awakening time, duration of mechanical ventilation, length of hospital stay, length of stay in the intensive care unit (ICU), and postoperative complications, including transient neurological dysfunction (TND), permanent neurological dysfunction (PND), paraplegia, reoperation for bleeding, renal dysfunction, hypoxemia, gastrointestinal bleeding, and in-hospital mortality. Postoperative laboratory parameters were also recorded.

2.2 Outcome Definitions

Awakening time was defined as the interval from discontinuation of sedative agents to the first response by the patient to verbal commands. Neurological outcomes were assessed at three standardized postoperative time points: within 24 hours, at 72 hours, and immediately before discharge. Assessments were performed by attending physicians in the ICU or on the general ward who were not directly involved in the intraoperative conduct of the surgery and were blinded to the perfusion group assignment of each patient. Neuroimaging (computed tomography or magnetic resonance imaging) was performed when clinically indicated by new neurological symptoms or prolonged altered mental status. TND was defined as temporary postoperative neurological abnormalities, such as confusion, agitation, delirium, or focal deficits, that resolved completely before discharge. PND was defined as persistent neurological deficits (*e.g.*, stroke, hemiplegia, or coma) that remained unresolved at the time of discharge.

2.3 General Information

This retrospective cohort study analyzed data from all patients with DeBakey type I aortic dissection who underwent Sun's surgery at the the First Affiliated Hospital of the University of South China from September 2023 to December 2024. Collected data included preoperative variables, such as age, sex, smoking history, history of hypertension, coronary heart disease, renal insufficiency, and peripheral vascular disease, as well as hemoglobin, APTT, PT, INR, CK, CK-MB, troponin, BNP, ALT, AST, blood urea nitrogen, creatinine, and creatinine clearance. Intraoperative variables included nasopharyngeal temperature, cardiopulmonary bypass time, cooling time, selective cerebral perfusion time, lower body circulatory arrest time, aortic cross-clamp time, rewarming time, and total operation time. Postoperative variables included awakening time, duration of tracheal intubation, postoperative ICU stay, postoperative hospital stay, TND, PND, paraplegia, reoperation for bleeding, renal dysfunction, hypoxemia, gastrointestinal bleeding, mortality, and postoperative biochemical results. Neurological complications were evaluated according to predefined neurological endpoint events. TND was defined as postoperative disorientation, agitation, confusion, unresponsiveness, or focal neurological deficits diagnosed by computed tomography or magnetic resonance imaging. PND was defined as the development of focal injury (stroke), global dysfunction (coma), or new focal or multiple brain lesions after surgery that persisted until hospital discharge.

2.4 Sample Selection

A total of 273 consecutive patients diagnosed with DeBakey type I aortic dissection who underwent Sun's procedure between September 2023 and December 2024 were initially screened. Patients were excluded if they met any of the following criteria: (1) preoperative cerebral infarction or hemorrhage (n = 42); (2) documented preoperative neurological dysfunction (n = 18); (3) incomplete clinical or biochemical data (n = 67); (4) history of prior sternotomy for cardiac surgery (n = 31); (5) concomitant procedures including mitral/tricuspid valve repair/replacement or coronary artery bypass grafting (n = 28); (6) emergency cardiopulmonary bypass due to hemodynamic instability (n = 15); (7) use of alternative perfusion strategies such as innominate-left common carotid artery perfusion or bilateral axillary perfusion (n = 9). After applying these exclusion criteria, a final cohort of 63 patients was included in the analysis. This study was approved by the Ethics Committee of the First Affiliated Hospital of the University of South China.

The choice of perfusion strategy was determined by the attending surgeon based on preoperative computed tomography angiography (CTA) findings and intraoperative assessment. Patients with imaging evidence of dissection involving the right axillary artery, severe atherosclerosis of the innominate artery, or anatomical variants precluding safe axillary cannulation were preferentially assigned to the three-branch perfusion group. Conversely, patients without contraindications to axillary cannulation could receive either strategy, with the three-branch technique being increasingly adopted during the latter half of the study period as institutional experience with this novel approach accumulated. No randomization was performed, consistent with the retrospective observational design of this study.

2.5 Operation Method

Right axillary artery intubation perfusion method: After induction of anesthesia, the patient was placed supine; surgical exposure was obtained through a right axillary artery incision and a median sternotomy, followed by standard sterile preparation and draping. A 5–8 cm skin incision was made lateral to the right subclavian finger (approximately 6–10 cm from the median sternum), and the axillary artery was isolated for subsequent cannulation. Midsternal thoracotomy was then performed, and the pericardium was opened and suspended. The brachiocephalic trunk, left common carotid artery, and left subclavian artery were sequentially dissected; Systemic heparinization was administered at 3 mg/kg. Cardiopulmonary bypass was established via intubation of the right axillary artery and right atrium, and a left ventricular vent was inserted through the right superior pulmonary vein. After ventricular fibrillation occurred, the ascending aorta was opened longitudinally, and myocardial protective solution was successively delivered through the left and right coronary openings. The heart was well perfused. The hematoma was removed, and the diseased ascending aorta (sinus junction, distal ascending aorta) was resected. The aortic valve and aortic sinus were inspected, and the proximal aortic anastomosis was completed using 5-0 Prolene sutures with the "sandwich" technique. When the nasopharyngeal temperature decreased to 25 °C, the brachiocephalic trunk, left common carotid artery, and left subclavian artery were sequentially clamped. Unilateral cerebral perfusion was initiated at 10 mL/kg, lower body circulatory arrest was established, and the aortic arch was opened and resected. A frozen elephant trunk stent graft (MicroPort CRONUS, Shanghai, China) was then placed into the descending aorta. The distal end of a four-branch graft (W. L. Gore & Associates, Newark, DE, USA) was anastomosed to the stented graft and the full thickness of the descending aortic wall using 3-0 Prolene sutures. The three side branches and proximal end of the

