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ORIGINAL ARTICLE

Risk-adjusted and case-matched comparative study between antegrade and retrograde cerebral perfusion during aortic arch surgery: based on the Japan Adult Cardiovascular Surgery Database

The Japan Cardiovascular Surgery Database Organization

**Akihiko Usui, MD, PhD · Hiroaki Miyata, PhD
Yuichi Ueda, MD · Noboru Motomura, MD, PhD
Shinichi Takamoto, MD**

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Abstract
Purpose. Antegrade cerebral perfusion (ACP) and retrograde cerebral perfusion (RCP) are two major types of brain protection for aortic arch surgery. A large-scale clinical study of RCP and ACP is important to clarify the respective characteristics for major adverse events. We conducted a comparative study to evaluate up-to-date clinical outcomes in Japan based on the Japan Adult Cardiovascular Surgery Database (JACVSD).
Methods. The subjects were confined to cases undergone electively with ACP or RCP for nondissection aneurysms in the ascending aorta and aortic arch between 2005 and 2008 from 13 467 aortic surgeries. There were 2209 ACP cases and 583 RCP cases. A risk-adjusted comparison based on 30-day mortality, operative mortality, and major morbidity was assessed by a multivariable logistic regression analysis. A conditional logistic regression analysis was also conducted in 499 propensity matched-pairs with ACP and RCP.
Results. A risk-adjusted analysis showed no significant differences between the ACP and RCP groups regarding 30-day mortality (3.5% vs. 2.6%), operative mortality (5.3% vs. 4.1%), or stroke (6.8% vs. 3.1%). Propensity-matched pairs also revealed no significant differences between ACP and RCP regarding 30-day mortality (3.4% vs. 2.4%), operative mortality (3.8% vs. 3.4%), or stroke rate (5.0% vs. 3.0%); however, RCP resulted in a significantly higher rate of transient neurological dysfunction (3.0% vs. 5.8%) and need for dialysis (1.6% vs. 4.2%).
Conclusion. Both RCP and ACP provide comparable clinical outcomes regarding both the mortality and stroke rates. RCP resulted in a higher incidence only in patients demonstrating transient neurological dysfunction and the need for dialysis.

Key words Brain protection · Aortic surgery · Stroke · Mortality · Database

A. Usui (✉) · H. Miyata · Y. Ueda · N. Motomura · S. Takamoto
Department of Cardiac Surgery, Nagoya University Graduate School of Medicine, 65 Tsurumai, Showa-ku, Nagoya, Aichi 466-8550, Japan
Tel. +81-52-744-2376; Fax +81-52-744-2383
e-mail: ausui@med.nagoya-u.ac.jp

Introduction

The optimal type of brain protection remains controversial for aortic arch surgery. There are two major brain protection methods that are generally utilized. One is antegrade cerebral perfusion (ACP), which maintains cerebral circulation by a low-flow volume of cold blood perfusion via two or three arch branches with separate cannulas under moderate or deep hypothermia. The other is retrograde cerebral perfusion (RCP), which is an alternate method of brain protection during deep hypothermic circulation arrest by perfusing a small volume of blood flow via the superior vena cava retrogradely.[1,2] Both ACP and RCP have advantages and drawbacks; therefore, surgeons should select the most appropriate modality according to the respective characteristics of these methods.

There have so far been a few prospective randomized clinical trials and numerous retrospective clinical studies to compare ACP and RCP.[3–5] They indicated either no obvious differences between the methods or a slight superiority of ACP; however, these data have not been updated, and their evidence level remains weak. Large-scale randomized prospective clinical studies are a reliable method to clarify the superiority of each type of brain protection, but a comparative clinical study utilizing a large database is also important to achieve a higher evidence level and to obtain up-to-date clinical outcomes. We used the Japan Adult Cardiovascular Surgery Database (JACVSD), which currently contains the clinical data from nearly half of all hospitals at Japanese institutions performing cardiovascular surgery. It is similar to The Society of Thoracic Surgeons National Adults Cardiac Database, and we thus conducted a large-scale comparative clinical study based on recent cases.[6] Although there were certain limitations in interpreting and evaluating results, the present study is considered to be the first clinical comparison of RCP and ACP using a large-volume database. This attempt should provide updated clinical outcomes, certain helpful information regarding the recent selection criteria of brain protection for aortic arch surgery, and thereby improve the quality control in the treatment of such cases.

