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Article

"Brain-First" Total Body Retrograde Perfusion and Retrograde Cerebral Perfusion in Hemi-Arch Replacement

Zhen Qin[1,2], Yannan Zhou[3], Bo Wang[1], Haohan Chen[3], Jiyue Xiong[1,]*, Jun Gu[2,]*

[1]Department of Anesthesiology, West China Hospital, Sichuan University, 610041 Chengdu, Sichuan, China
[2]Department of Cardiovascular Surgery, West China Hospital, Sichuan University, 610041 Chengdu, Sichuan, China
[3]West China School of Medicine, Sichuan University, 610065 Chengdu, Sichuan, China
*Correspondence: Xiongjiyue028@163.com (Jiyue Xiong); gujun@wchscu.cn (Jun Gu)

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Abstract

Objective: The purpose of this study is to compare the early outcomes of brain-first total body retrograde perfusion (Bf-TBRP) in comparison with retrograde cerebral perfusion (RCP) under moderate hypothermia circulatory arrest (MHCA) for hemi-arch replacement surgery. **Methods**: We analyzed the data of 88 patients who underwent hemi-arch replacement with Bf-TBRP (n = 18) or RCP (n = 70) under MHCA at West China Hospital of Sichuan University between 1 January 2020, and 31 July 2022. In-hospital mortality, neurological deficits, and other adverse events were recorded, which were evaluated with logistic regression to determine risk factors. **Results**: There was no significant difference between the Bf-TBRP and RCP groups in in-hospital mortality, cardiac events, neurological deficits, dialysis, gastrointestinal complications, and paralysis ($p > 0.05$). The Bf-TBRP group was associated with significantly shorter hospital stay [Bf-TBRP: 8 d (interquartile range (IQR), 7–10) *vs.* RCP: 10 d (IQR, 8–13), $p = 0.03$] and fewer platelet transfusions [Bf-TBRP: 1.0 (IQR, 0–1.0) *vs.* RCP: 1.0 (IQR, 1.0–2.0), $p = 0.05$] than the RCP group. On multivariable logistic regression analysis, emergency surgery ($p = 0.05$) and surgery duration ($p = 0.03$) were determined to be risk factors. **Conclusions**: The study showed that Bf-TBRP is a safe technique for patients undergoing hemi-arch replacement with MHCA.

Keywords

brain-first total body retrograde perfusion; hemi-arch replacement; moderate hypothermia circulatory arrest; retrograde cerebral perfusion

Introduction

Severe aortic arch abnormalities such as aortic arch aneurysms and aortic dissection often require surgical treatment, which involves hemiarch replacement [1,2]. However, despite significant advances in surgical techniques, post-operative mortality and morbidity remain high [3–7]. Ischemic organ injury can occur during the period of hypothermic circulatory arrest which is necessary for reconstruction of the ascending aorta and the arch vessels.

To address brain ischemia and hypoxia, three different cerebral protection strategies are currently available: isolated deep hypothermic circulatory arrest (DHCA), circulatory arrest combined with retrograde cerebral perfusion (RCP), and circulatory arrest combined with antegrade cerebral perfusion (ACP) [8]. Moderate or mild hypothermic circulatory arrest may also be used to avoid the potential harmful effects associated with prolonged hypothermia [9,10]. Nevertheless, the ideal method of protection is still controversial [11,12]. The insufficient perfusion of the lower body during circulatory arrest stands as another issue, specifically under elevated circulatory arrest temperature. Compared to deep hypothermia, there is the potential for spinal cord visceral organ ischemia, which could lead to paraplegia and kidney failure [13,14].

To overcome these limitations, we modified RCP and proposed the brain-first total body retrograde perfusion (Bf-TBRP) technique in 2021 [15]. This technique involves preferentially use of arterial blood to perfuse the brain through the superior vena cava during the anastomosis of the arch vessels, while simultaneously blocking the return of blood from the inferior vena cava. Consequently, a portion of the blood will enter the inferior vena cava through branches of the superior and inferior vena cava, thus providing perfusion of the abdominal organs [15]. We have previously demonstrated that Bf-TBRP combined with moderate hypothermia circulatory arrest (MHCA) can preferentially perfuse the brain while providing blood flow to vital organs in the lower body, effectively preventing ischemic damage to vital organs. This study sought to further exam the safety and clinical effects of Bf-TBRP by comparing the surgical outcomes of Bf-TBRP and RCP under MHCA in a larger sample size.

