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Cerebral protection using deep hypothermic circulatory arrest versus retrograde cerebral perfusion for aortic hemiarch reconstruction

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Abstract

Background: With evolutions in technique, recent data encourage the use of cerebral perfusion during aortic arch repair. However, a randomized data have demonstrated higher rates of neurologic injury according to MRI lesions using antegrade cerebral perfusion during hemiarch reconstruction.

Methods: This was a retrospective review of two institutional aortic center databases to identify adult patients who underwent aortic hemiarch reconstruction for elective aortic aneurysm or acute type A aortic dissection. Patients were stratified according to cerebral protection method: (1) deep hypothermic circulatory arrest (DHCA) group versus (2) DHCA/retrograde cerebral perfusion (RCP) group.

Results: A total of 320 patients and 245 patients underwent hemiarch reconstruction for aortic aneurysm electively and aortic dissection, respectively. In aneurysmal pathology, the DHCA group included 133 patients and the DHCA/RCP group included 187 patients. Operative mortality was 0.8% in the DHCA group and 2.7% in the DHCA/RCP group ($p = 0.41$). Kaplan–Meier survival estimates revealed comparable 2-year survival ($p = 0.14$). In dissection, 43 patients and 202 patients were included in the DHCA group and the DHCA/RCP group, respectively. Operative mortality was equivalent between the two groups (11.6% in the DHCA group and 9.4% in the DHCA/RCP group, $p = 0.58$). Long-term survival was similar at 2 years between the groups ($p = 0.06$). Multivariable analysis showed cerebral perfusion strategy was not associated with the composite outcome of operative mortality and stroke.

George J. Arnaoutakis and Takuya Ogami contributed equally to this study.

The data was presented at AATS aortic symposium on May 13, 2022 in Boston, MA.

Conclusions: In treating both elective and acute ascending aortic pathologies with hemiarch reconstruction, both DHCA alone or in combination with RCP yield comparable results.

KEYWORDS

aortic arch reconstruction, cerebral perfusion, cerebral protection, hemiarch replacement, hypothermic circulatory arrest

1 | INTRODUCTION

Hypothermic circulatory arrest (HCA) emerged to protect the central nervous system during aortic arch reconstruction.[1] Subsequently, various techniques for cerebral perfusion (CP) were introduced to perfuse the brain in antegrade or retrograde fashion during the reconstruction of aortic arch. Antegrade cerebral perfusion (ACP) is performed via right axillary artery, innominate artery, or antegrade via the respective arch vessels. Retrograde cerebral perfusion (RCP) necessitates cannulation in the superior vena cava, and the benefit of perfusion might be smaller than ACP given the nonphysiologic direction of flow.[2] Alternatively, RCP has the theoretical advantage of minimizing manipulation of head vessels required for ACP and removing debris or air from the cerebral circulation. The evidence for CP strategy has been conflicting, but RCP seems comparable to ACP for hemiarch replacement.[3–6] A recent meta-analysis collected 28 studies of hemiarch replacement including 2705 patients with HCA alone and 2817 patients with HCA and RCP.[7] Isolated HCA was associated with a significantly higher rate of mortality and stroke. The optimal choice of CP during aortic arch surgery is yet unknown, specifically during hemiarch replacement which typically requires shorter duration of circulatory arrest. Selection bias between each strategy may exist in a single institutional experience, which may limit the generalizability and preclude granular analysis due to small sample size. The purpose of this study was to compare the short- and long-term outcomes after hemiarch replacement between uniformed CP strategies in each institution across two aortic centers.

