







Article

Analysis of the Brain Protective Effect of Flow Percentage Cerebral Perfusion Combined With Unilateral Antegrade Selective Cerebral Perfusion in Acute Aortic Dissection Arch Reconstruction Surgery

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Academic Editor: Anton Sabashnikov

Submitted: 1 August 2025 Revised: 4 September 2025 Accepted: 18 September 2025 Published: 27 November 2025

Abstract

Background: To evaluate the neuroprotective efficacy of combining unilateral antegrade selective cerebral perfusion with percentage-controlled flow regulation during aortic arch reconstruction surgery for aortic dissection. **Methods:** A retrospective analysis was conducted using clinical data from 226 consecutive patients who underwent surgery for acute aortic dissection with arch reconstruction at our hospital between January 2020 and January 2021. Based on the cerebral protection strategy used, patients were divided into two groups: the percentage-flow cerebral perfusion group (n = 89) and the control group (n = 137). The severity of neurological impairment was rigorously evaluated using standardized biomarker assessments, including serial measurements of serum S100 β protein and neuron-specific enolase (NSE) levels. These biomarkers were systematically analyzed and compared between the two groups at two critical time points: preoperatively (baseline) and postoperatively during follow-up. Multivariate analysis was subsequently performed to identify independent risk factors associated with postoperative neurological dysfunction following surgical repair. **Results:** No statistically significant differences were observed in baseline characteristics or intraoperative parameters between the two groups (all $p > 0.05$). Postoperative mortality was comparable (4.5% vs. 4.4%, $p = 0.915$). However, the percentage-flow cerebral perfusion group showed a significantly lower incidence of neurological dysfunction—including both temporary and permanent deficits—compared to the conventional control group (8.98% vs. 18.98%, $p = 0.031$). Additionally, these patients demonstrated significantly shorter times to wakefulness and extubation (both $p < 0.05$). Serum biomarker analysis further indicated markedly elevated levels of S100 β and NSE in the control group relative to the percentage-flow group (both $p < 0.05$). Univariate and multivariate regression analyses identified age, unilateral cerebral perfusion time, and cardiopulmonary bypass (CPB) time as independent risk factors for postoperative neurological injury. A predictive model incorporating these variables exhibited strong discriminative power (area under the curve, AUC = 0.838) and good stability ($p = 0.256$). **Conclusion:** Optimized cerebral perfusion flow significantly shortens the time to awakening and extubation in patients undergoing acute aortic dissection repair, while reducing neurological injury, as supported by decreased serum levels of the biomarkers S100 β and NSE. These results indicate a considerable neuroprotective benefit. Moreover, multivariate analysis confirmed that age, unilateral cerebral perfusion duration, and cardiopulmonary bypass (CPB) time are independent risk factors for postoperative neurological impairment. A predictive model integrating these factors exhibited strong clinical applicability.

Keywords: acute aortic dissection; flow percentage; unilateral antegrade selective cerebral protection; arch reconstruction; model prediction

1. Introduction

Acute aortic dissection (AAD) is among the most life-threatening emergencies in cardiovascular medicine, with the highest mortality rate of all cardiac surgical conditions [1]. Without immediate surgical intervention, mortality can exceed 90% [2]. Sun's procedure—which entails replacement of the ascending aorta, total arch reconstruction, and distal stent-graft implantation—has become the preferred surgical approach for AAD owing to its favorable clinical outcomes [3,4]. Nevertheless, because the proce-

cedure requires reconstruction of the cerebral vascular supply, postoperative neurological complications such as anxiety, stroke, and delirium continue to pose significant challenges [5]. Therefore, optimizing cerebral protection strategies has become a crucial research priority for improving perioperative organ preservation in aortic dissection repair. Current clinical practice utilizes various cerebral protection strategies, such as deep hypothermic circulatory arrest, retrograde cerebral perfusion via the superior vena cava, unilateral antegrade selective cerebral perfusion (uSACP), and



bilateral antegrade selective cerebral perfusion (bSACP) [6]. Although our previous studies have confirmed the neuroprotective benefits of uSACP combined with moderate hypothermia in acute aortic dissection surgery, no standardized perfusion protocol has been widely established. Notably, significant inter-institutional variation remains in flow management strategies—with rates typically ranging from 5 to 15 mL/kg—and the assumed linear relationship between cerebral blood flow and patient body weight becomes unreliable beyond certain physiological thresholds. These observations highlight the importance of implementing goal-directed perfusion management to refine cerebral protection strategies [7,8].