Material and Methods

Study Design and Patient Population

We conducted an observational study, utilizing a prospectively maintained institutional database of all open

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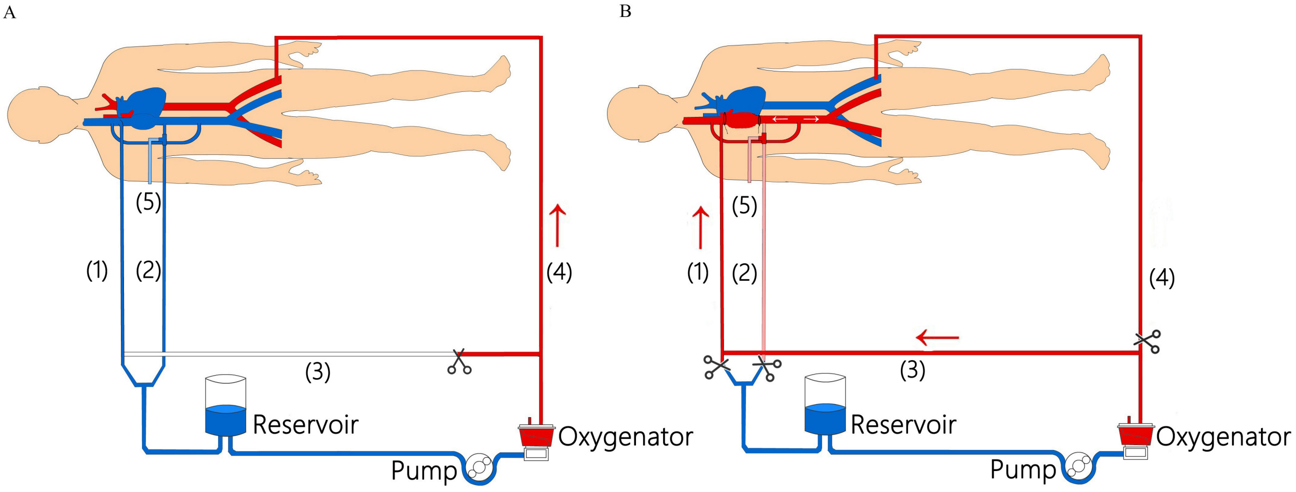

Fig. 1. The procedure of brain-first total body retrograde perfusion (Bf-TBRP) during the surgery. (A) Before and after Bf-TBRP, venous blood from the (1) superior vena cava (SVC) and (2) inferior vena cava (IVC) returns to the reservoir, then it is pumped to the oxygenator and back to the artery via the (4) arterial line. IVC pressure is monitored via a (5) lateral cannular port. The connecting branch between the arterial line and the SVC drainage line is clamped. (B) During moderate hypothermia circulatory arrest (MHCA), the systemic perfusion branch and the distal ends of both the SVC and IVC drainage lines are cross-clamped and the connecting branch (3) between the arterial line and the SVC drainage line is opened for perfusion. The oxygenated blood is diverted as retrograde cerebral perfusion (RCP), meanwhile, the blood from the connection vessel between SVC and IVC enters the lower body to perfuse the vital organs in the lower body.

proximal aortic surgeries performed at West China Hospital of Sichuan University from 1 January 2020, to 31 July 2022. This study was approved by the Medical Ethics Committee of West China Hospital of Sichuan University (No. 2018(24)). Written informed consent was signed by recruited patients. Definitions and terminology were consistent with the Society of Thoracic Surgeons (STS) database.

All patients with hemi-arch replacement listed as their index operation due to aortic dissection, aortic aneurysm, or intramural hematoma were included in the analysis. Patients under 18 years, who were pregnant or undergoing total arch replacement were excluded. In this patient cohort, 70 were performed with RCP, and 18 were performed with Bf-TBRP.

Operative Procedures

General anesthesia was induced and maintained by sevoflurane (H20070172, Jiangsu Hengrui Pharmaceuticals Co., Ltd, Lianyungang, Jiangsu, China) inhalation and intravenous infusions of propofol (H20213723, Haisco Pharmaceutical Group, Chengdu, Sichuan, China), sufentanil (31A102012, HUMANWELL GROUP, Yichang, Hubei, China), and cisatracurium (CIC0311A, Kingfriend, Nanjing, Jiangsu, China). Nasopharyngeal and rectal temperatures were monitored regularly, as well as invasive blood pressure in the left dorsalis pedis and bilateral radial arteries. A central venous catheter was inserted into the right internal jugular vein. Near-infrared spectroscopy (NIRS; EGOS-600A, Suzhou Engine Bio-medical Electronics, Suzhou, China) was used to monitor the cerebral perfusion. Transesophageal echocardiography was routinely performed.