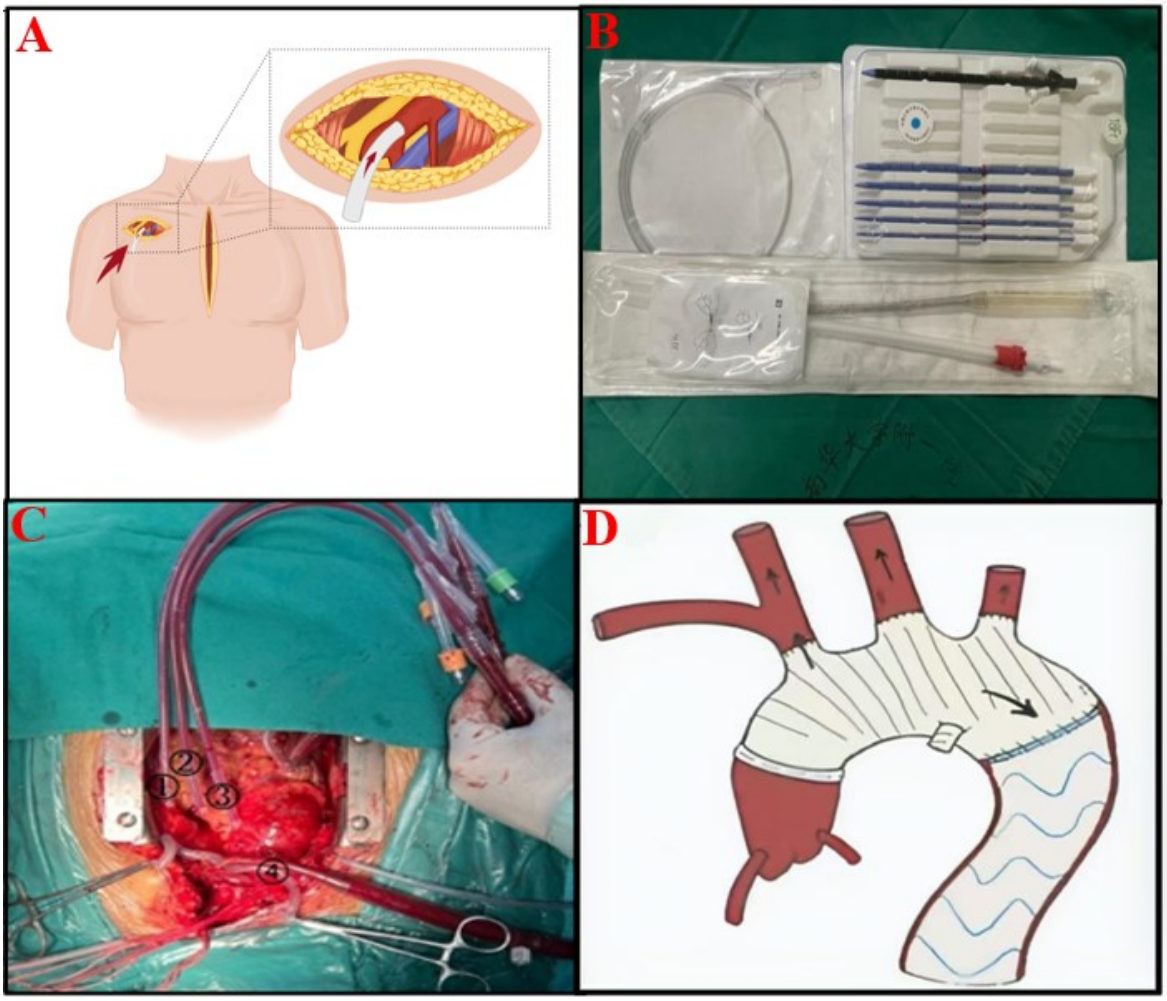

Fig. 1. Comparison of two aortic arch perfusion techniques. (A) Perfusion was performed through the right axillary artery cannula. (B) Upper aortic arch cannula kit. (C) Three branches of perfusion tubes. (D) Total arch replacement and frozen elephant trunk. Note: ①, ②, and ③ were inserted into the innominate artery, left common carotid artery, and left subclavian artery, respectively. ④ was cannulated into the aortic arch for perfusion.

four-branch graft were then blocked. A second cardiopulmonary bypass perfusion line was connected to the fourth branch of the graft to restore lower body perfusion. The proximal end of the graft was anastomosed end-to-end to the native proximal aorta using 4-0 Prolene sutures. After de-airing and lung recruitment, systemic circulation was resumed, coronary perfusion was restored, and rewarming was initiated. The heart resumed beating spontaneously, and the patient was transitioned to parallel circulation. The three branches of the graft were then sequentially anastomosed to the left common carotid artery, left subclavian artery, and brachiocephalic trunk to restore cerebral blood flow. Once the temperature reached 36 ℃ and hemodynamic stability was achieved, the patient was gradually weaned from cardiopulmonary bypass, hemostasis was secured, and the chest was closed (Fig. 1A).