In aortic dissection surgery, cerebral oxygen saturation serves as an indicator of cerebral metabolic status. However, its clinical utility for guiding cerebral perfusion is limited by significant measurement variability, which hinders accurate quantification of optimal perfusion flow. Similarly, pressure-based flow selection strategies are constrained by the inherent inaccuracies of current pressure monitoring technologies, compromising their reliability in ensuring adequate neurological perfusion. In contrast, percentage-based flow management enables personalized perfusion strategies that may offer superior neuroprotection. Building upon this theoretical framework, the present study investigates percentage-flow guided unilateral antegrade selective cerebral perfusion (uSACP) in acute aortic dissection surgery, with the objective of establishing optimized parameters for neurological protection and functional outcomes.

2. General Information and Methods

2.1 General Information

A retrospective analysis was conducted on the clinical data of 226 patients who underwent acute aortic dissection and concomitant arch reconstruction surgery in our cardiovascular surgery department from January 2020 to January 2021. Based on the cerebral protection strategies used, the patients were divided into a flow percentage cerebral perfusion group and a traditional group. Inclusion criteria: ① diagnosis of acute aortic dissection confirmed by arterial Coronary Computed Tomography Angiography(CTA); ② absence of involvement of the innominate artery, coronary arteries, valvular heart disease, or left common carotid artery; ③ age over 20 years; and ④ performance of arch reconstruction during surgery. Exclusion criteria: ① mortality within 24 hours post-surgery; ② preexisting hepatic or renal dysfunction; ③ preoperative neurological impairment; and ④ history of neurological disorders. All patients were informed and consented to this study, which was approved by Nanjing First Hospital's ethics committee (Ethics Approval No. KY20220805).

2.2 Methods

2.2.1 Surgical Method

All surgical procedures were performed by a dedicated vascular surgery team at our center following standardized protocols. Upon arrival in the operating room, patients received routine intravenous access along with simultaneous arterial pressure monitoring via cannulation of the left radial and dorsalis pedis arteries. Cardiopulmonary bypass (CPB) was established using a Sorin S5 heart-lung machine (Sorin Group Deutschland GmbH, Germany), an adult membrane oxygenator (Sorin Group, Saluggia, Italy), myocardial protection perfusion tubing (Weigao, Shandong, China), and extracorporeal circulation tubing (Tianjin Plastic Research Institute, Tianjin, China). The circuit was primed with a solution consisting of 1000 mL succinylated gelatin injection (Nanjing Chia Tai Tianqing Pharmaceutical Co., Ltd., Nanjing, China), 500 mL Ringer's acetate (Shijiazhuang Fourth Pharmaceutical Co., Ltd., Shijiazhuang, China), 150g of 20% human albumin (Wuhan Zhongyuan Ruide Biological Products Co., Ltd., HuBei, China), 500 mg methylprednisolone (Pfizer Inc, Liaoning, China), and 10 mg torasemide (Yangtze River Pharmaceutical Group, Jiangsu, China). Surgical cannulation was performed via the right axillary artery, with two-stage venous drainage through the right atrium. Myocardial protection was achieved using Del Nido crystalloid cardioplegia administered at a 4:1 crystalloid-to-blood ratio. The dosage was 20 mL/kg for patients weighing less than 50 kg and 1000 mL for those weighing 50 kg or more, supplemented by 500 mL of root perfusion. Arch reconstruction was initiated when the nasopharyngeal temperature reached 25 °C and bladder temperature approximated 28 °C.

After the repair, rewarming was commenced at a rate not exceeding 0.5 °C/min, with a water–nasopharyngeal temperature gradient maintained below 6 °C. This process began only after achieving mixed venous oxygen saturation (SvO₂) above 70%, completing the left common carotid artery anastomosis, and repaying the oxygen debt. During rewarming, 500 mg of methylprednisolone was administered, and 250 mL of 20% mannitol was infused when the patient's temperature reached 32 °C.