A standard cardiopulmonary bypass circuit was established. In the outlet line of the oxygenator, the arterial line was divided into one branch for systemic perfusion, and another branch (connecting branch) was connected to the superior caval drainage line to prepare for Bf-TBRP at MHCA (Fig. 1). After sternotomy and systemic heparinization, cardiopulmonary bypass was established via aortic and bicaval canulation. During bypass, the connecting branch was clamped. The pump was stopped when moderate hypothermia (nasopharyngeal temperature, 25 °C; rectal temperature, 27 °C) was achieved. Both the superior vena cava (SVC) and inferior vena cava (IVC) were snared. The branch for systemic perfusion and the distal end of the SVC drainage line was cross-clamped, but the connecting branch was de-clamped allowing the initiating of RCP. In the Bf-TBRP group (Fig. 1), the circuit setting was similar to the RCP group except the distal end of the IVC drainage line was also cross-clamped. The central venous pressure was kept <30 mmHg to prevent overperfusion.

To ensure a clear surgical field during the distal anastomosis, a small-bore drainage tube was inserted into the descending aorta to drain backflow from collateral vessels.

Outcomes

The primary outcome was a composite of outcomes including in-hospital mortality, and the incidence of postop-

Table 1. Baseline variables in patients treated with Bf-TBRP or RCP during Hemi-arch surgery.

Variables	Bf-TBRP (n = 18)	RCP (n = 70)	p value
Demographics and chronic comorbidities			
Age (yr)	58.1 ± 9.4	58.5 ± 10.9	0.88
Male	10 (55.6)	41 (58.6)	1.00
Body mass index (kg/m^2)	1.60 ± 0.16	1.66 ± 0.34	0.47
Current smoker	4 (22.2)	17 (24.3)	1.00
Hypertension	9 (50.0)	43 (61.4)	0.43
Ejection fraction (%)	67.5 (59.3, 70.3)	66.0 (59.8, 70.0)	0.63
Arrhythmia	0 (0)	0 (0)	
Previous coronary disease	0 (0)	2 (2.9)	1.00
Peripheral vascular disease	0 (0)	1 (1.4)	1.00
History of stroke	1 (5.6)	1 (1.4)	0.37
Preoperative paralysis	0 (0)	1 (1.4)	1.00
Diabetes	0 (0)	2 (2.9)	1.00
Laboratory index			
Hemoglobin (g/L)	129.6 ± 20.7	124.9 ± 23.4	0.45
Platelets (×10^9/L)	161.7 ± 62.4	169.5 ± 78.8	0.70
Leukocytes (×10^9/L)	6.9 (4.7, 12.7)	6.3 (5.3, 9.9)	0.81
C-reactive protein (mg/L)	2.3 (1.4, 84.0)	7.5 (12.3, 34.2)	0.46
Troponin-T (ng/L)	10.6 (8.9, 118.2)	16.5 (12.3, 61.9)	0.25
Creatinine level (umol/L)	95.0 (72.0, 129.5)	83.0 (66.5, 96.5)	0.46
Brain natriuretic peptides (pg/mL)	766.0 (98.0, 6884.0)	437.0 (135.0, 914.0)	0.96
Medicine			
Beta blocker	6 (33.3)	20 (28.6)	0.77
Anticoagulant	0 (0)	4 (5.7)	0.58
Pathological type			
Aortic dissection	7 (38.9)	21 (30.0)	0.66
Aortic aneurysm	9 (50.0)	35 (50.0)	1.00
Intramural hematoma	2 (11.1)	14 (20.0)	0.60
Emergency surgery	8 (44.4)	27 (38.6)	0.79
Redo surgery	0 (0)	3 (4.3)	1.00

Continuous data are expressed as mean ± standard deviation or median (interquartile range); categorical data, as n (%). $p < 0.05$ was considered significantly different. Bf-TBRP, brain-first total body retrograde perfusion; RCP, retrograde cerebral perfusion.

erative complications: cardiac events, neurological deficits, dialysis, *etc*. Cardiac events included arrhythmias needing medical intervention, cardiac arrest, postoperative myocardial infarction, and low cardiac output syndrome. Neurological deficits were categorized as either permanent neurological deficits (PND) or temporary neurological deficits (TND). PND included focal injury or global stroke at the time of discharge. Focal lesions were confirmed using brain computed tomography or magnetic resonance imaging. TND included postoperative confusion, agitation, seizure, or transient delirium without morphologic changes confirmed on imaging.