2 | MATERIALS AND METHODS

2.1 | Study design

The study was approved by the institutional review board at each institution the University of Pittsburgh Medical Center with waiver of informed consent (IRB number: STUDY18120143). This was a retrospective observational study using two institutional aortic center databases. Definitions and terminology were derived from the Society of Thoracic Surgeons (STS) database. UF recently adopted routine use of isolated deep HCA (DHCA) during hemiarch replacement surgery (DHCA group). All patients are cooled for minimum period of 30 min, to target core temperature <20°C. The core temperature was measured in the bladder. Bispectral electroencephalography is used to confirm cerebral quietude before initiating circulatory arrest. The graft is thoroughly de-aired before resuming cardiopulmonary bypass, and then rewarming is undertaken. UPMC has been using RCP with DHCA uniformly during hemiarch replacement, and the surgical technique was previously reported (DHCA/RCP group).[8] Hemiarch replacement was performed for (1) ascending aortic aneurysm that do not taper distally allowing for a clamped distal and removal of aneurysmal tissue, or (2) aortic dissection unless a patient has evidence of cerebral malperfusion, aortic arch tear, arch aneurysm, circumferential dissection, or known or suspected history of connective tissue disorder. All adult patients undergoing hemiarch replacement from 2014 through 2020 at UF Health (DHCA alone) and from 2011 through 2020 at UPMC were identified. We included the cohort who underwent hemiarch replacement for aortic aneurysm electively or acute type A aortic dissection. Patients who underwent hemiarch reconstruction for other indications were excluded.

2.2 | Outcomes

The primary endpoint was operative mortality or clinical stroke. Operative mortality was either the mortality within 30 days after the operation or in-hospital morality. Stroke was defined as permanent neurologic deficit due to brain injury confirmed by a neurologist and radiographic imaging. Additional endpoints included 2-year mortality, reoperation for bleeding, acute kidney injury defined by the Risk, Injury, Failure, Loss, and End-stage kidney disease (RIFLE) criteria.

2.3 | Statistical analysis

All values are two-sided, and *p*-value of 0.05 or less was considered as statistically significant. We tested continuous variables with Student's *t*-test if normally distributed and Mann–Whitney *U*-test if nonnormally distributed. Normally distributed variables were described as mean ± standard deviation and nonnormally distributed variables as median with interquartile range. The χ^2 test or Fisher's exact test was used for categorical variables. The logistic regression analysis was performed to assess whether CP strategy was associated with the composite outcome of operative mortality and stroke. Variables used in the model included CP, sex, aortic dissection (vs. elective aortic aneurysm), chronic lung disease, cerebrovascular disease, diabetes mellitus, peripheral vascular disease, and redo cardiac surgery. Variables were chosen according to the results of univariate analysis and previous literatures. The Forest plot was used to describe odds ratio. We generated the Kaplan–Meier survival curve. To compare the curves, the Log-rank test was adopted. Subgroup analysis was performed in patients who underwent hemiarch replacement according to aortic pathology including thoracic aortic aneurysm or aortic dissection. All statistical analysis was performed using R version 4.1.3 (R Foundation for Statistical Computing) and the graphical user interface EZR.[9]

3 | RESULTS

3.1 | Elective aortic aneurysm

DHCA group included 133 patients and DHCA/RCP group included 187 patients (Table 1). The mean age was 63.0 years old in the DHCA group and 60.1 years old in the DHCA/RCP group ($p = 0.054$). Patients in the DHCA group were more likely women (69.9% vs. 37.4%, $p < 0.001$), had higher rates of pre-existing diabetes (15.8% vs. 7%, $p = 0.02$) and chronic lung disease (24.1% vs. 15.0%, $p = 0.04$), and more likely to be undergoing a reoperative sternotomy (20.5% vs. 8.0%, $p < 0.002$). The DHCA/RCP group had higher burden of peripheral vascular disease (35.3% vs. 13.8%, $p < 0.001$). The median ejection fraction was similar (58% in both groups, $p = 1$). Central aortic cannulation was the standard cannulation technique in both groups using the modified Seldinger technique (Table 2). Concomitant valvular operations were equally performed between the two groups. The median nadir temperature was lower in the DHCA group (16.5°C vs. 20.5°C in the DHCA/RCP group, $p < 0.001$). While median CPB time was equivalent between groups, median myocardial ischemia time (120 vs. 138 min, $p < 0.001$) and circulatory arrest time were shorter in the DHCA group (9 vs. 15 min, $p < 0.001$). Operative mortality was 0.8% in the DHCA group versus 2.7% in the DHCA/RCP group ($p = 0.41$) (Table 3). The stroke rate was also similar between groups (3.8% in the DHCA group and 3.7% in the DHCA/RCP group, $p = 0.7$). Prolonged ventilation and intensive care unit length of stay were longer in the DHCA group while other outcomes were equivalent between the groups. The Kaplan–Meier long-term survival estimates revealed similar expected mortality ($p = 0.14$) (Figure 1).

