Repair of ascending and transverse aortic arch

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Objectives: This is a report to update our experience with repairs of the ascending and transverse arch, with an emphasis on the protective measures, including retrograde cerebral perfusion and blood flow and neurologic monitoring.

Methods: Retrospective data were collected from January 1991 to February 2010, and analysis was conducted on 1193 patients who had aneurysms involving the ascending aorta and arch.

Results: The 30-day mortality rate was 9.3%, but with a normal glomerular filtration rate, the mortality rate was 3%. In univariate analysis of the risk factors for death, the factors were advancing age of greater than 72 years (mortality, 14.8%; $P = .002$), the presence of coronary artery disease (mortality, 13.5%; $P = .02$), aortic pathology of acute dissection (mortality, 13.9%; $P = .004$), the emergency nature of the operation (mortality, 16.1%; $P = .0001$), and renal function in the lowest 3 quartiles of glomerular filtration rate (mortality, 6.9%, 10%, and 18.3%; $P = .03$, .0005, and .0001, respectively, with decreasing glomerular filtration rate). The highest quartile for pump time (>179 minutes) had a mortality rate of 18.1% ($P = .0001$). The overall stroke rate was 3%. In univariate analysis of risk factors for stroke, the stroke rate was 2.8% with and 4.2% without retrograde cerebral perfusion ($P = .30$), but when circulatory arrest time exceeded 40 minutes, the stroke rate was 1.7% with and 30% without retrograde cerebral perfusion ($P = .002$). Risk factors included age greater than 62 years (stroke rate, 4%; $P = .04$), hypertension (stroke rate, 3.7%; $P = .03$), emergency operations (stroke rate, 4.9%; $P = .04$), and glomerular filtration rate of less than 56 (stroke rate, 4.3%; $P = .05$). In multiple logistic regression for risk factors for stroke, age was associated with an odds ratio of 1.04 ($P = .008$), and emergency conditions had an odds ratio of 2.17 ($P = .03$).

Conclusions: Retrograde cerebral perfusion was associated with a trend toward a reduced incidence of hospital mortality and, in patients receiving prolonged hypothermic circulatory arrest, a reduced incidence of stroke. (J Thorac Cardiovasc Surg 2011;142:630-3)

The optimal strategy for cerebral protection during ascending and transverse aortic arch repair remains undetermined. Since the study by Griep and colleagues¹ reporting the initial use of profound hypothermic circulatory arrest for transverse arch repairs, 2 cerebral protective approaches have emerged: retrograde cerebral perfusion (RCP) and antegrade cerebral perfusion (ACP). Ueda and associates² first reported RCP used in conjunction with profound hypothermic circulatory arrest during ascending and transverse arch repairs. Reported advantages of RCP were flushing out of atheromatous debris, uniform cerebral cooling, ease of use, and potential nutritive support.²⁻⁴ ACP, which is used by the majority of groups, claimed improved neurologic outcomes during arch repair.⁵ It was suggested that provid-

ing ACP would allow for a longer duration of cerebral protection because of the improved ability to provide direct nutritive flow and oxygen to cerebral tissues.⁶⁻¹² The difficulty in assessing the efficacy of these approaches, however, has been related to the varying cannulation strategies, differing monitoring approaches, and use of combinations of techniques.

We adopted the use of RCP as the main method of cerebral protection in 1993 following animal and clinical results.^{13,14} Since that time, we have reported good results regarding neurologic outcome during ascending and arch repairs.³ This report updates our experience with RCP with repairs of the ascending and transverse arch aorta.

MATERIALS AND METHODS

Patients

Based on data collection between January 1991 and February 2010, our group repaired 1290 aneurysms involving the ascending aorta and arch. Complete data were available on 1193 cases, and these comprised our study sample. The median age of the patient was 65 years and ranged from ages 16 to 93 years. The cases included 754 (63%) male and 439 (37%) female subjects. The mortality rate of the study sample (112/1193 [9.3%]) was not different from that of the excluded population (15/97 [15.4%]), indicating that the sample analyzed is representative of the census ($P = .07$).

Stroke was defined as any gross focal neurologic brain injury, either temporary or permanent, as identified on neurologic examination by a neurology consultant and confirmed with computed tomographic scanning or magnetic resonance imaging. Emergency/urgent cases included rupture,

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Abbreviations and Acronyms

ACP = antegrade cerebral perfusion

GFR = glomerular filtration rate

RCP = retrograde cerebral perfusion

acute dissection, and symptomatic aneurysms related to infection or fistulas.