Additionally, this study sought to evaluate complications and other indicators associated with operative mortality. Secondary outcomes included the oxygen index of 4 hours after surgery, re-exploration for bleeding, tracheotomy, and reintubation. Furthermore, the duration of mechanical ventilation, duration of intensive care unit stays, and duration of hospital stay were recorded.

We also evaluated blood product management during the surgery. The incidence of red blood cells, fresh frozen plasma, and platelet transfusion requirements, as well as the corresponding volume (measured in units), were gathered for both groups.

Statistical Methods and Analysis

The normality of the distribution of continuous data was assessed using the Shapiro-Wilks test, for which $p > 0.05$ was taken to indicate normal distribution. Variables showing a normal distribution were expressed as mean ± standard deviation, and differences were assessed using an independent *t*-test. Other variables were expressed as median (inter-quartile range), and differences were assessed using the Mann–Whitney U test. Categorical variables were expressed as numbers (percentages), and differences were assessed using a Chi-square test. To investigate potential factors associated with primary outcomes, logistic regression models were performed. Odds ratio (OR) was estimated with 95% confidence intervals (CIs). Potential risk factors included baseline demographic data, laboratory index, pathological type, surgery type, and intraoperative variables. Baseline demographic data included general health status (age, gender, and body mass index), smoking behavior (current smoker), and cardiac function related factors (hypertension, previous coronary disease, ejection fraction, and history of stroke). Pathological type was categorized as aortic dissection, aortic aneurysm, and intramural hematoma. Surgery type was divided into emergency surgery and redo surgery. Intraoperative variables included rectal temperature, nasopharyngeal temperature, circulatory arrest time, cross-clamp time, and cardiopulmonary bypass (CPB) time, and surgery duration. Firstly, we performed the univariate logistic regression analysis to identify the potential association between the primary outcomes and all selected potential factors. Secondly, we adjusted the results with factors that were considered significantly relevant ($p < 0.05$) and performed the multivariate logistic regression. All analyses were conducted in R (version 4.3.0, R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>) and differences with $p < 0.05$ were considered statistically significant.

Results

Baseline Demographic, Clinical, and Operative Variables

A total of 88 patients undergoing hemi-arch replacement under MHCA were identified, of whom 18 were performed with Bf-TBRP and 70 performed with RCP. Baseline variables of the patients are shown in Table 1. The age, sex index, and body mass index were similar between groups. The RCP group included more patients with other combined diseases, such as hypertension [43 (61.4%) *vs.* 9 (50.0%); $p = 0.43$], previous coronary disease [2 (2.9%) *vs.* 0 (0%); $p = 1.00$], peripheral vascular disease [1 (1.4%) *vs.* 0 (0%); $p = 1.00$], and diabetes [2 (2.9%) *vs.* 0 (0%); $p = 1.00$], although the difference was not significant. No significant difference was observed in the laboratory index, medicine, and pathological type between groups.

The intraoperative variables are shown in Table 2. No significant differences existed between groups regarding concomitant procedures, cannulation site, lowest temperature, and circulatory arrest time. The median of cross-clamp time [112 (101, 142) *vs.* 114 (99, 158); $p = 0.90$], CPB time [161 (147, 194) *vs.* 182 (150, 217); $p = 0.22$], and surgery duration [345 (306, 429) *vs.* 368 (314, 431); $p = 0.41$] were less in the Bf-TBRP group, although the difference was not significant.

Pressure and CPB Flow

During Bf-TBRP, the central venous pressure was at an average of 24.4 ± 9.3 mmHg (Fig. 2A). The pressure in the inferior vena canal measured through the side opening cannula was 14.0 ± 6.98 mmHg (Fig. 2A). The average CPB flow rate under RCP and Bf-TBRP was 268.0 ± 115.1 mL/min and 152.3 ± 121.2 mL/min respectively (Fig. 2B), and the mean difference (MD) between the two groups was statistically significant (MD: 115.7; 95% confidence interval (CI): 55.5–175.9; $p < 0.001$).