3.2 | Acute type A aortic dissection

DHCA group and DHCA/RCP group included 43 and 187 patients, respectively (Table 4). Female gender and white race were more common in the DHCA group. Cerebrovascular disease was observed more frequently in the DHCA group (25.0% vs. 12.4% in the DHCA/RCP group, $p = 0.049$) while other comorbidities were equally seen between the two groups. Similar to elective aneurysm cases, central aortic cannulation was the main cannulation strategy in both groups (Table 5). Aortic valve replacement was required in 34.9% of the DHCA group and 21.3% of the DHCA/RCP group ($p = 0.07$). Coronary artery bypass was similarly performed in two groups (11.6% in the DHCA group vs. 13.4% in the DHCA/RCP group, $p = 1$). Median CPB time was significantly longer in the DHCA group (197 vs. 174 min, $p = 0.02$) whereas myocardial ischemia time and circulatory arrest time were similar between the two groups. Operative mortality was 11.6% in the DHCA group and 9.4% in the DHCA/RCP group, $p = 0.58$) (Table 6). There was no significant difference in the stroke rate between groups. Other postoperative outcomes were also equivocal except for prolonged ventilation and the intensive care unit

TABLE 1 Preoperative characteristics between DHCA group and DHCA/RCP group in elective aneurysm

Variable	DHCA (*N* = 133)	DHCA/RCP (*N* = 187)	*p* Value
Age (years, mean ± SD)	63.0 ± 13.8	60.1 ± 13.1	0.054
Sex: Women (%)	93 (69.9)	70 (37.4)	<0.001
Race: White (%)	123 (93.9)	181 (96.8)	0.27
Body mass index (kg/m^2, median [IQR])	28.7 [25.5, 32.3]	29.1 [24.7, 32.9]	0.90
Comorbidities (%)			
Diabetes mellitus	21 (15.8)	13 (7.0)	0.02
Chronic lung disease	32 (24.1)	28 (15.0)	0.04
Peripheral vascular disease	18 (13.8)	66 (35.3)	<0.001
Cerebrovascular disease	20 (15.2)	21 (11.2)	0.31
Previous myocardial infarction	12 (9.0)	21 (11.2)	0.58
Preoperative creatinine (mg/dl, median [IQR])	0.99 [0.84, 1.13]	0.9 [0.8, 1.1]	0.07
Ejection fraction (%, median [IQR])	58.0 [53.0, 60.0]	58.0 [55.0, 60.0]	1
Redo cardiac surgery (%)	27 (20.5)	15 (8.0)	0.002

Abbreviations: DHCA, deep hypothermic circulatory arrest; IQR, interquartile range; RCP, retrograde cerebral perfusion.

TABLE 2 Intraoperative data between DHCA group and DHCA/RCP group in elective aneurysm

Variable	DHCA (N = 133)	DHCA/ RCP (N = 187)	p Value
Concomitant operations (%)			
Aortic valve replacement	74 (55.6)	113 (60.4)	0.42
Mitral valve replacement	3 (2.3)	3 (1.6)	0.7
Double valve	2 (1.5)	2 (1.1)	1
Coronary artery bypass grafting	22 (16.5)	35 (18.7)	0.66
Central aortic cannulation (%)	127 (100)	178 (99.4)	1
CPB time (min, median [IQR])	177.0 [157.0, 220.0]	189.0 [161.5, 229.0]	0.14
Myocardial ischemia time (min, median [IQR])	120.0 [90.0, 156.0]	138.0 [106.5, 181.5]	0.001
Circulatory arrest time (min, median [IQR])	9.0 [7.0, 12.0]	15.0 [12.0, 20.0]	<0.001
Nadir body temperature (°C, median [IQR])	16.5 [14.6, 18.2]	20.5 [19.4, 21.7]	<0.001

Abbreviations: CBP, cardiopulmonary bypass; DHCA, deep hypothermic circulatory arrest; IQR, interquartile range; RCP, retrograde cerebral perfusion.