Three-branch aortic arch vessel cannulation and perfusion: The initial steps of anesthesia, median sternotomy, and pericardial suspension were performed as described for the axillary artery group. The brachiocephalic trunk, left common carotid artery, and left subclavian artery were dissected and encircled. Following systemic heparinization, an arterial perfusion cannula was inserted directly into the aortic arch, and cardiopulmonary bypass was established with right atrial drainage. Myocardial protection, resection of the diseased ascending aorta, and proximal aortic anastomosis were performed using the same technique described above. When the nasopharyngeal temperature reached 25 °C, the brachiocephalic trunk, left common carotid artery, and left subclavian artery were sequentially clamped. Individual perfusion cannulas were inserted into each of the three arch vessels, and whole-brain perfusion was initiated at 10 mL/kg. The aortic arch perfusion line was then

Table 1. Comparison of preoperative population characteristics and parameters between group A and group B.

Indexes	Group A	Group B	*p*-value
Age (years)	50.38 ± 9.25	55.35 ± 10.06	0.045
Gender, n (%)			
Male	28 (87.5)	25 (80.6)	0.509
Female	4 (12.5)	6 (19.4)	
Smoking history, n (%)			
No	18 (56.3)	23 (74.2)	0.135
Yes	14 (43.8)	8 (25.8)	
A history of high blood pressure, n (%)			
No	4 (12.5)	8 (25.8)	0.179
Yes	28 (87.5)	23 (74.2)	
History of coronary heart disease, n (%)			
No	31 (96.9)	26 (83.9)	0.104
Yes	1 (3.1)	5 (16.1)	
Transient renal insufficiency, n (%)			
No	31 (96.9)	29 (93.5)	0.613
Yes	1 (3.1)	2 (6.5)	
Peripheral vascular diseases, n (%)			
No	30 (93.8)	27 (87.1)	0.426
Yes	2 (6.3)	4 (12.9)	
Coagulation function			
APTT (s)	33.10 ± 4.92	36.53 ± 9.35	0.077
PT (s)	12.40 (11.60, 13.50)	14.00 (11.00, 14.70)	0.081
INR	1.06 (1.00, 1.12)	1.11 (0.98, 1.17)	0.429
Hemoglobin (g/L)	132.56 ± 14.68	125.13 ± 19.72	0.094
Troponin (pg/mL)	14.38 (9.61, 36.05)	14.33 (10.16, 34.05)	0.978
BNP (pg/mL)	373.45 (262.10, 558.35)	293.30 (121.50, 439.00)	0.088
ALT (U/L)	24.80 (15.10, 41.83)	17.8 0 (12.20, 45.50)	0.371
AST (U/L)	26.70 (16.28, 39.75)	22.60 (15.70, 46.50)	0.858
Creatinine (μmol/L)	112.29 ± 46.32	100.94 ± 35.89	0.139

Note: Group A: axillary artery group; Group B: three-branch group. APTT, activated partial thromboplastin time (reference range: 25–35 s); PT, prothrombin time (reference range: 10–14 s); INR, international normalized ratio (reference range: 0.8–1.2); ALT, alanine aminotransferase (reference range: 7–40 U/L); AST, aspartate aminotransferase (reference range: 13–35 U/L); transient renal insufficiency: serum creatinine >177 μmol/L; BNP, B-type natriuretic peptide (1–450 pg/mL).

clamped, lower body circulatory arrest was established, and the aortic arch was resected. The frozen elephant trunk stent was deployed into the descending aorta. All subsequent steps, including distal anastomosis, lower body reperfusion, proximal graft anastomosis, rewarming, and weaning from cardiopulmonary bypass, were identical to those described for the axillary artery cannulation group (Fig. 1B–D).

2.6 Perioperative Management and Perfusion Protocol

All surgical procedures were performed by a single dedicated aortic surgical team at our institution, consisting of senior attending surgeons, a cardiac anesthesiologist, and a consistent perfusionist team. No changes in core team members occurred during the study period, ensuring consistency in surgical technique and intraoperative decision-making. Cardiopulmonary bypass was established according to a standardized institutional protocol for aortic arch surgery. Systemic heparinization was administered to achieve a target activated clotting time appropriate for DHCA. Non-pulsatile flow was maintained within a standard range according to body surface area. For selective cerebral perfusion, the perfusion parameters were applied uniformly regardless of cannulation strategy. Cerebral flow rate was adjusted for body weight, and the perfusion pressure was maintained within a predefined target range monitored via an arterial line. Perfusate temperature and target hematocrit during selective cerebral perfusion were kept consistent across groups in accordance with institutional practice. Lower-body circulatory arrest was initiated when the nasopharyngeal temperature reached the target hypothermic threshold. Rewarming was performed at a controlled rate to avoid excessive temperature gradients. Postoperative sedation was managed according to a standardized unit-based protocol, and weaning was initiated once hemodynamic stability and normothermia were achieved.

2.7 Statistical Methods

Statistical analysis was performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were first assessed for normality using the Shapiro–Wilk test. Normally distributed data were compared between groups using the independent samples *t*-test and are presented as the mean ± standard deviation (SD). Non-normally distributed data are expressed as median (interquartile range, IQR) and were compared using the Mann–Whitney U test. Categorical variables are expressed as frequencies and percentages, and comparisons between groups were performed using the chi-square test or Fisher's exact test, as appropriate.