Postoperative Outcomes

Table 3 summarizes the postoperative results. The Bf-TBRP group showed a decreased risk of primary outcomes: 6 (33.3%) *vs.* 37 (52.9%) in the RCP group, but the difference was not statistically significant ($p = 0.19$). Neurological deficits were the main postoperative complication, occurred in 5 (27.8%) and 20 (28.6%) patients in the Bf-TBRP and RCP group, respectively. The difference between groups was also nonsignificant (**Supplementary Table 1**). The oxygen index (4 hours after surgery) was 308 mmHg (interquartile range (IQR), 145–389) for the Bf-TBRP group and 220 mmHg (IQR, 144–319) for the RCP, there was no significant difference ($p = 0.18$). The incidence of re-exploration for bleeding [Bf-TBRP: 1 (5.6%) *vs.* RCP: 1 (1.4%); $p = 0.37$], tracheotomy [Bf-TBRP: 0 *vs.* RCP: 2 (2.9%); $p = 1.00$], and reintubation [Bf-TBRP: 1 (5.6%) *vs.* RCP: 2 (2.9%); $p = 0.50$] were not significant between two groups. The duration of hospital stay in the Bf-TBRP group was 8 d (IQR, 7–10), which is significantly lower than that of the RCP group, 10 d (IQR, 8–13) ($p = 0.03$). Thirteen cases in the Bf-TBRP group (72.2%) and fifty-five cases in the RCP group (78.5%) required platelet transfusions ($p = 0.54$). We found slightly significant differences between groups in the volume of platelets transfused [Bf-TBRP: 1.0 (IQR, 0–1.0) *vs.* RCP: 1.0 (IQR, 1.0–2.0); $p = 0.05$]. No significant differences existed in the need for red blood cells transfusions (Volume: $p = 0.63$; Rate: $p = 0.79$) and fresh frozen plasma (Volume: $p = 0.49$; Rate: $p = 0.75$).

To further determine risk factors for primary outcomes, logistic regression based on univariable and multivariable analyses was conducted (Table 4). The multivariable logistic regression model was adjusted for hypertension, pathological type, presence or absence of emergency, and surgery duration. The results revealed emergency surgery (odds ratio (OR) = 3.14; 95% CI: 0.99–10.46; $p = 0.05$) and surgery duration (OR = 1.01; 95% CI: 1.00–1.01; $p = 0.03$) to be independent risk factors for the pri-

Table 2. Intraoperative variables in patients treated with Bf-TBRP or RCP during Hemi-arch surgery.

Variables	Bf-TBRP (n = 18)	RCP (n = 70)	*p* value
Concomitant procedures			
Root replacement*	16 (88.9)	49 (70.0)	0.14
Coronary artery bypass grafting	0 (0)	2 (2.9)	1.00
Aortic valve replacement	1 (5.6)	1 (1.4)	0.37
Mitral valve replacement	0 (0)	2 (2.9)	1.00
Cannulation site			
Femoral artery	16 (88.9)	60 (85.7)	1.00
Axillary artery	2 (11.1)	12 (2.9)	0.73
Lowest temperature			
Rectal (°C)	25.7 ± 1.3	25.6 ± 1.4	0.81
Nasopharyngeal (°C)	24.3 (23.5, 24.6)	23.8 (23.1, 24.5)	0.13
Circulatory arrest (min)	26.0 (19.0, 29.0)	22.0 (18.0, 25.0)	0.30
Cross-clamp time (min)	112.0 (101.0, 142.0)	114.0 (99.0, 158.0)	0.90
Cardiopulmonary bypass time (min)	161.0 (147.0, 194.0)	182.0 (150.0, 217.0)	0.22
Surgery duration (min)	345.0 (306.0, 419.0)	368.0 (314.0, 431.0)	0.41

Continuous data are expressed as mean ± standard deviation or median (interquartile range); categorical data, as n (%). $p < 0.05$ was considered significantly different. Bf-TBRP, brain-first total body retrograde perfusion; RCP, retrograde cerebral perfusion. *Root replacement includes Bentall-type full root replacement or valve-sparing root replacement.