TABLE 3 Perioperative outcomes between DHCA group and DHCA/RCP group in elective aneurysm

Variable (%)	DHCA (N = 133)	DHCA/ RCP (N = 187)	p Value
Operative mortality	1 (0.8)	5 (2.7)	0.41
ICU length of stay (days, median [IQR])	3.7 [2.7, 5.7]	1.3 [1.0, 2.2]	<0.001
Sepsis	3 (2.3)	1 (0.5)	0.31
Stroke	5 (3.8)	7 (3.7)	1
Prolonged ventilation (>24 h)	25 (18.8)	13 (7.0)	0.002
Renal failure	4 (3.0)	7 (3.7)	1
Reexploration for bleeding	3 (2.3)	9 (4.8)	0.37
Blood product transfusion	38 (28.6)	46 (24.6)	0.44

Abbreviations: DHCA, deep hypothermic circulatory arrest; ICU, intensive care unit; IQR, interquartile range; RCP, retrograde cerebral perfusion.

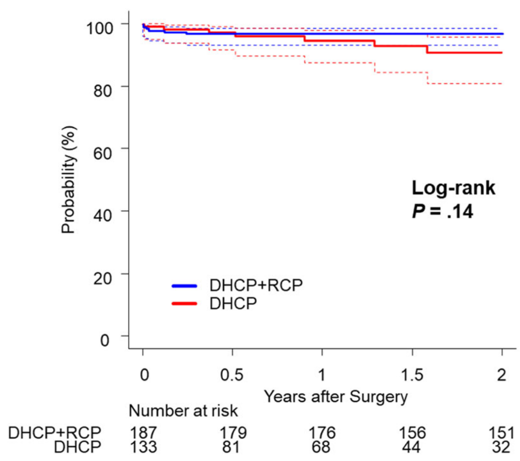

FIGURE 1 Long-term estimated survival curve after hemiarch replacement with deep hypothermic circulatory arrest in elective aortic aneurysm. The survival probability was plotted against years after surgery (solid lines). The 95% confidence interval was also demonstrated (dotted lines). The number of patients at risk is shown at the bottom. DHCP, deep hypothermic circulatory arrest; RCP, retrograde cerebral perfusion.

length of stay. The mortality was equivalent between the two groups at 2 years ($p = 0.06$) (Figure 2).

3.3 | Multivariable analysis for operative mortality and stroke

The logistic regression analysis revealed that CP strategy was not associated with the composite outcome of operative mortality and stroke (odds ratio [OR]: 1.11, 95% confidence interval [CI]: 0.51–2.41, $p = 0.79$) (Figure 3). Aortic dissection (vs. elective aortic aneurysm) was the only independent factor associated with the worse outcome (OR: 2.83, 95% CI: 1.48–5.41, $p = 0.002$).

4 | DISCUSSION

The present study examined patients undergoing hemiarch replacement at two aortic centers and compared outcomes between those with and without RCP during DHCA. The main points are summarized as the following. First, the operative mortality and postoperative

TABLE 4 Preoperative characteristics between DHCA group and DHCA/RCP group in acute type A aortic dissection

Variable	DHCA (*N* = 43)	DHCA/ RCP (*N* = 202)	*p* Value
Age (years, mean ± SD)	61.6 ± 14.1	62.8 ± 13.6	0.61
Sex: Women (%)	30 (69.8)	96 (47.5)	0.01
Race: White (%)	27 (64.3)	169 (83.7)	0.01
Body mass index (kg/m^2, median [IQR])	28.1 [24.9, 33.1]	29.1 [25.7, 34.3]	0.34
Comorbidities (%)			
Diabetes mellitus	5 (12.5)	25 (12.4)	1
Chronic dialysis use	0 (0)	4 (2.0)	1
Chronic lung disease	10 (23.3)	41 (20.3)	0.68
Peripheral vascular disease	16 (39.0)	60 (29.7)	0.27
Cerebrovascular disease	10 (25.0)	25 (12.4)	0.049
Previous myocardial infarction	7 (18.4)	41 (20.3)	1
Preoperative creatinine (mg/dl, median [IQR])	1.03 [0.86, 1.33]	1.0 [0.9, 1.3]	0.84
Ejection fraction (%, median [IQR])	55.0 [54.5, 56.0]	55.0 [51.0, 60.0]	0.63
Redo cardiac surgery (%)	7 (17.9)	26 (12.9)	0.45

Abbreviations: DHCA, deep hypothermic circulatory arrest; IQR, interquartile range; RCP, retrograde cerebral perfusion.