Technique

Our methods for repairing ascending and arch aneurysms have been described previously.¹⁵⁻¹⁷ We use cardiopulmonary bypass, profound hypothermia, circulatory arrest, and RCP. We monitor cerebral function with infrared spectroscopy or power mode transcranial Doppler scanning to confirm the presence of cerebral circulation. A 10-lead electroencephalogram is used to monitor brain function. The patient is cooled until the electroencephalogram is isoelectric. This usually coincides with a nasopharyngeal temperature of between 20°C and 15°C. Once that temperature is achieved and the pupils are fixed and dilated, cardiopulmonary bypass is discontinued and circulatory arrest is established. RCP through the superior vena caval cannula is initiated. The flow rate varies based on the information obtained from the power mode transcranial Doppler ultrasound and bilateral infrared spectroscopic analysis. This is to demonstrate the adequacy of RCP, as determined by the presence of reversed flow in the middle cerebral artery. In the past, we found that the high opening pressure required to maintain the flow is usually less than 500 mL/min. We were able to maintain the pressure of the superior vena cava at less than 25 mm Hg.

The arch is generally repaired by resecting the 2 lateral walls and the lesser curvature and replacing it with a Dacron graft. If there is an aneurysm present in the descending or thoracoabdominal aneurysm, then we use the standard elephant trunk technique with a collared graft.¹⁸ The graft is inserted into the descending thoracic aorta at about 10 to 15 cm, and the collar ring is sewn to the thoracic aorta distal to the left subclavian artery. A side hole is made in the graft for reattachment of the cerebral and subclavian vessels. Bleeding points are secured, cerebral perfusion is restarted, and systemic circulation is allowed to flow through the sidearm, which is pre-manufactured and attached to the graft. The patient's head is raised, and the body is rewarmed.

Then we turn our attention to the tubular portion of the ascending aorta, which we excise, and suture our graft above the supracoronary ascending aorta. In cases in which the aortic root is dilated, the root is replaced with a composite valve graft prosthesis. In the event of acute dissection, we reconstruct the aortic root and resuspend the valve and reattach the reconstructed supracoronary ascending aorta to the graft.

Once the distal anastomosis is accomplished, we rewarm the patient's heart to a myocardial septal temperature of 30°C, and then we release the ascending aortic clamp and restore the flow to the coronary circulation. Once the patient's core body temperature is 36°C and they are able to maintain good systemic blood pressure and sinus rhythm, they are weaned from cardiopulmonary bypass.

The Committee for the Protection of Human Subjects at the University of Texas Medical School at Houston approved review of the data collected for this study. Consent was waived for the retrospective analysis.

RESULTS

The 30-day mortality rate was 9.3%, or 112 of 1193, but with a normal glomerular filtration rate (GFR), the mortality rate was 3%. The hospital mortality was 9.1% (109/1193). Table 1 shows the univariate analysis of the risk

TABLE 1. Univariate analysis of mortality risks

Variable	Total (%)	Deaths (%)	OR	95% CI	P value
Total	1193 (100)	112 (9.3)			
Age					
≤55	298 (25.0)	20 (6.7)			
56–64	301 (25.2)	14 (4.7)	0.68	0.34–1.37	.28
65–71	277 (23.2)	31 (11.2)	1.75	0.98–2.86	.06
≥ 72	317 (26.6)	47 (14.8)	2.21	1.34–3.64	.002
Female sex	439 (36.8)	43 (9.8)	1.08	0.72–1.61	.71
Male sex	754 (63.2)	69 (9.2)	1		
HTN	872 (73.1)	77 (8.8)	0.79	0.52–1.21	.27
No HTN	321 (26.9)	35 (10.9)	1		
COPD	248 (20.8)	24 (9.7)	1.04	0.65–1.68	.87
No COPD	945 (79.2)	88 (9.3)	1		
CAD	237 (19.9)	32 (13.5)	1.71	1.01–2.65	.02
No CAD	956 (80.1)	80 (8.4)	1		
Pathology					
Acute dissection	296 (24.8)	41 (13.9)	1.75	1.19–2.56	.004
Chronic dissection	215 (18.0)	17 (7.9)	1.00	0.59–1.69	1.0
Aneurysm	682 (57.2)	54 (7.9)	1		
Emergency	285 (23.9)	46 (16.1)	2.46	1.64–3.67	.0001
Elective	908 (76.1)	66 (7.3)			
GFR					
≤56	279 (23.4)	51 (18.3)	6.09	3.06–2.14	.0001
57–78	310 (25.9)	31 (10.0)	3.33	1.62–6.88	.0005
79–106	304 (25.5)	21 (6.9)	2.30	1.07–4.95	.03
≥107	300 (25.2)	9 (3.0)	1		
Pump time (min)					
Not reported		14			
≤119	299 (25.3)	18 (6.0)	1		
120–146	293 (24.9)	16 (5.5)	0.91	0.47–1.74	.76
147–178	294 (24.9)	21 (7.1)	1.19	0.65–2.18	.58
≥179	293 (24.9)	53 (18.1)	3.01	1.81–5.00	.0001
RCP	1002 (84.0)	87 (8.6)	0.63	0.39–1.01	.055
No RCP	191 (16.0)	25 (13.1)			