3. Results

To assess the potential for selection bias, we compared the baseline characteristics of the 63 included patients with those of the 210 excluded patients who otherwise met the surgical inclusion criteria but were omitted due to incomplete data or concomitant procedures. Only age showed a statistically significant difference between the two cohorts. No significant differences were observed between the two cohorts in sex distribution, hypertension prevalence, or preoperative creatinine levels, suggesting that the final study cohort was broadly representative of the overall surgical population.

This retrospective cohort study included 63 patients with DeBakey type I aortic dissection who underwent Sun's surgery at our center between September 2023 and December 2024, including 53 males and 10 females. Patients were divided into group A (axillary artery perfusion group) and group B (three-branch perfusion group) according to the perfusion cannulation strategy. Group A included 28 males (87.5%) and 4 females (12.5%), whereas group B included 25 males (80.6%) and 6 females (19.4%). The mean age was 50.38 ± 9.25 years (range, 28–68 years) in group A and 55.35 ± 10.06 years (range, 31–77 years) in group B.

A comparison of preoperative population characteristics and blood biochemical results between the two groups is presented in Table 1.

Comparison of preoperative demographic characteristics and routine blood biochemical indices between group A and group B showed no significant differences (all $p > 0.05$), including smoking history (43.8% vs. 25.8%), history of hypertension (87.5% vs. 74.2%), history of coronary heart disease (3.1% vs. 16.1%), transient renal insufficiency (3.1% vs. 6.5%), peripheral vascular disease (6.3% vs. 12.9%), hemoglobin (132.56 ± 14.68 vs. 125.13 ± 19.72), troponin [14.38 (9.61, 36.05) vs. 14.33 (10.16, 34.05)], BNP [373.45 (262.10, 558.35) vs. 293.30 (121.50, 439.00)], ALT [24.80 (15.10, 41.83) vs. 17.80 (12.20, 45.50)], AST [26.70 (16.28, 39.75) vs. 22.60 (15.70, 46.50)], and creatinine (112.29 ± 46.32 vs. 100.94 ± 35.89).

Comparisons of surgical methods and intraoperative parameters between the two groups are presented in Tables 2,3.

Among the 63 patients included in the study, 32 were assigned to group A. In this group, Sun's surgery was performed in 3 cases (9.4%), Bentall + Sun's surgery in 7 cases (21.9%), ascending aorta replacement + Sun's surgery in 6 cases (18.7%), and AVP + ascending aorta replacement + Sun's surgery in 16 cases (50.0%). Group B included 31 patients, with 0 cases (0.0%) undergoing Sun's surgery, 8 cases (25.8%) undergoing Bentall + Sun's surgery, 7 cases (22.6%) undergoing ascending aorta replacement, and 16 cases (51.6%) undergoing AVP + ascending aorta replacement + Sun's surgery. There was no significant difference between the two groups ($p > 0.05$), indicating good comparability.

Comparison of intraoperative parameters between groups A and B using the independent sample *t*-test/rank-sum test showed no significant differences in cardiopulmonary bypass time (245.16 ± 46.70 vs. 234.10 ± 60.74),

Table 2. Surgical methods.

Operation name	Group A	Group B	*p*-value
Sun's surgery, n (%)	3 (9.4)	0 (0.0)	0.372
Bentall + Sun's surgery, n (%)	7 (21.9)	8 (25.8)	
Ascending aorta replacement + Sun's procedure, n (%)	6 (18.7)	7 (22.6)	
AVP + ascending aorta replacement + Sun's procedure, n (%)	16 (50.0)	16 (51.6)	

Note: AVP, aortic valve plasty.

Table 3. Comparison of surgical methods and intraoperative parameters between group A and group B.

Indexes	Group A	Group B	*p*-value
Nasopharyngeal temperature (°C)	24.02 ± 2.17	24.90 ± 1.45	0.014
Cardiopulmonary bypass time (min)	245.16 ± 46.70	234.10 ± 60.74	0.155
Cooling time (min)	93.69 ± 23.63	87.06 ± 26.59	0.268
Selective cerebral perfusion time (min)	34.44 ± 8.41	31.32 ± 6.47	0.220
Lower body circulatory arrest time (min)	34.44 ± 8.41	31.32 ± 6.47	0.220
Aortic occlusion time (min)	148.38 ± 28.55	144.94 ± 41.46	0.339
Rewarming time (min)	100.19 ± 32.14	89.87 ± 21.03	0.196
The operation time (min)	459.81 ± 178.85	494.65 ± 88.07	0.655

Note: Data are presented as the mean ± standard deviation (SD). Selective cerebral perfusion time and lower body circulatory arrest time are identical because lower body circulatory arrest is initiated simultaneously with selective cerebral perfusion, in accordance with institutional protocol.

cooling time (93.69 ± 23.63 vs. 87.06 ± 26.59), selective cerebral perfusion time (34.44 ± 8.41 vs. 31.32 ± 6.47), lower body circulatory arrest time (34.44 ± 8.41 vs. 31.32 ± 6.47), aortic occlusion time (148.38 ± 28.55 vs. 144.94 ± 41.46), rewarming time (100.19 ± 32.14 vs. 89.87 ± 21.03), or operation time (459.81 ± 178.85 vs. 494.65 ± 88.07 (all $p > 0.05$)). However, there was a significant difference in the lowest nasopharyngeal temperature (24.02 ± 2.17 vs. 24.90 ± 1.45) ($p < 0.05$).