Methods

Study population

The JACVSD started in 2000 to estimate the surgical outcomes after cardiovascular procedures in many centers throughout Japan. The database currently captures clinical information from nearly half of the hospitals of all Japanese units performing cardiovascular surgery. The data collection form has a total of 255 variables (definitions are available online at http://www.jacvsd.umin.jp), and they are almost identical to those in the STS National Database (definitions are available online at http://sts.org). JACVSD developed a software program for a web-based data collection system, and through this system the data manager of each participating hospital was responsible for forwarding their data electronically to the central office. Although participation in the JACVSD is voluntary, the completion of such data is normally given high priority. The accuracy of the submitted data was maintained by a data audit, which was achieved by random, monthly visits by administrative office members to a participating hospital when the data were checked against clinical records. The validity of JACVSD data has been further confirmed by an independent comparison of the volume of cardiac surgery at a particular hospital entered in the JACVSD versus that reported to the Japanese Association for Thoracic Surgery Registry.[7]

We examined 13 467 thoracic aortic surgery procedures between January 1, 2005 and December 31, 2008. Clinical outcomes of thoracic aortic surgery are affected by various factors, especially aneurysm type, range of replacement, and emergency status. We therefore excluded patients with a ruptured aneurysm, Stanford A/B dissection, surgical status of urgent/emergent/salvage, and range of replacement descending/thoracoabdominal/abdominal. We also excluded procedures performed at low-volume centers, defined as those in which the average annual thoracic aortic surgery volume was fewer than five procedures. The subjects analyzed in the present study were confined to those with nondissection aneurysms of the ascending aorta and aortic arch who underwent aortic arch surgery electively via a median sternotomy in large-volume centers. The subjects comprised 4642 cases; and another 3075 patients were treated while under brain protection. There were 2209 patients with ACP, 583 with RCP, 266 with hypothermic circulatory arrest (HCA), and 17 who were subjected to other methods.

The JACVSD has no exclusion criteria regarding patient selection. All adult patients, including those in emergency situations, are therefore considered to be candidates for JACVSD. In addition, any JACVSD records that had been obtained without the patients' informed consent were excluded from this analysis. Records with missing (or out of range) age, sex, or 30-day status were also excluded. With the exception of the body surface area, all missing or out-of-range values were imputed using the sex-specific median value; these cases comprised only 3.1% of all cases. After this data cleaning, the population for this risk model analyses resulted in 2792 instances of thoracic aortic surgery (2209 ACP, 583 RCP) from 143 participating sites throughout Japan (Fig. 1).

Endpoints

The primary outcomes measured from the JACVSD were the 30-day mortality rate and the operative mortality rate. The 30-day mortality included death within 30 days of operation even though the patient was discharged from the hospital within 30 days of operation. Operative mortality meant that any patient who died within the index hospitalization, regardless of the length of hospital stay, and including any patient who died after being