OR, Odds ratio; CI, confidence interval; HTN, hypertension; COPD, chronic obstructive pulmonary disease; CAD, coronary artery disease; GFR, glomerular filtration rate; RCP, retrograde cerebral perfusion.

factors for death, which were advancing age of greater than 72 years (mortality, 14.8%; $P = .002$), the presence of coronary artery disease (mortality, 13.5%; $P = .02$), aortic pathology of acute dissection (mortality, 13.9%; $P = .004$), the emergency nature of the operation (mortality, 16.1%; $P = .0001$), and renal function in the lowest 3 quartiles of GFR (mortality, 6.9%, 10%, and 18.3%; $P = .03$, .0005, and .0001, respectively, with decreasing GFR). The highest pump time range (>179 minutes) had a mortality rate of 18.1% ($P = .0001$). The overall stroke rate was 3%.

Table 2 shows the univariate analysis of risk factors for stroke. For all cases, the stroke rate was 2.8% with and 4.2% without RCP ($P = .30$), but for cases in which circulatory arrest time exceeded 40 minutes, the stroke rate was 1.7% with and 30% without RCP ($P = .002$). Risk factors

TABLE 2. Univariate analysis of risk factors for stroke

Variable	Total (%)	Strokes (%)	OR	95% CI	P value
Total	1193 (100)	36 (3.0)			
Age (y)					
≤50	298 (25.0)	3 (1.0)	1		
51–62	301 (25.2)	10 (3.3)	3.38	0.8–19.26	.09
63–71	277 (23.2)	11 (4.0)	4.07	1.06–22.89	.04
≥72	317 (26.6)	12 (3.8)	3.87	1.03–21.54	.04
Female sex	439 (36.8)	14 (3.2)	1.09	0.55–2.17	.86
Male sex	754 (63.2)	22 (2.9)	1		
HTN	872 (73.1)	32 (3.7)	3.02	1.06–8.61	.03
No HTN	321 (26.9)	4 (1.3)	1		
COPD	248 (20.8)	11 (4.4)	1.71	0.83–3.52	.14
No COPD	945 (79.2)	25 (2.7)	1		
CAD	237 (19.9)	8 (3.4)	1.16	0.52–2.57	.67
No CAD	956 (80.1)	28 (2.9)	1		
Pathology					
Acute dissection	296 (24.8)	11 (3.7)	1.21	0.52–2.68	.74
Chronic dissection	215 (18.0)	4 (1.9)	0.60	0.15–1.80	.49
Aneurysm	682 (57.2)	21 (3.1)	1		
Emergency	285 (23.9)	14 (4.9)	2.08	1.05–4.12	.04
Elective	908 (76.1)	22 (2.4)	1		
GFR					
≤56	279 (23.4)	12 (4.3)	3.33	1.06–10.44	.05
57–78	310 (25.9)	12 (3.9)	2.98	0.95–9.34	.08
79–106	304 (25.5)	8 (2.6)	2.00	0.60–6.70	.39
≥107	300 (25.2)	4 (1.3)	1		
Pump time (min)					
Not reported		14			
≤119	299 (25.3)	7 (2.3)	1		
120–146	293 (24.9)	12 (4.1)	1.78	0.69–4.59	.24
147–178	294 (24.9)	6 (2.0)	0.87	0.29–2.62	.80
≥179	293 (24.9)	11 (3.8)	1.63	0.62–4.26	.44
RCP	1002 (84.0)	28 (2.8)	0.66	0.29–1.47	.30
No RCP	191 (16.0)	8 (4.2)			
For circulatory arrest times					
>40 min					
RCP	233 (95.9)	4 (1.7)	0.04	0.01–0.22	.002
No RCP	10 (4.1)	3 (30.0)			

OR, Odds ratio; CI, confidence interval; HTN, hypertension; COPD, chronic obstructive pulmonary disease; CAD, coronary artery disease; GFR, glomerular filtration rate; RCP, retrograde cerebral perfusion.

included age greater than 62 years (stroke rate, 4%; $P = .04$), hypertension (stroke rate, 3.7%; $P = .03$), emergency operations (stroke rate, 4.9%; $P = .04$), and GFR of less than 56 (stroke rate, 4.3%; $P = .05$).