A comparison of postoperative recovery, complication incidence, and routine biochemical indices between the two groups is presented in Table 4.

Comparison of postoperative parameters between groups A and B showed the following results: intubation time (50.83 ± 57.11 vs. 42.01 ± 37.81 h), ICU stay [6.00 (5.00, 7.00) vs. 5.00 (4.00, 7.00) d], hospital stay [26.00 (20.00, 33.00) vs. 21.00 (17.00, 31.00) d], TND (28.1% vs. 12.9%), paraplegia (12.5% vs. 9.7%), reoperation for bleeding (0% vs. 3.2%), transient renal insufficiency (28.1% vs. 22.6%), hypoxemia (18.8% vs. 6.5%), and stress ulcer (21.9% vs. 9.7%). Postoperative coagulation parameters, including APTT (39.17 ± 7.97 vs. 42.23 ± 14.58 s; $p = 0.309$), PT (15.08 ± 3.66 vs. 14.09 ± 2.78 s; $p = 0.233$), and INR (1.31 ± 0.33 vs. 1.18 ± 0.21; $p = 0.069$), as well as hemoglobin (101.31 ± 17.27 vs. 101.90 ± 18.86 g/L), troponin [516.55 (321.80, 966.10) vs. 561.20 (257.50, 777.70)], BNP [697.70 (401.33, 3565.50) vs. 1080.00 (456.90, 5100.30)], ALT [17.75 (13.60, 36.70) vs. 16.90 (11.80, 28.60)], and AST [52.80 (44.05, 87.00) vs. 53.10 (40.70, 72.00)], did not differ significantly between the groups (all $p > 0.05$). In contrast, awakening time [6.67 (5.00, 10.00) vs. 3.00 (1.75, 4.00) h; $p < 0.001$], PND (21.9% vs. 3.2%; $p = 0.026$), mortality (25.0% vs. 3.2%; $p = 0.026$), and creatinine [157.50 (110.50, 180.00) vs. 114.00 (97.00, 163.00); $p = 0.025$] differed significantly between the groups.

A total of eight patients died in group A: four from multiple organ failure, two from acute heart failure, and two from stroke. In group B, one patient died from acute cardiac insufficiency secondary to myocardial ischemic necrosis caused by preoperative aortic dissection involving the left and right coronary arteries. Postoperative serum creatinine was significantly lower in the three-branch perfusion group than in the axillary artery group (131.53 ± 47.62 μmol/L vs. 169.63 ± 78.13 μmol/L; $p = 0.025$). However, the incidence of clinically defined postoperative renal insufficiency (serum creatinine >177 μmol/L) did not differ significantly between the two groups (22.6% vs. 28.1%; $p = 0.613$). This discrepancy suggests that although the three-branch perfusion strategy was associated with a statistically significant reduction in mean creatinine, this difference did not translate into a clinically meaningful reduction in the rate of renal dysfunction as defined by our institutional threshold. Given the notable difference in mortality between the two groups (25.0% vs. 3.2%; $p = 0.026$), we performed a descriptive comparison of the deceased patients. Patients who died in group A (axillary artery group) had a mean age of 56.4 ± 7.2 years, a mean preoperative creatinine level of 138.5 ± 52.3 μmol/L, and a mean cardiopulmonary bypass time of 278.6 ± 52.4 minutes. In comparison, the single deceased patient in group B was 68 years old, with a preoperative creatinine level of 156 μmol/L and a cardiopulmonary bypass time of

Table 4. Comparison of postoperative recovery, complication rate, and routine biochemical indexes between group A and group B.

Indexes	Group A	Group B	*p*-value
Awakening time (h)	6.67 (5.00, 10.00)	3.00 (1.75, 4.00)	<0.001
Tracheal intubation time (h)	36.00 (20.75, 52.71)	22.00 (17.00, 58.50)	0.262
Length of stay in ICU (d)	6.00 (5.00, 7.00)	5.00 (4.00, 7.00)	0.061
Length of hospital stay (d)	26.00 (20.00, 33.00)	21.00 (17.00, 31.00)	0.216
PND, n (%)			
No	25 (78.1)	30 (96.8)	0.026
Yes	7 (21.9)	1 (3.2)	
TND, n (%)			
No	23 (71.9)	27 (87.1)	0.136
Yes	9 (28.1)	4 (12.9)	
Paraplegia, n (%)			
No	28 (87.5)	28 (90.3)	1.000
Yes	4 (12.5)	3 (9.7)	
Reoperation due to bleeding, n (%)			
No	32 (100)	30 (96.8)	0.492
Yes	0 (0)	1 (3.2)	
Transient renal insufficiency, n (%)			
No	23 (71.9)	24 (77.4)	0.613
Yes	9 (28.1)	7 (22.6)	
Hypoxemia, n (%)			
No	26 (81.3)	29 (93.5)	0.257
Yes	6 (18.8)	2 (6.5)	
Stress induced ulcer, n (%)			
No	25 (78.1)	28 (90.3)	0.302
Yes	7 (21.9)	3 (9.7)	
Death, n (%)			
No	24 (75)	30 (96.8)	0.026
Yes	8 (25)	1 (3.2)	
Coagulation function			
APTT (s)	39.17 ± 7.97	42.23 ± 14.58	0.309
PT (s)	15.08 ± 3.66	14.09 ± 2.78	0.233
INR	1.31 ± 0.33	1.18 ± 0.21	0.069
Hemoglobin (g/L)	101.31 ± 17.27	101.90 ± 18.86	0.869
Troponin (pg/mL)	516.55 (321.80, 966.10)	561.20 (257.50, 777.70)	0.726
BNP (pg/mL)	697.70 (401.33, 3565.50)	1080.00 (456.90, 5100.30)	0.339
ALT (U/L)	17.75 (13.60, 36.70)	16.90 (11.80, 28.60)	0.741
AST (U/L)	52.80 (44.05, 87.00)	53.10 (40.70, 72.00)	0.680
Creatinine (μmol/L)	157.50 (110.50, 180.00)	114.00 (97.00, 163.00)	0.025