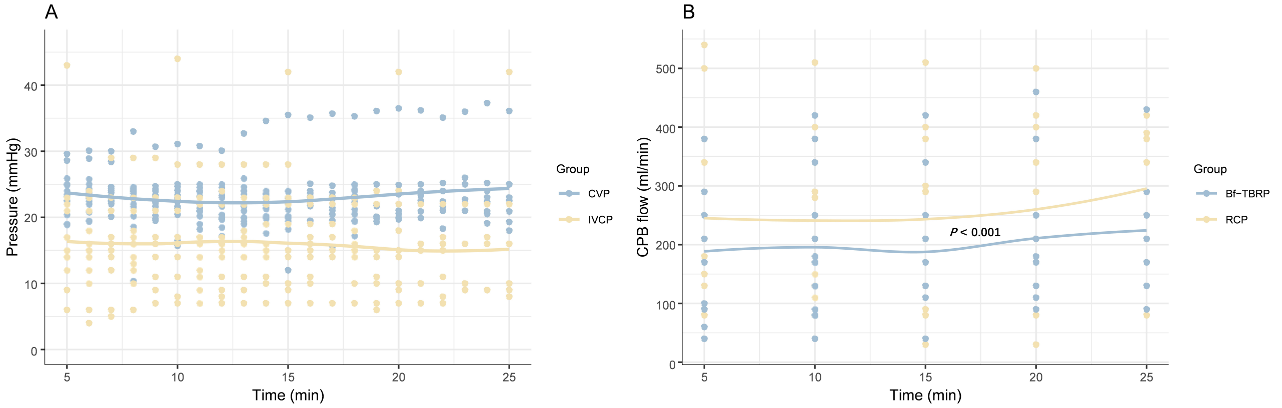

Fig. 2. Pressure and cardiopulmonary (CPB) flow during hemi-arch replacement. (A) Pressures in the central line and inferior vena cava during "Brain-first" total body retrograde perfusion. (B) Blood flow during cardiopulmonary bypass under "Brain-first" total body retrograde perfusion and retrograde cerebral perfusion, the mean difference (MD) between the two groups was statistically significant (MD: 115.7; 95% confidence interval (CI): 55.5–175.9; $p < 0.001$). CVP, central venous pressure; IVCP, inferior vena cava pressure; CPB, cardiopulmonary bypass; Bf-TBRP, brain-first total body retrograde perfusion; RCP, retrograde cerebral perfusion.

mary outcomes. The logistic regression model was also performed to investigate the risk factors for neurological deficits (**Supplementary Table 2**). Only aortic dissection was significant in the multivariate logistic regression analysis (OR = 2.96; 95% CI: 1.00–8.88; $p = 0.05$).

Discussion

Brain protection is a crucial component in arch replacement surgery involving circulatory arrest. The associated factors include circulatory arrest time, cerebral temperature, and cerebral perfusion. Deep hypothermia circulatory arrest (DHCA) alone, DHCA with RCP, DHCA with antegrade cerebral perfusion (ACP), and MHCA with ACP are four major strategies applied in clinical practice [8,12]. DHCA was initially introduced to avoid brain ischemia by reducing metabolic demands, but it does not provide cerebral perfusion, thereby possibly resulting in neurological deficits [16]. ACP and RCP were subsequently developed as adjuncts to DHCA, which has been demonstrated to reduce mortality and morbidity, and could be employed during extended periods of circulatory arrest [12,17,18]. How-

Table 3. Postoperative outcomes between two groups.