Table 3 shows the multiple logistic regression results in terms of risk factors for stroke. Age was associated with an odds ratio of 1.04 ($P = .008$), and emergency conditions had an odds ratio of 2.17 ($P = .03$).

DISCUSSION

Since the 1970s, the main method for repair of complex ascending and arch aneurysms has been with the use of

TABLE 3. Risk factors for stroke (multiple logistic regression)

Variable	Parameter Estimate	Odds Ratio	95% CI	P value
Intercept	−5.9407			
Age	0.0354	1.04	1.01–1.06	.008
Emergency status	0.7749	2.17	1.09–4.32	.03

CI, Confidence interval.

profound hypothermia and circulatory arrest. In the 1980s, RCP was used as an adjunct to extend the patient's tolerance of cerebral ischemic time. RCP remained controversial because there was no randomized trial to prove its efficacy. In this study we found that RCP protects patients from stroke. Incidentally, we also observed a trend in decreasing mortality with use of RCP ($P = .055$). Because the causes of death were not necessarily related to stroke, the relationship of mortality and RCP remained unclear. In univariate analysis age was a risk factor for stroke if the patient's age was greater than 70 years. The presence of hypertension and the emergency nature of the operation were also significant risks. Pump time was not a significant factor in either univariate or multivariate analysis. At a circulatory arrest time of greater than 40 minutes, we found great benefit in the use of RCP. In multiple logistic regression, as described in Table 3, older age and emergency status were more likely to result in the occurrence of stroke.

In the mid-1980s and 1990s, several methods were devised to extend the tolerance of the brain to ischemia and thus to minimize the risk of stroke. One method is to use ACP, either through axillary cannulation or with direct balloon catheter insertion into the left or right common carotid artery, perfusing in an antegrade fashion. This required monitoring of the right radial artery, keeping the cerebral perfusion pressure at greater than 40 to 60 mm Hg and the flow rate at about $10 \text{ mL} \cdot \text{mg}^{-1} \cdot \text{min}^{-1}$. We used this integrated approach of antegrade and retrograde perfusion and found that there was no difference in pressure using antegrade or retrograde perfusion.¹⁹ We have continued to use cardiopulmonary bypass, profound hypothermia, and circulatory arrest along with RCP.

With the advent of endovascular treatment of various thoracic aneurysms, a hybrid approach was introduced. This uses the ascending aorta for cardiopulmonary bypass and places the ascending aorta from the graft to the brachiocephalic arteries. Alternatively, it uses the proximal portion of the ascending aorta as a graft site and branches into the brachiocephalic artery, followed by insertion of the stent graft in the ascending arch and descending thoracic aorta. The incidence of stroke and mortality has been high in several studies; the potential benefits might be greater in elderly, very high-risk patients, with less benefit for younger low-risk patients compared with open approaches.²⁰ There are others who advocate moderate hypothermia in patients with arch aneurysms with good results.²¹ We think that the

patient should be protected with the use of profound hypothermia with cardiopulmonary bypass to minimize potential neurologic damage.

In summary, we used RCP as described in our technique. We used transcranial Doppler scanning to direct the retrograde perfusion, as well as cerebral oximetry to demonstrate RCP in the cerebral vessels. This has been shown to improve the stroke rate, as well as the mortality rate. Some have stated that RCP is detrimental for increased cerebral edema and hypothermia.⁶ In this study RCP had superior results when adjusting the superior vena caval pressure to less than 25 mm Hg. The rate was 1.7% compared with 4.1% without RCP ($P = .002$), despite a prolonged cerebral ischemia of greater than 40 minutes.

In conclusion, repair of ascending and arch aneurysms can be done with an acceptable mortality rate (especially with elective surgery and normal GFR) and morbidity (stroke rate). RCP was associated with a trend toward a reduced incidence of hospital mortality and, in patients receiving prolonged hypothermic circulatory arrest, a reduced incidence of stroke.

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