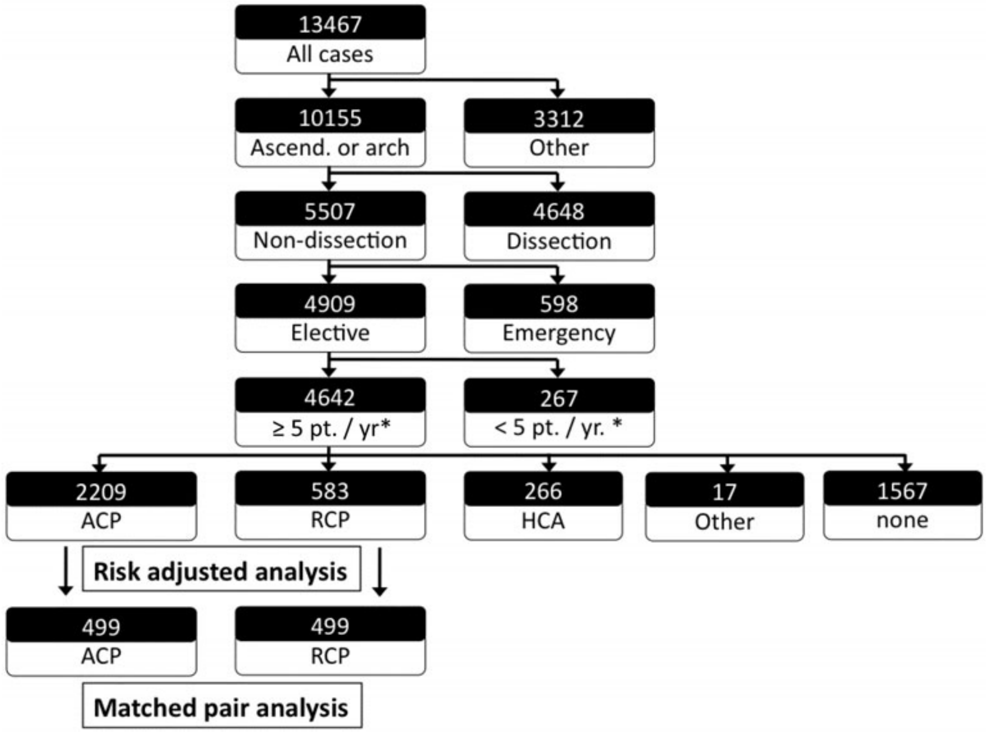

Fig. 1 Patient selection. *Ascend.*, ascending; *ACP*, antegrade cerebral perfusion; *RCP*, retrograde cerebral perfusion; *HCA*, hypothermic circulatory arrest. *Average annual thoracic aortic surgery volume

discharged from hospital up to 30 days from the date of the operation. Hospital-to-hospital transfer was not considered discharge.[8]

In a previous study,[9] major morbidity was defined as the following five postoperative in-hospital complications: stroke that was a new neurological dysfunction and continuing for >72 h; reoperation for any reason; need for mechanical ventilation for more than 24 h after surgery; renal failure requiring dialysis; a deep sternal wound infection. In this study we also use transient neurological dysfunction, continuous coma over 24 h, and paraparesis/paraplegia as neurological complications of thoracic aortic surgery. Transient neurological dysfunction included any neurological dysfunction that recovered completely within 72 h, including transient ischemic attack, reversible ischemic neurological deficit, or delirium, regardless of the radiological findings.

Statistical analysis

We compared the baseline demographics for patients who underwent RCP surgery with those who had ACP surgery. Differences between the two types of brain protection were determined using the χ^2 test for categorical variables and the *t*-test for continuous variables. The trends in RCP surgery over time were determined using logistic regression analysis, whereby the independent variable was the type of brain protection and the dependent variable was the month of surgery.

The unadjusted effects of RCP at 30 days and the operative mortality and five major postoperative morbidities were assessed using logistic regression analysis. For risk-adjusted comparisons, a multivariable logistic regression model was used to determine the effect of RCP. The preoperative risk factors described in Table 1 (hospital thoracic aortic surgery volume, time trends, and range of replacement), which were shown as predictors for mortality and morbidity in JACVSD thoracic aorta risk models,[6] were listed as dependent variables, and mortality or morbidity was established as an independent variable according to a logistic regression analysis.