Note: Group A: axillary artery group; Group B: three-branch group. PND, permanent neurological disorder (including stroke and hypoxic brain damage); TND, transient neurological disorder (transient ischemic attack, confusion, and psychosis); APTT, activated partial thromboplastin time (reference range: 25–35 s); PT, prothrombin time (reference range: 10–14 s); INR, international normalized ratio (reference range: 0.8–1.2); ALT, alanine aminotransferase (reference range: 7–40 U/L); AST, aspartate aminotransferase (reference range: 13–35 U/L); transient renal insufficiency: serum creatinine >177 μmol/L.

310 minutes. Notably, six of the eight deaths in group A were associated with postoperative neurological complications (stroke or coma), whereas the death in group B was attributed to preoperative myocardial ischemia. These descriptive data suggest that the excess mortality in group A may have been driven by neurological rather than cardiac or renal causes, which is consistent with the higher incidence of PND observed in this group. However, the small number of events precludes definitive statistical conclusions.

4. Discussion

Aortic dissection occurs when the aortic intima and tunica media rupture for multiple reasons, allowing blood to enter through the breach and separate the tunica media from the tunica adventitia of the aorta. The resulting formation of true and false lumens within the vessels [7] constitutes a fatal cardiovascular disease that seriously threatens the life and health of patients [8]. Recently, substantial advances in techniques such as selective cerebral perfusion and DHCA have improved the long-term prognosis of patients undergoing aortic arch surgery for DeBakey type I aortic dissection [9,10]; however, the incidence of postoperative neurological complications and mortality remains high [11,12]. Aortic arch surgery is fundamentally centered on protecting the heart and the organs of the upper and lower body. Indeed, an effective organ-protection strategy should avoid complications such as poor perfusion and aortic rupture, while also addressing organ and tissue hypoperfusion resulting from DeBakey type I aortic dissection. This remains one of the central challenges of aortic surgery. With the continued refinement of perfusion strategies for aortic arch surgery by experts worldwide, different perfusion methods have been developed, including axillary artery cannulation [13,14,15], innominate artery cannulation [16,17], and bilateral antegrade cerebral perfusion using the innominate artery combined with the left common carotid artery [5], all of which have achieved favorable clinical results. In 2014, the European Society of Cardiology recommended transaxillary artery intubation as the preferred surgical cannulation method for DeBakey type I aortic dissection, potentially for the following reasons: (1) the collateral circulation of the carotid and shoulder arteries is rich, making distal limb ischemia less likely [14]; (2) the vessel is less commonly affected by atherosclerosis and dissection [18]; (3) this approach avoids retrograde embolization and extension of the dissection [19]. Meanwhile, studies have shown that at least 50% of people have variations in the Circle of Willis. In some patients with Circle of Willis variations, unilateral selective cerebral perfusion via right axillary artery intubation is inferior to bilateral cerebral perfusion and is associated with a higher incidence of postoperative cerebral neurological complications. Meanwhile, although axillary artery perfusion provides good cerebral protection, this approach requires a longer period of vessel dissection, and postoperative right upper-hand swelling and dysfunction have been reported in some patients. Therefore, an effective intraoperative perfusion strategy for the head and upper body is clinically important for preventing neurological complications involving the brain and upper extremities. An increasing number of scholars have adopted the "head-first" strategy to reduce postoperative neurological complications [20]. Based on this concept, our center led the adoption of a new intubation perfusion method: the superior three-branch perfusion tube of the aortic arch for intraoperative head and upper body perfusion, and achieved satisfactory results in early clinical application.