TABLE 5 Intraoperative data between DHCA group and DHCA/RCP group in acute type A aortic dissection

Variable	DHCA (*N* = 43)	DHCA/ RCP (*N* = 202)	*p* Value
Concomitant operations (%)			
Aortic valve replacement	15 (34.9)	43 (21.3)	0.07
Coronary artery bypass grafting	5 (11.6)	27 (13.4)	1
Central aortic cannulation (%)	35 (92.1)	177 (89.4)	0.78
CPB time (min, median [IQR])	197.0 [161.5, 257.0]	174.0 [146.0, 207.8]	0.02
Myocardial ischemia time (min, median [IQR])	119.0 [91.0, 173.0]	111.0 [90.0, 137.0]	0.38
Circulatory arrest time (min, median [IQR])	27.0 [18.5, 32.5]	25.0 [20.0, 30.0]	0.99
Nadir body temperature (°C, median [IQR])	15.7 [14.2, 17.5]	21.0 [19.9, 22.8]	<0.001

Abbreviations: CBP, cardiopulmonary bypass; DHCA, deep hypothermic circulatory arrest; IQR, interquartile range; RCP, retrograde cerebral perfusion.

stroke rate were comparable between those CP strategies in elective aortic aneurysm and acute type A aortic dissection. Second, there was no significant difference in long-term prognosis. Third, aortic dissection was independently associated with the composite outcome of operative mortality and stroke.

The mortality and stroke rates in the present study were reasonably low compared to prior reports. Previous studies showed the mortality after hemiarch replacement ranged from 3.1% to 11.7%.[8,10–14] The stroke rate has been reported as 0.9%–9.3% in their series. A retrospective study investigated 440 patients including 315 (71.6%) aortic aneurysm and 91 (20.7%) acute dissection who underwent hemiarch replacement to compare outcomes between ACP (82%) and RCP (18%) using propensity-score matched cohorts. They reported the overall operative mortality of 3.4% and the clinical stroke rate of 3.0%.[12] A Dutch study included 289 patients who underwent hemiarch replacement.[13] In-hospital mortality was 11.4%, and the rate of permanent neurologic dysfunction was 9.3%. While many studies included heterogenous cerebral protection strategies

TABLE 6 Perioperative outcomes between DHCA group and DHCA/RCP group in acute type A aortic dissection

Variable (%)	DHCA (N = 43)	DHCA/ RCP (N = 202)	p Value
Operative mortality	5 (11.6)	19 (9.4)	0.58
ICU length of stay (days, median [IQR])	6.0 [3.6, 13.1]	2.6 [1.5, 6.0]	<0.001
Sepsis	1 (2.3)	5 (2.5)	1
Stroke	4 (9.3)	7 (3.5)	0.11
Prolonged ventilation (>24 h)	22 (51.2)	67 (33.2)	0.04
Renal failure	8 (18.6)	28 (13.9)	0.48
Reexploration for bleeding	0 (0)	9 (4.5)	0.37
Blood product transfusion	25 (58.1)	102 (50.5)	0.4

Abbreviations: DHCA, deep hypothermic circulatory arrest; ICU, intensive care unit; IQR, interquartile range; RCP, retrograde cerebral perfusion.

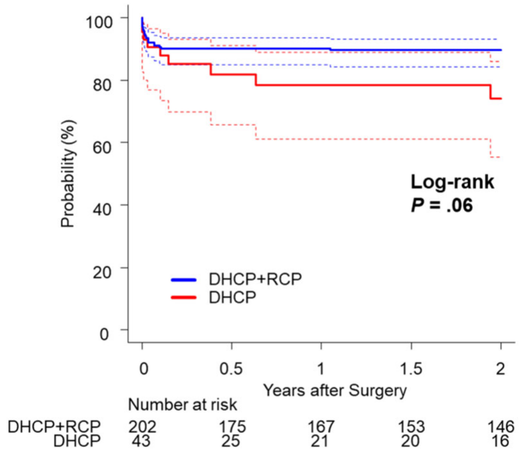

FIGURE 2 Long-term estimated survival curve after hemiarch replacement with deep hypothermic circulatory arrest in aortic dissection. The survival probability was plotted against years after surgery (solid lines). The 95% confidence interval was also demonstrated (dotted lines). The number of patients at risk is shown at the bottom. DHCP, deep hypothermic circulatory arrest; RCP, retrograde cerebral perfusion.