The second method of adjustment involved matching patients with similar probability of undergoing RCP surgery. Because the patients were not randomly assigned to receive RCP, we used propensity score matching to adjust for differences in baseline characteristics.[10] We performed a one-to-one matched analysis without replacement on the basis of the estimated propensity score, calculated from 37 variables mainly collected from the preoperative and operative factors of each patient (Table 1). The log odds of the probability that a patient received a RCP (the “logit”) was modeled as a function of the confounders that we identified and included in our data set. Using the estimated logits, we first randomly selected a patient in the group undergoing RCP and then matched that patient with a patient in the group receiving ACP with the closest estimated logit value. Patients

Table 1 Variables for propensity matching analysis

Variable	*P*	Odds ratio	95% CI	
			Low	High
Time trend	0.1042	0.9328	0.8577	1.0145
Age	0.0107	0.9037	0.8362	0.9767
Sex	0.8772	1.0249	0.7506	1.3993
Smoking	0.0410	0.7867	0.6250	0.9903
Diabetes	0.0578	1.3900	0.9891	1.9533
Renal failure	0.1832	0.7178	0.4406	1.1696
Dialysis	0.3066	0.6123	0.2391	1.5681
Hyperlipidemia	0.7550	1.0372	0.8247	1.3044
Hypertension	0.0677	0.7945	0.6207	1.0169
Cerebrovascular accident	0.1824	0.3422	0.0707	1.6552
Endocarditis	0.2709	2.0373	0.5739	7.2324
COPD (moderate, severe)	0.0249	1.7574	1.0737	2.8765
extracardiac disease, peripheral	0.0127	1.4980	1.0900	2.0588
Neurological dysfunction	0.4434	0.7743	0.4025	1.4893
Marfan syndrome	0.0443	0.3841	0.1511	0.9759
Aortic stenting	0.2459	0.3593	0.0638	2.0246
Myocardial infarction	0.1315	1.5167	0.8827	2.6059
Congestive heart failure	0.2019	1.3272	0.8593	2.0499
Unstable angina	0.9949	1.0038	0.3107	3.2431
Shock	0.9996	0.0000	0.0000	–
Cardiopulmonary resuscitation	0.9991	0.0000	0.0000	–
Arrhythmia	0.6028	0.9049	0.6212	1.3184
NYHA class IV	0.4337	0.4814	0.0772	3.0016
Preoperative inotropic agents	0.0073	3.9837	1.4512	10.9356
Triple-vessel disease	0.0339	1.6946	1.0409	2.7588
Left main disease	0.2663	0.6874	0.3549	1.3312
LV function (poor)	0.9619	0.9740	0.3308	2.8681
Aortic valve stenosis	0.0003	1.8764	1.3362	2.6352
Tricuspid valve insufficiency	0.6819	0.5749	0.0407	8.1145
Reoperation	0.2803	1.2422	0.8379	1.8414
CABG surgery	0.2321	1.1993	0.8902	1.6159
Valve surgery	0.0110	1.5117	1.0992	2.0790
BMI >30 kg/m^2	0.2352	0.6733	0.3504	1.2937
BSA >1.5	0.8635	1.0069	0.9310	1.0890
Range of replacement				
Root	0.4516	1.1542	0.7945	1.6766
Ascending	0.6171	1.0643	0.8336	1.3590
Arch	0.0000	0.2100	0.1627	0.2710

CI, confidence interval: COPD, chronic obstructive pulmonary disease; NYHA, New York Heart Association; LV, left ventricular; CABG, coronary bypass graft; BMI, body mass index; BSA, body surface area

in the group undergoing RCP who had an estimated logit within 0.6 SD of the selected patients in the group receiving ACP were eligible for matching. We selected 0.6 SD because this value has been shown to eliminate approximately 90% of the bias in observed confounders[11] (C-statistic of the propensity model is 0.778 ± 0.011). Differences in clinical variables were tested using the χ^2 test for categorical variables and the *t*-test for continuous variables. A conditional logistic regression analysis was used to determine the overall effect of RCP surgery in these matched-pairs groups.