Subsequent vascular reconstructions included proximal anastomosis of the ascending aorta, followed by repair of the left subclavian and innominate arteries. Cardiopulmonary bypass was discontinued after the core temperature exceeded 35 °C and adequate cardiac function was confirmed by transesophageal echocardiography. Throughout the procedure, mean arterial pressure was maintained between 60–80 mmHg. Blood gas management followed alpha-stat principles, switching to pH-stat during deep hypothermic circulatory arrest, and then returning to alpha-stat after rewarming, with PaCO₂ maintained between 35–45 mmHg.

2.2.2 Cerebral Perfusion Protection Method

In this study cohort, all patients received intraoperative oxygen delivery (DO₂) management according to the following protocol: moderate hypothermia combined with unilateral selective cerebral perfusion was utilized. Throughout the cooling and rewarming phases, DO₂ was maintained above 280 mL/(m²·min). DO₂ was calculated using the formula: DO₂ = [Hb (g/L) × 0.134 × SaO₂ + PaO₂ (mmHg) × 0.0031] × flow rate [L/(m²·min)] × 10.

For the percentage-flow cerebral perfusion group, the initial unilateral perfusion flow was set at 15% of the pre-deep hypothermic circulatory arrest (DHCA) average flow rate. The pre-DHCA average flow was calculated by multiplying each recorded flow value during the cardiopulmonary bypass (CPB) period prior to DHCA by its corresponding time interval, summing these products, and dividing by the total duration. This 15% threshold was selected based on the physiological assumption that cerebral blood flow comprises approximately 15–20% of total cardiac output.

In the conventional group, perfusion was managed according to body surface area-based flow targets (1.8–2.8 L/m²·min), with unilateral cerebral perfusion fixed at 5 mL/(kg·min). In both groups, near-infrared spectroscopy (NIRS) was employed to guide dynamic adjustment of perfusion flow, maintaining NIRS values at or above 80% of the preoperative baseline. Additionally, the maximum allowable perfusion flow did not exceed 20% of the real-time flow rate measured immediately before DHCA.

2.3 Outcome Measures

2.3.1 Primary outcomes

The incidence of neurological injury was compared between the groups and classified as either temporary or permanent dysfunction. Temporary neurological dysfunction

(TND) included delayed awakening, anxiety, agitation, and delirium. Delirium was assessed at least twice daily using the Confusion Assessment Method for the ICU (CAM-ICU). Anxiety and irritability were evaluated with the Hospital Anxiety and Depression Scale (HADS) and the Richmond Agitation-Sedation Scale (RASS), respectively. Permanent neurological dysfunction (PND) encompassed stroke, coma, and epilepsy. The diagnosis of epilepsy adhered to the International League Against Epilepsy (ILAE) criteria and was confirmed in all cases by routine electroencephalography (EEG), with independent review by two neurologists. The incidence rate of neurological dysfunction was calculated as: (number of cases with neurological dysfunction / total number of cases) × 100%.

2.3.2 Secondary outcomes

Serum levels of neurological injury biomarkers—S100β and neuron-specific enolase (NSE)—were compared between the groups. Peripheral venous blood samples (3–5 mL) were collected preoperatively and one week postoperatively. Following centrifugation, serum concentrations of S100β and NSE were quantified using enzyme-linked immunosorbent assay (ELISA) in accordance with the manufacturer’s instructions.

2.4 Data Statistics

Statistical analyses were conducted using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Continuous variables are expressed as mean ± standard deviation and were compared using independent Student’s *t*-tests. Categorical variables are presented as frequencies (n) and percentages (%), and group differences were assessed with Pearson’s chi-square test. Multicollinearity among variables was evaluated using the variance inflation factor (VIF). A two-tailed *p*-value of less than 0.05 was considered statistically significant.

Table 1. Comparative analysis of perioperative baseline characteristics between two groups.

Variables	Flow percentage cerebral perfusion group (n = 89)	Control group (n = 137)	χ ² /t value	<i>p</i> value
Gender Male/Female (n)	67/22	93/44	1.093	0.296
Age (years)	59.8 ± 5.9	61.3 ± 6.2	1.811	0.071
BMI (kg/m ²)	26.8 ± 1.8	27.3 ± 1.9	1.973	0.051
Hypertension (n)	78	121	0.141	0.707
Diabetes (n)	6	11	0.010	0.920
Hyperlipidemia (n)	26	51	1.206	0.272
Left ventricular ejection fraction (%)	56.7 ± 5.4	57.0 ± 4.9	0.432	0.666
Death (n)	4	6	0.011	0.915
Length of stay in ICU (d)	1.2 ± 0.6	1.3 ± 0.5	1.356	0.176
Acute renal failure (n)	7	13	0.032	0.857
Number of CRRT cases beside the bed (n)	2	4	0.014	0.908
Number of re-thoracotomies (n)	1	2	0.144	0.705
Mechanical assisted cardiac function (IABP/ECMO) (n)	3	5	0.066	0.797

BMI, Body Mass Index; Mechanical support includes intra-aortic balloon pumping (IABP) and extracorporeal membrane oxygenation (ECMO).