From September 2023 to December 2024, 273 patients with DeBakey type I aortic dissection underwent aortic arch surgery (total aortic arch replacement plus descending aortic stent implantation) at our center. A total of 63 patients were included in this study: 32 in the axillary artery intubation group and 31 in the upper three-branch aortic arch intubation group. The experimental data showed differences between the two groups. (1) Awakening time: We did not change the surgical methods of patients, but changed the method of head and upper body perfusion. Indeed, by perfusing the brachiocephalic trunk, left common carotid artery, and left subclavian artery separately through the three branches of the aortic arch, the brain and upper body were more fully perfused; patients were more likely to recover earlier after surgery, consistent with previous research. (2) TND and PND: In the axillary artery perfusion group, postoperative neurological complications included 7 cases of PND, including 4 cases of hemiplegia and 3 cases of deep coma. There were also 9 cases of TND, including 5 cases of delayed awakening, 3 cases of delirium, and 1 case of transient confusion. All 9 patients with TND recovered by discharge. In the superior aortic arch perfusion group, postoperative neurological complications included 1 case of PND and 1 case of hemiplegia. There were 4 cases of TND, including 3 cases of shallow coma with delayed recovery and 1 case of delirium. All 4 patients recovered by discharge. The in-hospital mortality rate in the axillary artery group (25%) was higher than that reported in some contemporary series of type A aortic dissection repair (typically 14%–18%). Several factors may account for this observation. First, this was a relatively small single-center cohort, and mortality rates can fluctuate substantially in limited sample sizes. Second, 6 of the 8 deaths in Group A were directly attributable to neurological complications, suggesting that the higher mortality in this group was closely linked to the increased incidence of PND. Third, the patients in this study represented a real-world, consecutive series without exclusion of high-risk cases. Although the mortality difference was statistically significant, the small number of events warrants cautious interpretation, and larger studies are needed to confirm whether the three-branch perfusion strategy confers a survival benefit. Permanent neurological dysfunction: The occurrence of neurological complications is closely related to patient rehabilitation and long-term prognosis. Moreover, neurological complications after aortic dissection have been reported to include cerebral infarction, cerebral hemorrhage, paralysis, and vegetative state [21], as well as secondary complications, such as tracheotomy [22], pulmonary infection, intestinal flora dysregulation [23], muscle wasting, and other associated complications. These complications can both significantly affect patient recovery and increase the economic and psychological burden on families, and directly threaten the lives of

patients. In our retrospective data, 7 patients in the axillary artery group developed PND (4 cases of hemiplegia and 3 of vegetative state), and 8 patients died; 6 deaths were associated with neurological complications, and treatment was withdrawn in 2 cases. In the experimental group, there is 1 case of cerebral complication (hemiplegia), including 1 patient who died. Therefore, the superior aortic arch triple-branch perfusion technique can significantly reduce the incidence of cerebral complications and accelerate patient recovery.

We believe that the lower incidence of neurological complications with three-branch perfusion cannulation compared with the axillary perfusion group may be due to the following reasons: The traditional axillary artery cannulation strategy provides unilateral cerebral perfusion via the right vertebral artery and the right common carotid artery. In contrast, the left common carotid artery and left vertebral artery may receive insufficient blood supply. The left common carotid artery supplies the first 2/3 of the brain, and the left vertebral artery forms the vertebrobasilar artery system, which supplies the brain and brainstem tissue. Meanwhile, the superior trisection of the aortic arch perfuses the innominate artery, the left common carotid artery, and the left subclavian artery separately, which is more consistent with the physiological state and provides a more appropriate perfusion volume and pressure. Compared with axillary artery perfusion, perfusion through the upper three branches of the aortic arch also has the following advantages: (1) This approach reduces the need for an additional incision, causes less trauma, and enables faster postoperative recovery; (2) This method avoids brachial plexus injury from the free axillary or subclavian artery, thereby reducing complications such as paralysis and partial loss of function in the right arm. (3) Three-branch perfusion avoids bleeding at the intubation site of the right axillary or subclavian artery. (4) The technique simplifies the surgical approach by eliminating the need for additional axillary incision and dissection. (5) Separate perfusion of the three supra-aortic branches provides whole-brain blood flow, offers better cerebral protection, and is more physiologically appropriate. The purpose of this retrospective analysis was not to reject the axillary artery perfusion, as outcomes may also be related to the degree of brachial trunk vascular involvement, the development of the Circle of Willis, and the clinical experience of the surgeon, rather than to categorically recommend three-branch perfusion as the optimal perfusion method for aortic dissection surgery. Rather, our single-center clinical data confirmed that the three-branch perfusion method is also a safe and effective surgical perfusion method for aortic dissection, with the advantages of less trauma, technical simplicity, and a relatively low incidence of neurological complications.

The neuroprotective advantage of the three-branch perfusion strategy may be further understood through the lens of cerebral hemodynamics and oxygen metabolism [24,25,26]. Anatomical studies have demonstrated that incomplete or functionally inadequate collateral circulation via the Circle of Willis is present in at least 50% of the general population [27]. In such individuals, unilateral antegrade cerebral perfusion via the right axillary artery may result in relative hypoperfusion of the left hemisphere and posterior circulation territories, thereby increasing the vulnerability of these regions to ischemic injury during circulatory arrest. In contrast, the three-branch technique delivers oxygenated blood simultaneously to both the carotid and vertebral arteries, thereby ensuring symmetrical, physiologically distributed cerebral flow regardless of the competence of the Circle of Willis.

Emerging evidence from intraoperative near-infrared spectroscopy (NIRS) monitoring supports this concept. Studies have reported that bilateral or multi-vessel perfusion strategies are associated with higher and more stable regional cerebral oxygen saturation (rSO_2) values, particularly in the left hemispheric channels, compared with unilateral right-sided perfusion [28,29]. Furthermore, computational fluid dynamics modeling has demonstrated that direct cannulation of the arch branches reduces energy loss and turbulent flow that can occur with retrograde or single-vessel perfusion. Collectively, these physiological and biomechanical data provide a mechanistic rationale for the superior neurological outcomes observed in the three-branch perfusion group, despite the slightly higher nadir temperature. This finding underscores the primacy of adequate and symmetrical flow distribution over absolute hypothermic depth in contemporary cerebral protection strategies [30,31,32].