Table 2 Baseline patient characteristics

Variable	Antegrade cerebral perfusion		Retrograde cerebral perfusion		*P*
	No.	%	No.	%	
Patients	2209		583		
Sex (male)	1642	74	393	67	0.001
Smoking	1229	56	254	44	0.000
BMI >30 kg/m^2	78	4	14	2	0.193
Diabetes	317	14	84	14	1.000
Renal failure	187	8	30	5	0.009
Dialysis	43	2	8	1	0.392
Cerebrovascular accident	342	15	64	11	0.007
COPD (moderate, severe)	100	5	25	4	0.824
Extracardiac disease, peripheral	285	13	67	11	0.364
Neurological dysfunction	76	3	13	2	0.147
Myocardial infarction	75	3	26	4	0.261
Congestive heart failure	83	4	60	10	0.000
Arrhythmia	175	8	59	10	0.093
NYHA class IV	9	0	2	0	1.000
Preoperative inotropic agents	11	0	11	2	0.002
Left main disease	71	3	17	3	0.791
LV function (bad)	14	1	7	1	0.176
Reoperation	146	7	49	8	0.143
CABG surgery	404	18	109	19	0.857
Range of replacement					
root	140	6	99	17	0.000
Ascending	854	39	358	61	0.000
Arch	1843	83	237	41	0.000
Age (years), mean (SD)	70.4 (9.9)		66.9 (11.4)		0.000
BSA, mean (SD)	1.63 (0.18)		1.62 (0.18)		0.100

We also examined the effect of RCP on prespecified high-risk subgroups, including elderly patients (≥65 and <65 years old), range of replacement (ascending, arch), and operating time including the cross-clamp time and perfusion time.

Results

Patient characteristics

There were 2209 patients who underwent ACP and 583 patients who had RCP. Patient characteristics of the two groups are shown in Table 2. The RCP group showed a

Table 3 Risk-adjusted analysis

Parameter	Antegrade cerebral perfusion		Retrograde cerebral perfusion		Odds ratio (95% CI)	*P*
Patients	No. 2209	%	No. 583	%		
30-day mortality	77	3.5	15	2.6	0.63 (0.25–1.58)	0.324
Operative mortality	118	5.3	24	4.1	0.74 (0.37–1.49)	0.401
Morbidity						
Stroke	151	6.8	18	3.1	0.61 (0.29–1.28)	0.189
Transient	100	4.5	29	5.0	1.45 (0.91–2.32)	0.123
Continuous coma ≥24 h	62	2.8	7	1.2	0.99 (0.99–1.00)	0.563
Paraparesis/paraplegia	58	2.6	16	2.7	0.96 (0.41–2.28)	0.934
Prolonged ventilation	404	18.3	83	14.2	1.00 (0.67–1.50)	0.996
Reoperation for any reason	204	9.2	45	7.7	0.98 (0.59–1.65)	0.948
Renal failure dialysis required	74	3.3	26	4.5	2.51 (1.04–6.03)	0.040
Deep sternal infection	45	2.0	16	2.7	1.12 (0.39–3.24)	0.837
ICU stay ≥8 days	323	14.6	68	11.7	1.03 (0.99–1.09)	0.838

ICU, intensive care unit

significant lower male ratio, smoking rate, renal failure rate, and cerebrovascular accident rate compared to the ACP group. On the other hand, the RCP group was younger and showed a higher rate of congestive heart failure and the use of preoperative inotropic agents than did the ACP group. Replacement in the RCP group occurred at a higher frequency in the aortic root and ascending aorta than in ACP group and at a lower frequency in the aortic arch.