Table 2. Intraoperative characteristics comparison between two groups.

Variables	Flow percentage cerebral perfusion group (n = 89)	Control group (n = 137)	t value	p value
Cerebral perfusion minimum temperature				
Minimum Nasopharyngeal temperature (°C)	24.6 ± 0.6	24.8 ± 0.9	1.846	0.066
Minimum Bladder temperature (°C)	27.6 ± 0.5	27.7 ± 0.5	1.469	0.143
Cerebral perfusion flow (L/min)	0.62 ± 0.2	0.56 ± 0.3	1.661	0.098
Unilateral brain perfusion time (min)	22.5 ± 4.8	22.9 ± 5.1	0.589	0.556
Minimum intraoperative Hb (g/L)	88.1 ± 13.2	86.9 ± 12.9	0.677	0.499
Minimum intraoperative DO ₂ (L/m ² ·min)	289.8 ± 10.8	287.3 ± 9.4	1.571	0.071
CPB time	156.7 ± 23.4	158.4 ± 24.0	0.525	0.600
Aortic cross-clamp time	89.6 ± 11.5	88.4 ± 12.0	0.747	0.456

Hb, Hemoglobin; DO₂, Oxygen transport index; CPB, cardiopulmonary bypass.

3. Results

3.1 Comparison of Baseline Data Between Two Groups of Patients

The two groups exhibited similar baseline characteristics, with no statistically significant differences in preoperative demographics, intraoperative parameters—such as perfusion time, aortic cross-clamp time, and cerebral perfusion duration—or the incidence of perioperative complications (all $p > 0.05$). A detailed comparison is provided in Table 1.

3.2 Comparison of Cerebral Perfusion Parameters Between Groups

No statistically significant differences (all $p > 0.05$) were observed between the two groups in key cerebral perfusion parameters, including minimum perfusion temperature, flow rate, cerebral perfusion duration, cardiopulmonary bypass (CPB) time, aortic cross-clamp time, intraoperative minimum hemoglobin levels, or oxygen delivery (DO₂), as summarized in Table 2.

3.3 Comparison of Intraoperative Cerebral Oxygen Saturation Between Two Groups of Patients

The results indicated no statistically significant differences in regional cerebral oxygen saturation (rSO₂) between the two groups either preoperatively or at 5 minutes after the initiation of deep hypothermic circulatory arrest (all $p > 0.05$). However, significant intergroup differences emerged during rewarming to 36 °C, with the percentage-flow cerebral perfusion group showing significantly higher rSO₂ values than the conventional perfusion group ($p < 0.05$). These outcomes are illustrated in Fig. 1.

3.4 Comparison of the Incidence of Neurological Dysfunction Between the Two Groups

The percentage-flow cerebral perfusion group showed superior clinical outcomes relative to the conventional management group, with statistically significant reductions in the incidence of both temporary and permanent neurological dysfunction, as well as shorter median wake-up times

and expedited extubation durations (all $p < 0.05$). Detailed results are presented in Table 3.

3.5 Comparison of Peripheral Serum S100β and NSE Expression Levels Before and After Surgery in Two Groups of Patients

Preoperative serum levels of S100β and NSE showed no significant differences between the two groups (both $p > 0.05$). At one week after surgery, both biomarkers were significantly elevated in all patients compared to preoperative levels ($p < 0.05$). Notably, the conventional control group exhibited markedly higher concentrations of both S100β and NSE than the percentage-flow cerebral perfusion group (all $p < 0.05$). Detailed results are shown in Fig. 2.