Variables	Bf-TBRP (n = 18)	RCP (n = 70)	p value
Primary outcomes	6 (33.3)	37 (52.9)	0.19
In-hospital mortality	0 (0)	5 (7.1)	0.55
Cardiac events	0 (0)	7 (10.0)	0.36
Arrhythmia needed medical intervention	0 (0)	4 (5.7)	0.58
Cardiac arrest	0 (0)	2 (2.9)	1.00
Postoperative myocardial infraction	0 (0)	0 (0)	1.00
Low cardiac output syndrome	0 (0)	1 (1.4)	1.00
Neurological deficits	5 (27.8)	20 (28.6)	1.00
PND	1 (5.6)	5 (7.0)	1.00
TND	4 (22.2)	15 (21.4)	1.00
Dialysis	1 (5.6)	5 (7.1)	1.00
Gastrointestinal complications	0 (0)	0 (0)	
Paralysis	0 (0)	0 (0)	
Secondary outcomes			
Oxygen index of 4 hours after surgery	308 (145, 389)	220 (144, 319)	0.18
Re-exploration for bleeding	1 (5.6)	1 (1.4)	0.37
Tracheotomy	0 (0)	2 (2.9)	1.00
Reintubation	1 (5.6)	2 (2.9)	0.50
Duration of mechanical ventilation (h)	18 (10, 53)	24 (15, 46)	0.19
Duration of intensive care unit stay (d)	3 (2, 3)	4 (2, 6)	0.28
Duration of hospital stay (d)	8 (7, 10)	10 (8, 13)	0.03
Requirement of blood product			
Red blood cells			
Volume (units)	1.5 (0, 4.8)	2.0 (0, 4.0)	0.63
Rate	10 (55.5)	42 (60.0)	0.79
Fresh frozen plasma			
Volume (units)	0 (0, 0)	0 (0, 0.4)	0.49
Rate	3 (16.6)	17 (24.2)	0.75
Platelet			
Volume (units)	1.0 (0, 1.0)	1.0 (1.0, 2.0)	0.05
Rate	13 (72.2)	55 (78.5)	0.54

Continuous data are expressed as median (interquartile range); categorical data, as n (%). $p < 0.05$ was considered significantly different. Bf-TBRP, brain-first total body retrograde perfusion; RCP, retrograde cerebral perfusion; PND, permanent neurological deficits; TND, temporary neurological deficit.

ever, the utilization of DHCA is recognized to be associated with many potential complications, prompting several investigators to propose MHCA as an alternative [19–22]. Following the widespread of this technology to ensure brain protection, some other concerns have been raised as these technologies could lead to distal organ dysfunction and ischemia [23–25]. Hypoperfusion of vita visceral organs (kidney, intestine, lung, adrenal glands) may consequently lead to extended stay in the intensive care unit and increased mortality.

We introduced a technique, Bf-TBRP, adapting RCP for total body perfusion during MHCA in hemi-arch replacement [15]. This technique utilizes communicating branches between superior the and inferior venae cavae (specifically the peri-cardiophrenic, azygos, and hemi-azygos veins) to transfer blood from the upper to the lower body. Unlike conventional RCP, which requires the central venous pressure to reach 25 mmHg [26], Bf-TBRP effectively enables sufficient brain perfusion at a lower central venous pressure via connecting branches between the superior and inferior venae cavae shunting cerebral blood flow, thus simultaneously ensuring lower body perfusion. We observed no fluid retention or essential organ injuries. The present observational study sought to explore the safety and clinical efficacy of surgical outcomes related to Bf-TBRP, based on a larger sample size. The findings revealed no significant difference in baseline data and primary outcomes (mortality and complications) between the Bf-TBRP group and the RCP group, which demonstrate the safety of Bf-TBRP. The multivariable analysis revealed that emergency surgery and surgery duration were significant factors for adverse outcomes. Previous studies have reported increased mortality and complication rates following emergency surgery for total arch replacement [27,28], and hemi-

Table 4. Univariate and multivariate logistic regression risk analyses of primary outcomes.

Variable	Crude odds ratio [a] (95% confidential interval)	p value	Adjusted odds ratio [b] (95% confidential interval)	p value
Age	1.02 (0.98–1.06)	0.31		
Male vs female	0.70 (0.30–1.63)	0.41		
Body mass index	1.80 (0.39–8.35)	0.46		
Current smoker	1.20 (0.45–3.21)	0.71		
Hypertension	3.64 (1.50–9.24)	0.00	2.08 (0.64–6.72)	0.22
Ejection fraction	1.03 (0.99–1.08)	0.18		
Previous coronary disease	1.05 (0.06–17.30)	0.97		
Stroke history	1.05 (0.06–17.30)	0.97		
Laboratory index				
C-reactive protein	1.01 (1.00–1.02)	0.06		
Troponin-T	1.00 (1.00–1.01)	0.11		
Creatinine level	1.01 (1.00–1.02)	0.06		
Brain natriuretic peptides	1.00 (1.00–1.00)	0.28		
Pathological type				
Intramural hematoma	2.76 (1.90–15.11)	0.09		
Aortic dissection	4.02 (1.57–11.13)	0.00	0.85 (0.19–3.61)	0.82
Aortic aneurysm	0.24 (0.10–0.58)	0.00	0.74 (0.19–2.95)	0.67
Emergency surgery	3.90 (1.61–9.98)	0.00	3.14 (0.99–10.46)	0.05
Redo surgery	2.15 (0.19–24.57)	0.54		
Rectal temperature	1.21 (0.88–1.67)	0.25		
Nasopharyngeal temperature	0.69 (0.44–1.07)	0.10		
Circulatory arrest time	1.00 (0.96–1.05)	0.88		
Cross-clamp time	1.01 (1.00–1.02)	0.14		
CPB time	1.01 (1.00–1.02)	0.10		
Surgery duration	1.01 (1.00–1.01)	0.02	1.01 (1.00–1.01)	0.03
Bf-TBRP	0.45 (0.15–1.32)	0.15		