Risk-adjusted analysis

The 30-day and operative mortality rates were 3.5% and 5.3%, respectively, for ACP patients and 2.6% and 4.1%, respectively, for RCP patients; no significant differences were observed between the groups according to a risk-adjusted analysis. The stroke rate was 6.8% in the ACP group and 3.1% in the RCP group. The RCP group had a rather lower stroke rate, but the difference was not significant. The rates of prolonged ventilation, reoperation, deep sternal infection, and paraparesis/paraplegia also showed no significant differences between the groups. Only the rate of renal failure that required dialysis was higher in the RCP group (4.5%) than in the ACP group (3.3%) with significance ($P = 0.04$). (Table 3).

Propensity-matched pairs

Based on the above results, we evaluated 499 ACP patients and 499 RCP patients using case-matching with the propensity score. There were no significant differences in the various preoperative factors even regarding the range of replacement (Table 4). There were no significant differences between the two groups regarding

Table 4 Patient characteristics by propensity-matched pairs

Variable	Antegrade cerebral perfusion		Retrograde cerebral perfusion		*P*
Patients	No. 499	%	No. 499	%	
Sex (male)	333	67	334	67	1.000
Smoking	228	46	219	44	0.611
BMI >30 kg/m^2	11	2	13	3	0.837
Diabetes	73	15	68	14	0.716
Renal failure	24	5	27	5	0.774
Dialysis	6	1	7	1	1.000
Cerebrovascular accident	57	11	57	11	1.000
COPD (moderate, severe)	25	5	22	4	0.765
Extracardiac disease peripheral	70	14	62	12	0.513
Neurological dysfunction	12	2	13	3	1.000
Myocardial infarction	23	5	22	4	1.000
Congestive heart failure	45	9	41	8	0.735
Arrhythmia	51	10	48	10	0.832
NYHA class IV	0	0	1	0	1.000
Preoperative inotropic agents	7	1	4	1	0.547
Left main disease	11	2	15	3	0.522
LV function (bad)	4	1	5	1	1.000
Reoperation	41	8	38	8	0.815
CABG surgery	89	18	89	18	1.000
Range of replacement					
Root	75	15	73	15	0.929
Ascending	285	57	286	57	1.000
Arch	235	47	235	47	1.000
Age (years), mean (SD)	67.8 (12.2)		67.5 (11.3)		0.723
BSA, mean (SD)	1.61 (0.19)		1.62 (0.18)		0.383

Table 5 Outcomes of propensity-matched analysis

Variable	Antegrade cerebral perfusion		Retrograde cerebral perfusion		Odds ratio (95%CI)	*P*
Patients	No. 499	%	No. 499	%		
30-Day mortality	17	3.4	12	2.4	0.75 (0.35–1.59)	0.454
Operative mortality	19	3.8	17	3.4	0.96 (0.48–1.87)	0.894
Morbidity						
Stroke	25	5.0	15	3.0	0.62 (0.32–1.21)	0.164
Transient	15	3.0	29	5.8	2.11 (1.11–4.02)	0.022
Continuous coma ≥24 h	9	1.8	5	1.0	0.74 (0.24–2.27)	0.598
Paraparesis/paraplegia	14	2.8	15	3.0	1.09 (0.52–2.30)	0.811
Prolonged ventilation	83	16.6	69	13.8	0.89 (0.62–1.27)	0.541
Reoperation for any reason	50	10.0	35	7.0	0.69 (0.39–1.23)	0.219
Renal failure dialysis required	8	1.6	21	4.2	2.87 (1.25–6.60)	0.013
Deep sternal infection	8	1.6	10	2.0	1.23 (0.48–3.15)	0.569
ICU stay ≥8 days	52	10.4	56	11.2	1.13 (0.75–1.69)	0.551

30-day mortality (ACP 3.4% vs. RCP 2.4%) and operative mortality (ACP 3.8% vs. RCP 3.4%). The rate of neurological complications was interesting. The RCP group showed a somewhat lower stroke rate but without a significant difference (ACP 5.0% vs. RCP 3.0%); however, a significantly higher rate of transient neurological dysfunction was observed (ACP 3.0% vs. RCP 5.8%). The presence of continuous coma and paraparesis/paraplegia showed no significant differences between the groups. The rate of renal failure requiring dialysis was also significantly higher in the RCP group than in the ACP group (ACP 1.6% vs. RCP 4.2%).