3.6 Univariate and Multivariate Analysis of Neurological Dysfunction After Acute Aortic Dissection Surgery

Our analysis identified several significant predictors of postoperative neurological dysfunction after acute aortic dissection surgery. Univariate analysis indicated that patients who developed neurological complications were significantly older, had a higher prevalence of diabetes, and exhibited longer cardiopulmonary bypass (CPB) times, aortic cross-clamp durations, and unilateral antegrade cerebral perfusion periods compared to those without neurological impairment (all $p < 0.05$). Multivariate regression analysis confirmed four independent risk factors: advanced age, prolonged unilateral cerebral perfusion time, cerebral perfusion strategy, and total CPB duration. The resulting predictive model showed strong discriminative ability, with an area under the curve (AUC) of 0.838 (95% CI: 0.817–0.938), and good calibration (Hosmer–Lemeshow $\chi^2 = 9.574$, $p = 0.256$), supporting its potential clinical utility for risk stratification. Detailed results are presented in Tables 4,5 and Fig. 3.

4. Discussion

Preserving neurological function is a critical priority in aortic arch reconstruction for acute dissection repair [9]. This complex surgical procedure differs fundamen-

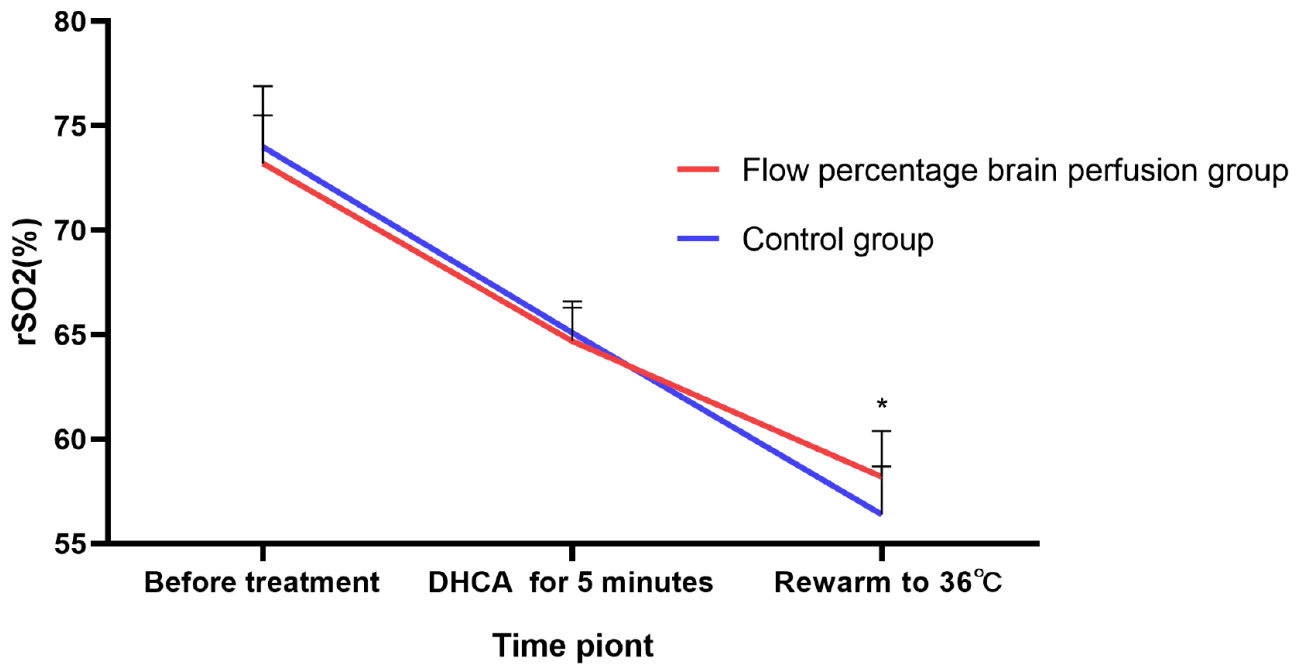


Fig. 1. Comparison of regional cerebral oxygen saturation (rSO₂) levels at different time points during the surgery between the two groups of patients. *: $p < 0.05$.

Table 3. Comparison of the incidence of neurological dysfunction between the two groups of patients.