Bf-TBRP, brain-first total body retrograde perfusion; RCP, retrograde cerebral perfusion; CPB, Cardiopulmonary bypass. [a], No covariates was adjusted. [b], Odds ratios are adjusted for the presence or absence of hypertension, pathological type, presence or absence of emergency surgery, and surgery duration. $p < 0.05$ was considered significant.

arch replacement [29]. Longer surgery durations can lead to extended periods of hypoperfusion in vital organs and exacerbate ischemic conditions, thereby elevating the likelihood of adverse postoperative events.

We found that the Bf-TERP group has a shorter hospital stay and a reduced need for platelet transfusions. Prior research has indicated a correlation between the utilization of blood products during total arch replacement and the occurrence of major adverse events [30,31]. A recent study published in 2023 [32] revealed that the requirement for blood product transfusion during proximal aortic surgery was significantly associated with elevated rates of mortality, stroke, reoperation, and dialysis dependence. Bf-TBRP provides sufficient perfusion for the lower body and visceral organs, avoiding severe ischemia and injuries, which could explain the reduced need for blood product transfusion.

In this study, we also observed a large difference in the CPB flow rate between the two groups during surgery. The reason for the decrease in the Bf-TBRP group compared with the RCP group maybe the blockage of the inferior vena cava reflux tube. During RCP, blood flow enters the inferior vena cava through the communicating branches. When the inferior vena cava reflux tube is not blocked (during RCP), the shunted blood flow easily returns to the blood reservoir. During this time, the resistance is small and the shunt volume is large, so that flow is increased. When the inferior vena cava reflux tube is blocked (during Bf-TBRP), the shunted blood flow cannot return to the blood reservoir and creates a higher pressure in the inferior vena cava, so the shunted blood flow is less than the RCP. Therefore, despite the greater RCP flow, there was also ineffective perfusion via the communicating branch - inferior vena cava - storage tank.

Several limitations of the data merit discussion. First, it should be noted that this study is a retrospective comparative analysis conducted solely at a single center, which may introduce potential biases due to its nonrandomized design. Consequently, it is recommended that future clinical investigations employ multi-center data to corroborate or challenge our findings. Moreover, as Bf-TBRP is a newly introduced technique, the patient population is still small, which restricted the number of patients we could recruit. Our capacity to identify significant differences between groups and the robustness of the evidence may have been hampered by the relatively small sample size and the uneven group allocation. In addition, this study only focused on short-term outcomes, which may have missed long-term adverse events. Prolonged follow-up periods are needed in future investigation to evaluate the durability of the findings. Lastly, the Bf-TBRP technique was initially developed under MHCA, so whether the safety and efficacy of this technique still remain under other temperature settings warrants further exploration.

Conclusions

The results of the study claimed the safety of Bf-TBRP in patients undergoing hemi-arch replacement under MHCA, and provides new data on this technique of cerebral perfusion that concurrently provides both lower limb and brain perfusion. The short-term clinical efficacy is comparable with RCP. Further research is warranted to evaluate the efficacy of Bf- TBRP compared with traditional cerebral perfusion strategies on both short-term and long-term survival.

Availability of Data and Materials

The datasets generated and analyzed during the current study are not publicly available due to the agreement with the patient but are available from the corresponding author on reasonable request.

Author Contributions

ZQ, JX and JG contributed to the conception and methodology. ZQ, YZ, BW, and HC contributed to the data acquisition, statistical analysis, and visualization. ZQ, YZ, and BW contributed to the main manuscript. JX and JG contributed to supervision and review. 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 to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

The study was approved by the Medical Ethics Committee of West China Hospital, Sichuan University (No. 2018(24)). Written informed consent was signed by all the recruited patients.

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.59958/hsf.7447.

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