A particularly noteworthy finding of this study is that patients in the three-branch perfusion group demonstrated superior neurological outcomes and shorter awakening times despite having a significantly higher lowest nasopharyngeal temperature during circulatory arrest (24.90 ± 1.45 vs. 24.02 ± 2.17; $p = 0.014$). This observation challenges the traditional paradigm that deeper hypothermia is invariably associated with enhanced neuroprotection [33]. We postulate that this phenomenon reflects the primacy of perfusion quality and distribution over absolute hypothermia depth in contemporary cerebral protection strategies [34,35,36].

Deep hypothermia reduces cerebral metabolic demand, but its protective effect is contingent upon adequate delivery of oxygen and substrate to meet residual metabolic requirements. In unilateral axillary perfusion, the left hemisphere and posterior circulation may experience relative or absolute hypoperfusion, particularly in patients with incomplete Circle of Willis collaterals. Under such conditions, even profound hypothermia cannot fully compensate for inadequate oxygen delivery, leading to ischemic injury in vulnerable regions. Conversely, the three-branch technique ensures symmetrical, physiology-mimicking perfusion to both carotid and vertebrobasilar territories, thereby

maintaining higher and more uniform cerebral oxygen tension across all vascular beds. This enhanced oxygen supply likely increases the tolerance of the brain to slightly higher temperatures by preventing the mismatch between metabolic demand and substrate delivery that underlies ischemic injury [37].

Support for this interpretation comes from intraoperative NIRS studies, which have consistently demonstrated that bilateral or multivessel perfusion strategies are associated with higher and more stable regional cerebral oxygen saturation (rSO_2) values than unilateral perfusion, particularly in the left frontal region [28,38,39]. Furthermore, experimental data suggest that maintenance of cerebral autoregulation and microvascular perfusion is better preserved when flow is delivered through multiple native arch vessels rather than via a single collateral-dependent route [40]. Thus, the slightly higher nasopharyngeal temperature in the three-branch group may be a clinically acceptable and perhaps even desirable trade-off when cerebral perfusion is optimized, as this technique mitigates the adverse systemic effects of prolonged deep hypothermia (coagulopathy, capillary leak, organ dysfunction) without compromising neurological integrity [41]. These data have important clinical implications: findings suggest that with an optimized multivessel perfusion strategy, the target temperature for circulatory arrest could be safely elevated, thereby reducing cooling and rewarming times and associated morbidities. This hypothesis warrants prospective investigation with rigorous neuromonitoring.

With advances in aortic dissection perfusion techniques and continued progress in surgery, anesthesia, and intensive care, axillary artery cannulation perfusion has been used less frequently at our center. In contrast, the number of cases managed with three-branch cannulation perfusion has steadily increased. Accordingly, we plan to include more cases in future retrospective and prospective studies and to focus further on basic research. Preliminary exploration of the mechanisms underlying the occurrence, development, diagnosis, treatment, and prevention of postoperative neurological dysfunction is expected to reduce the incidence of postoperative cerebral and neurological complications further, accelerate patient rehabilitation, reduce the psychological and economic burden on patients, and improve the long-term quality of life of patients. We acknowledge that there was a statistically significant difference in baseline age between the two groups, with patients in the three-branch perfusion group being approximately 5 years older on average ($p = 0.045$). Advanced age is a well-established risk factor for adverse neurological outcomes and mortality following aortic arch surgery. Therefore, the older age profile in the three-branch perfusion group would be expected to bias the results against this group. The fact that the three-branch perfusion group nevertheless demonstrated significantly shorter awakening time and a lower incidence of PND suggests that the observed benefits of this technique are robust. Had the groups been perfectly matched for age, it is plausible that the advantages of the three-branch strategy would have been even more pronounced. Consequently, we elected not to perform multivariable adjustment given the limited sample size and the conservative direction of the baseline imbalance, which does not weaken but rather strengthens the validity of our primary findings.

5. Limitations

This was a single-center retrospective study, and the results were influenced by the sample size and by uncollected or omitted cases, which may have introduced bias. Thus, future research should increase the sample size and conduct large, multicenter, prospective studies for further validation. Additionally, detailed postoperative renal function data, such as hourly urine output and creatinine clearance, were not consistently available for all patients, limiting a comprehensive assessment of renal outcomes.

6. Conclusions

1. Three-branch intubation perfusion of the aortic arch provides better cerebral protection, shortens postoperative awakening time, and reduces the incidence of PND.

2. Three-branch intubation perfusion of the aortic arch is equally safe and effective, and the impact of this approach on patient outcomes with respect to coagulation, cardiac, liver and kidney, respiratory, and digestive tract function is similar to that of traditional axillary artery perfusion.

Availability of Data and Materials

The datasets generated and analyzed during the current study are not publicly available due to patient privacy and ethical restrictions but are available from the corresponding author on reasonable request for academic and research purposes.

Author Contributions

JuanL contributed to study conceptualization, performed formal analysis, wrote the original draft, and secured funding. JiaL conducted the investigation and was responsible for data curation. JW assisted in patient enrollment and performed data validation. YX supported clinical resource acquisition and participated in data collection. ML curated clinical data and contributed to manuscript review. CL supervised the project, data curation, administered the research activities, and critically reviewed and edited the manuscript. All authors revised the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study follows the Declaration of Helsinki and was approved by the Medical Ethics Committee of the First Affiliated Hospital of the University of South China (Approval No: 2023LL0214001). Written informed consent was obtained from all participants or their legal guardians prior to enrollment.

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Conflicts of Interest

The authors declare no conflict of interest.

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