Other types of morbidity included prolonged ventilation, reoperation, and deep sternal infection, but no significant differences were observed between the groups. The rate of a long ICU stay (>8 days) was also similar for the two groups (Table 5).

Discussion

Generally, the most utilized major brain protection methods are ACP and RCP. Each method has advantages and disadvantages. RCP requires no additional cannulas or clamps on the aortic arch branches, which might cause arterial damage or embolic stroke, and no additional extracorporeal circuits such as those used in ACP. However, RCP has the drawback of a limited safe duration. Ueda and coworkers reported RCP to be a useful adjunct for aortic arch surgery with up 80 min of HCA, although prolonged RCP is a risk factor for mortality and morbidity.[12] Generally, RCP should not exceed 60 min when flow is insufficient because it is nonphysiological perfusion.[13] The RCP duration has been reported to be associated with the incidence of stroke, as well as with transient neurological dysfunction.[14] There is some correlation between the severity of transient neurological dysfunction and the duration of RCP.[3]

On the other hand, ACP provides reliable cerebral circulation, but it requires additional cannulas on the arch branches, which increases the chance of embolic stroke, and additional pump circuits, which clutter the operative field. ACP can provide better and more uniform brain protection than can RCP for a long period of time. Di Eusanio and colleagues demonstrated that ACP of >90 min is not associated with an increased risk of mortality or a negative neurological outcome.[15] Therefore, the most important advantage of ACP is the fact that it has no time restrictions, even for complicated aortic arch reconstruction. However, ACP is associated with an increasing risk of embolic stroke.[16] Cannulation or clamping of the arch branches increases the chance of embolism of arteriosclerotic debris or air. An uneven distribution of the intracranial blood flow is associated with selective cannulation , which may cause local brain damage.

There have been a few randomized comparative studies and many retrospective ones between RCP and ACP.[17] Okita and colleagues evaluated 60 consecutive total arch replacements allocated randomly to RCP or ACP and concluded that both RCP and ACP resulted in acceptable levels of mortality and morbidity, but the prevalence of transient brain dysfunction was significantly higher in RCP.[3] Hagl and associates retrospectively analyzed the outcomes in 717 survivors of ascending and aortic arch surgery and determined that the method of brain protection did not influence the outcome of stroke; however, ACP did result in a significant reduction in the incidence of transient neurological dysfunction.[4] Barnard and coworkers searched 408 papers on RCP and ACP and showed ACP to be superior as an adjunct to HCA when compared to RCP or HCA alone, but their clinical evidence was weak.[5]

The surgical outcomes after aortic surgery are strongly affected by an emergency state including aortic rupture or acute aortic dissection. The range of aneurysms, including those of the aortic root, ascending, aortic arch, descending, or thoracoabdominal aorta, is also a strong predictor for mortality and morbidity. The 2006 annual survey of thoracic and cardiovascular surgery in Japan revealed the 30-day mortality to be 10.9% for acute and 4.4% for chronic Stanford type A dissection, and it was 4.5% for unruptured nondissection aneurysm and 19.4% for the ruptured type.[7] The 30-day mortality was also different depending on the replaced site. It was 2.6% in the ascending aorta, 4.5% in the ascending and arch, 11.0% in the arch and descending aorta, 4.5% in the descending aorta, and 9.0% in the thoracoabdominal aorta, respectively, in unruptured nondissection aneurysms. Therefore, we excluded dissection, rupture, and urgent/emergent/salvage status. The range of replacement was also limited to within the ascending aorta and aortic arch, excluding the descending/thoracoabdominal/abdominal aorta. The surgical outcomes may be affected by the clinical experience of the surgeons, and so we excluded any procedures performed at low-volume centers where the annual thoracic aortic surgery volumes were fewer than five procedures.