for strategic comparisons, they also had heterogeneous aortic pathologies including aneurysm and dissection. We performed analyses between major aortic pathologies, elective aortic aneurysm, and acute type A aortic dissection, because the variety of reported outcomes in the literature is partly due to heterogeneous populations. The relatively large sample size in the current study enabled such a separated analysis. The higher, though not statistically significant, stroke rate observed in the DHCA group for aortic dissection only may influenced by the higher preoperative rates of cerebrovascular disease in the DHCA group.

An STS database study examined 7830 patients who underwent aortic arch replacement with circulatory arrest excluding aortic

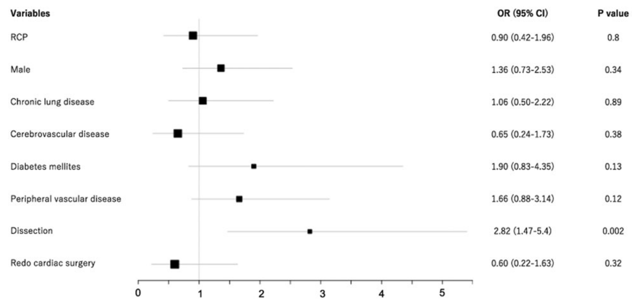

FIGURE 3 Multivariable analysis for the composite outcome of operative mortality and stroke. The odds ratio was plotted with the 95% confidence interval (solid lines) using Forest plot. The dotted line shows the odds ratio of 1. RCP, retrograde cerebral perfusion.

dissection from 2014 through 2016.[15] Ascending or hemiarch replacement was performed in 6891. The operative mortality and the stroke rate were 6.5% and 5.4%, respectively. In contrast, another STS database study investigated 6387 counterparts for type A aortic dissection and demonstrated much worse outcomes with mortality of 16.5% and a stroke rate of 12.7%.[16] While heterogenous inclusion of aortic pathologies with more emergency nature of aortic dissection may have impact on operative mortality and stroke rate in most aortic arch reconstructions, it may not be true for hemiarch replacement in experienced centers.[8,11]

The optimal CP strategies during aortic arch reconstruction have been debated, and still continue to be investigated. The above propensity-score matched cohort study revealed the similar outcomes between ACP and RCP during hemiarch replacement.[12] However, ACP requires manipulation of arch vessels which may be unnecessarily extra maneuvers for hemiarch replacement. Currently, there are few prospective randomized trials comparing CP strategies, and the Deep Hypothermia and Retrograde Cerebral Perfusion Against Moderate Hypothermia and Antegrade Cerebral Perfusion for Aortic Arch Surgery (DRAMA) study specifically examined outcomes for hemiarch replacement.[10] Whereas clinical stroke was similarly observed between ACP and RCP, the authors revealed higher incidence of silent cerebral embolic events with ACP (100% vs. 45% with RCP, $p < 0.01$), and supported potential superiority of RCP during hemiarch replacement. Among the cohort of the aforementioned STS database study, including patients with aneurysm, 2390 (34.7%) patients did not receive any CP while antegrade or retrograde perfusion was performed in 2721 (39.5%) and 1780 (25.8%), respectively.[15] They found better operative mortality or stroke rate with DHCA with ACP or RCP, or moderate HCA with ACP compared to those without. Importantly, their protective effect of CPs became significant in patients with 20 or more minutes duration of circulatory arrest. The STS database study of type A dissection included 1819 patients without CP and 1305 patients with RCP.[16] While they showed significantly better operative mortality or stroke rate in arch replacement with RCP than those without CP overall, there was no difference in the outcomes between CP strategies in a shorter period of circulation arrest. They suggested that isolated HCA less than 20 min might be safe during hemiarch replacement for aortic dissection. The

German Registry for Acute Aortic Dissection Type A (GERAADA) study examined type A aortic dissections in the German Registry involving 44 institutions in German-speaking countries. Of 1558 patients, isolated HCA was instituted in 22.8%, and CP was used for the rest.[17] They found similar mortality and permanent neurological dysfunction between isolated HCA and HCA with CP as long as circulatory arrest time is less than 30 min. There was no significant difference between operative mortality or stroke rate between CP strategies in the present study possibly because median circulatory arrest times were less than 10 min in the isolated DHCA group. In our analyses of each aortic pathology, these outcome equivalence between cerebral protection strategies persisted. Additionally, this study also showed similar long-term survival between the CP strategies. In an experienced aortic center, it seems reasonable to pursue hemiarch replacement with deep hypothermia and without any CP to achieve good clinical outcomes if a short period of circulatory arrest is planned.