Group	Awake time (h)	Extubation time (h)	TND components				PND components			Total
			Awakening Delay	Anxiety	Irritable	Delirium	Stroke	Coma	Epilepsy	
Flow percentage cerebral perfusion group (n = 89)	8.77 ± 1.7	12.6 ± 2.8	2	2	2	2	0	1	1	10
Control group (n = 137)	9.89 ± 1.9	14.9 ± 3.0	4	8	7	7	1	1	2	30
χ^2/t value	4.510	5.780				4.210				4.210
p value	<0.001	<0.001				0.040				0.040

TND, Temporary nervous dysfunction; PND, Permanent nervous dysfunction.

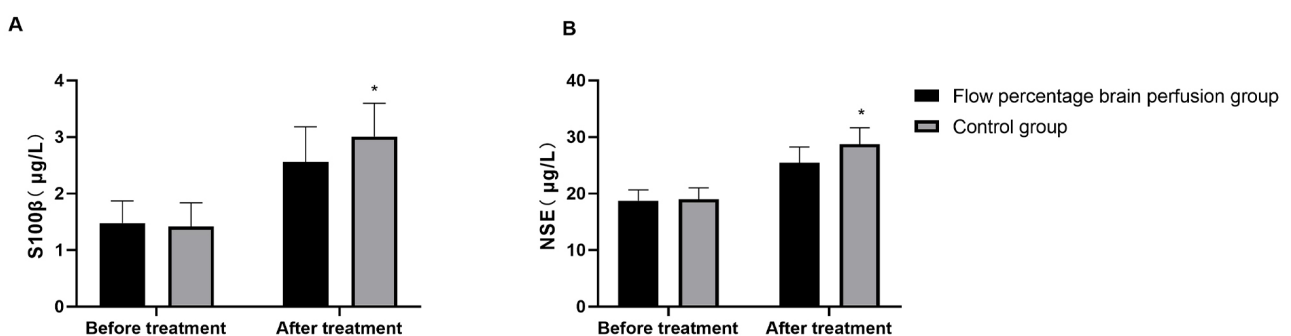


Fig. 2. Markers of neurological injury in both groups of patients. (A) The expression levels of serum S100β in the two groups of patients. (B) The expression levels of serum NSE in the two groups of patients. *: $p < 0.05$.

tally from routine cardiac operations due to its requirements for prolonged cardiopulmonary bypass, systemic hypothermia, deep hypothermic circulatory arrest of the lower body, and intricate arch reconstruction—all of which substantially disrupt cerebral metabolic homeostasis [10]. Con-

temporary cerebral protection strategies during arch reconstruction have yielded satisfactory clinical outcomes. Advances in understanding cerebral injury mechanisms and continuous refinement of surgical techniques have led to a consensus favoring progressively higher circulatory ar-

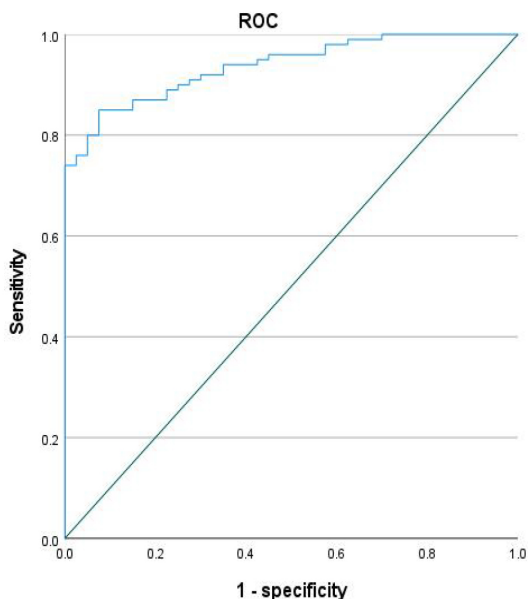
Table 4. Univariate analysis of neurological dysfunction after acute aortic dissection surgery.