The results of this study were simple. No significant differences were detected between the groups regarding mortality, including 30-day mortality and operative mortality. No postoperative in-hospital complications showed any significant differences, except for transient neurological dysfunction and renal failure. It is interesting to note that RCP was associated with either an identical or somewhat lower stroke rate but a significantly higher rate of transient neurological dysfunction in comparison to ACP. These results are consistent with those of previous reports in regard to the fact that RCP results in an increased incidence of transient neurological dysfunction. Transient neurological dysfunction may be caused by brain ischemia during RCP. RCP is a nonphysiological type of perfusion that provides only a limited protective effect for the brain. Therefore, prolonged RCP may cause neurological dysfunction. A significant difference was observed only in the propensity-matched analysis, which synchronized each factor but showed no significant differences in the risk-adjusted analysis by using logistic regression analysis.

As a result, all surgeons know of the disadvantages and limitations of RCP. They should therefore carefully select the patients based on the appropriate indications and thus should use RCP only on a case-by-case basis.

It was also an interesting finding that RCP is more often (than ACP) associated with renal failure that requires dialysis, whereas RCP had a lower rate of preoperative renal failure. The incidence of postoperative renal failure is thought to be related to the length of lower body ischemia. ACP may supply a limited blood flow even for the lower body via collateral circulation, whereas RCP cannot provide any blood flow to the lower body. It is a new and important finding that RCP may increase the risk of postoperative renal failure.

Circulatory arrest is another brain protection modality for aortic arch surgery. There were 266 patients with deep hypothermic circulatory arrest in this study. The 30-day and operative mortality rates for these patients were 3.0% and 4.9%, respectively. The postoperative complication rate of stroke, transient neurological dysfunction, continuous coma, paraparesis/paraplegia, and renal failure requiring dialysis were 6.0%, 2.6%, 2.6%, 3.0%, and 3.8%, respectively. No significant differences were observed between RCP and hypothermic circulatory arrest using the χ^2 test (Table 3). This comparison was not a risk-adjusted analysis; however, hypothermic circulatory arrest was also found to provide comparable clinical outcomes, including mortality and neurological dysfunction.

Limitations

There were several limitations in the present study in regard to data interpretation. It was a retrospective clinical study based on a large-scale database, and it provides weaker clinical evidence than does a randomized prospective study. The selection criteria for type of brain protection varies at each institution depending on institutional strategies or each surgeon's preference. Surgical strategy for aortic arch surgery also tends to differ at each institution.

The duration of RCP or ACP was not evaluated because these factors were not described in the JACVSD database. It is a major limitation of this study but cannot be addressed. Although there were no significant effects of RCP on operative mortality regarding the cross-clamp time [odds ratio (OR): <120 min, 1.71, $P = 0.361$; ≥120 min, 0.71, $P = 0.44$), perfusion time (OR: <200 min, 0.73, $P = 0.652$; ≥200 min, 1.138, $P = 0.745$); or operating time (OR: <400 min, 0.732, $P = 0.621$; ≥400 min, 1.335, $P = 0.487$), there may be a tendency for RCP to be used less frequently than ACP for complex arch reconstruction. However, it is most important that the brain protection method be selected on a case-by-case basis in consideration of aortic anatomy, aortic disease, or co-morbidities.

Conclusion

The present study is the first clinical study based on a large-scale database. The findings indicated that both RCP and ACP provide excellent and comparable clinical outcomes, including mortality and stroke rates. RCP resulted only in a higher incidence of transient neurological dysfunction and renal failure that required dialysis. As ACP and RCP have their own advantages and drawbacks, surgeons should select the most appropriate modality according to the respective characteristics of the methods and of the patients.

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