Circulatory arrest time was significantly shorter in patients who underwent isolated DHCA for aortic aneurysm in this study. Before initiating DHCA, emphasis on extensive dissection and mobilization of the proximal transverse arch facilitates an expeditious hemiarch anastomosis. There were low rates of re-exploration for bleeding seen in this study, reinforcing the notion that these reconstructions can be performed expeditiously yet without sacrificing hemostasis. Even using a felt sandwich technique for acute dissection repair at UF Health, DHCA times can remain relatively brief. While longer circulatory arrest time is a well-known factor associated with poorer outcomes after aortic arch surgery in general, the outcomes were similar between the groups in the current study.[15,16] The safe duration of circulatory arrest has been investigated in animal and human studies.[18,19] The cerebral metabolic rate decreases to 16%–25% of baseline at 15–20°C with DHCA, and 20–30 min is the proposed safe duration for DHCA without CP according to the International Aortic Arch Surgery Study Group (IAASSG).[20] Evidence showed an increased rate of complications after 20–40 min of circulatory arrest without CP.[21–23] Additionally, studies that utilized CP still demonstrated worse outcomes with a longer duration of circulatory arrest time, as shown in the above STS database study.[15] The GERAADA study also found doubling of 30-day mortality with ACP after 60 min of use.[17] Despite CP, the protection may not be enough especially with RCP. Another potential reason is the ischemia of lower body while brain circulation is maintained by CP. A porcine study showed more than 60% of pigs developed spinal cord injuries after 90 min of selective CP during HCA and 100% of those experienced paraplegia after 120 min.[24] Alternatively, longer circulatory arrest time can be a surrogate of surgical complexity. Acknowledging these facts, it is not unexpected that the outcomes were similar between the groups in the present study as the median circulatory arrest time was shorter than the harmful turning points.

There are several limitations in the present study. First, the follow-up duration was shorter in the isolated DHCA group, which may impact Kaplan–Meier survival estimates curves. Second, institutional differences might have an impact on outcomes such as prolonged ventilation and length of stay in the intensive care unit which might be affected by the institutional policy or protocol. However, the routine use of each different cerebral protection strategy mitigated selection bias within each institution which is frequently seen in a single-institutional study. Additionally, comparison using a larger sample size reduced the concern of underpower. Nevertheless, this study was retrospective, and unavoidable bias may exist.

5 | CONCLUSION

Both DHCA alone or in combination with RCP yielded comparable results in treating both elective and acute ascending aortic pathologies. While circulatory arrest duration is a consideration, these findings affirm the safety of these cerebral protection strategies in aortic hemiarch reconstruction.

AUTHOR CONTRIBUTIONS

George J. Arnaoutakis: Design, data interpretation, drafting article, approval of article. **Takuya Ogami**: Data interpretation, statistics, drafting article, approval of article. **Christopher M. Bobba**: Data interpretation, critical revision of article, approval of article. **Derek Serna-Gallegos**: Data interpretation, critical revision of article, approval of article. **James A. Brown**: Data interpretation, critical revision of article, approval of article. **Eric I. Jeng**: Data interpretation, critical revision of article, approval of article. **Tomas D. Martin**: Data interpretation, critical revision of article, approval of article. **Thomas M. Beaver**: Data interpretation, critical revision of article, approval of article. **Sarah Yousef**: Data interpretation, critical revision of article, approval of article. **Forozan Navid**: Data interpretation, critical revision of article, approval of article. **Ibrahim Sultan**: Design, data interpretation, critical revision of article, approval of article.

CONFLICTS OF INTEREST

G. J. A. receives consulting fees for Terumo Aortic. I. S. receives institutional research support from Abbott, Atricure, cryolife, and Medtronic. None related to this manuscript. The remaining authors declare no conflict of interest.

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