Variable	Neurological dysfunction(+)	Neurological dysfunction(-)	χ^2/t value	<i>p</i> value
	(n = 40)	(n = 186)		
Gender Male/Female (n)	29/11	131/55	1.093	0.296
Age (years)	69.8 ± 5.2	70.3 ± 5.8	0.503	0.615
BMI (kg/m ²)	27.1 ± 1.7	27.8 ± 2.0	1.973	0.051
Hypertension (n)	31	168	0.141	0.707
Diabetes (n)	6	11	3.907	0.048
Hyperlipidemia (n)	17	60	1.206	0.272
Left ventricular ejection fraction (%)	56.8 ± 5.2	57.3 ± 5.1	0.432	0.666
Cerebral perfusion flow (L/min)	0.54 ± 0.2	0.63 ± 0.2	2.504	0.013
Flow percentage method	10	77	4.210	0.040
Weight Estimation Algorithm	30	109		
Unilateral cerebral perfusion time (min)	25.5 ± 4.8	22.0 ± 5.1	3.977	<0.001
Minimum intraoperative Hb (g/L)	85.1 ± 8.2	86.9 ± 7.6	1.340	0.182
Minimum intraoperative DO ₂ (L/m ² ·min)	290.8 ± 5.8	289.3 ± 6.4	1.366	0.133
CPB Time	166.7 ± 13.2	156.4 ± 12.8	4.5892	<0.001

Table 5. Multivariate logistic analysis of neurological dysfunction after acute aortic surgery.

Variable	<i>p</i>	OR	95% CI
Per 1-year increase for age	0.013	2.685	1.104~4.053
Per 10-minute increase for uSACP time	0.001	4.765	2.474~8.718
Per 10-minute increase CPB time	0.027	3.087	1.604~7.393
Cerebral perfusion flow method	0.039	2.014	1.336~3.550

uSACP, unilateral antegrade selective cerebral perfusion.

**Fig. 3. Area under the curve (AUC) curve of the model for neurological function impairment in acute aortic surgery.**

rest temperatures, marking a transition from deep to moderate hypothermia. Substantial evidence indicates that unilateral selective cerebral perfusion combined with moderate hypothermia (24–28 °C) not only improves overall surgical efficacy but also reduces the incidence of stroke [11].

Our data show that cardiopulmonary bypass (CPB) times in both cohorts were only slightly longer than those observed in complex valve procedures, with an overall perioperative mortality rate of 4.6%—consistent with contemporary published outcomes [12]. These results affirm that technical advancements and optimized thermal management can effectively shorten CPB duration without compromising procedural safety. Nevertheless, current evidence remains largely based on single-center experiences, and the lack of standardized cerebral perfusion protocols continues to raise concerns regarding both safety and therapeutic efficacy.

In this study, we implemented goal-directed perfusion management to optimize tissue oxygenation during surgical intervention. Current evidence indicates that this perfusion strategy enhances neuroprotection in aortic dissection repair [13]. Nevertheless, significant controversy remains regarding optimal cerebral perfusion protocols. Conventional flow rate determination typically relies on patient weight and perfusion pressure parameters, supplemented by intraoperative cerebral oxygen saturation monitoring. This approach has several limitations: (1) cerebral oximetry readings exhibit considerable variability due to anesthetic depth, hypothermic conditions, and individual physiological differences; (2) the inherent latency of saturation monitoring impedes real-time flow precision; and (3) these limitations collectively increase the risk of both cerebral hyperperfusion and hypoperfusion, potentially exacerbating

neurological injury. Physiological studies suggest that cerebral blood flow normally accounts for 15–20% of total cardiac output [14]. When normalized to brain tissue mass—approximately 2% of total body weight—percentage-based flow calculation may better reflect actual cerebral perfusion demands. Therefore, our study aimed to evaluate the neuroprotective efficacy of precision-adjusted percentage-flow cerebral perfusion, with the ultimate goal of establishing an optimized brain protection protocol for aortic arch surgery [15].

Guided by existing evidence on goal-directed perfusion in cardiac surgery, we maintained an intraoperative oxygen delivery (DO_2) target of $280 \text{ mL/m}^2\cdot\text{min}$. Cerebral perfusion was initiated at 15% of the mean pre-deep hypothermic circulatory arrest (DHCA) flow rate and dynamically adjusted using near-infrared spectroscopy (NIRS) monitoring [16]. Although both groups showed comparable rates of major neurological complications such as stroke and seizures, the percentage-flow perfusion group demonstrated superior outcomes in several key areas: (1) a significantly lower incidence of transient neurological dysfunction; (2) improved cerebral oxygenation, reflected by higher NIRS values; and (3) reduced times to wakefulness and extubation. These results indicate that percentage-flow adjusted cerebral perfusion enables a more physiological flow distribution, leading to enhanced oxygen delivery, improved metabolic regulation, and optimized perfusion dynamics. Consequently, this approach offers strengthened neuroprotection—a conclusion that supports and extends previous research findings [17,18].

This study further evaluated the expression levels of brain injury biomarkers under different perfusion strategies. The results demonstrated that postoperative serum levels of S100 β and NSE were significantly lower in the percentage-flow perfusion group compared to the conventional control group. These findings support the view that percentage-flow perfusion improves perfusion efficiency, helps maintain an optimal flow rate, enhances cerebral metabolic conditions, and reduces brain injury-related factors—consistent with conclusions from previous studies [19–21].

Building upon previous studies examining risk factors for neurological impairment after acute aortic dissection surgery, we analyzed data from the present patient cohort. The analysis identified age, unilateral cerebral perfusion time, and cardiopulmonary bypass (CPB) duration as significant contributors to postoperative neurological injury. Advanced age is associated with a progressive decline in physiological reserve, particularly affecting the cardiovascular and nervous systems. In elderly patients, pre-existing cerebral arteriosclerosis may reduce baseline cerebral blood flow, increasing susceptibility to ischemic injury during surgery. Furthermore, the aging brain exhibits reduced tolerance to ischemia, rendering it more vulnerable to irreversible neuronal damage under conditions of inadequate

perfusion. Unilateral cerebral perfusion—while useful for reducing overall cerebral perfusion pressure in selected scenarios—carries an inherent risk of hypoperfusion in the non-perfused hemisphere. Prolonged unilateral perfusion may exacerbate oxygen and nutrient deficiency in contralateral brain regions, potentially leading to neurological complications. Additionally, extended CPB time represents a major risk factor for neurological injury. Prolonged bypass can induce systemic hypothermia, acid-base imbalance, and coagulation disorders, all of which may adversely affect nervous system integrity. These findings align with previously published reports [22–24].

Limitations

This study has several limitations. As a single-center, retrospective, nested case-control investigation, it is inherently susceptible to certain biases. Moreover, in patients with higher baseline hemoglobin levels, conventional perfusion management may already provide adequate oxygen delivery, potentially diminishing the demonstrated superiority of percentage-flow cerebral perfusion. Variability in blood product transfusion protocols across centers may also affect the comparative outcomes between perfusion strategies. Other potential confounding factors include differences in surgical team experience, anesthesia management, and postoperative care, all of which could influence neurological and operational outcomes. Additionally, the use of near-infrared spectroscopy (NIRS) for perfusion guidance has inherent limitations, such as inter-individual variability and susceptibility to interference from extracranial tissues, which may affect the accuracy of cerebral oxygenation assessment. Extending the follow-up period to validate the long-term neurological outcomes and further corroborate the conclusions of this study remains an important objective for future research.

In summary, the percentage-flow cerebral perfusion strategy in acute aortic dissection surgery enhances intraoperative neuroprotection, reduces the incidence of neurological injury, and shortens both mechanical ventilation duration and time to postoperative awakening. This approach can be recommended for clinical application. Furthermore, this study identified age, unilateral cerebral perfusion time, and cardiopulmonary bypass duration as significant influencing factors for postoperative neurological injury. The predictive model incorporating these variables demonstrated favourable efficacy, supporting its potential utility in risk stratification and perioperative management.

5. Conclusion

The implementation of percentage-flow-based cerebral perfusion management in acute aortic dissection surgery significantly enhances intraoperative cerebral protection. This strategy not only shortens the duration of postoperative mechanical ventilation and facilitates faster recovery from anesthesia but also effectively reduces the in-

idence of neurological complications. Furthermore, our results indicate that neurological injury is associated with patient age and the duration of cerebral perfusion during cardiopulmonary bypass. The developed predictive model demonstrates strong clinical utility, providing valuable guidance for optimizing cerebral perfusion strategies in this high-risk surgical population.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author, Wan, upon reasonable request.

Author Contributions

YHY: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. JCS: Data curation, Software, Validation, Visualization, Writing – review & editing. LW: Conception, Design, Resources, Supervision, Project administration, Funding acquisition. ZHW: Acquiring the patient data, Interpreting the imaging results. LLW: Investigation, Resources, Data curation, Writing – original draft. All authors contributed to editorial changes in 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 was performed in line with the principles of the Declaration of Helsinki. Approval was granted by Nanjing First Hospital's ethics committee (Ethics Approval No. KY20220805). All patients/participants or their families/legal guardians gave their written informed consent before they participated in the study.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

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