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RESEARCH ARTICLE

Neurologic and Renal Outcomes of Elective Proximal Aortic Repair and Current Cannulation Trends

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Abstract

Background: We aimed to determine factors influencing neurologic dysfunction and acute kidney injury (AKI) in patients undergoing elective aortic aneurysm repair and we also investigated them according to cannulation sites.

Methods: From January 2012 to April 2018, 112 patients received proximal aortic repair. We used aortic arch, axillary and femoral artery cannulation. Antegrade cerebral protection and total circulatory arrest were used.

Results: We detected 6 (5.4%) transient and 6 (5.4%) permanent neurologic dysfunction. Peripheral arterial diseases, total bypass time, transfusion and AKI showed correlation with neurologic dysfunction. Peripheral arterial diseases and AKI were independent risk factors ($p < 0.05$). AKI was reported in 38 patients. Postoperative revision, cross-clamp time, total bypass time and total circulatory arrest showed correlation with AKI ($p < 0.05$). Patients with neurologic dysfunction (66%) and patients with AKI (63%) had more femoral cannulation.

Conclusion: Proximal aortic repair can be achieved with low morbidity and mortality using appropriate cerebral protection and cannulation technique. Neurologic dysfunction and AKI are important factors for aortic surgery and femoral cannulation has the highest risk for neurologic dysfunction and AKI.

Keywords

Aortic aneurysm, Neurologic dysfunction, Kidney injury, Cannulation

Introduction

Cerebral protection is a big technical difficulty for aortic surgery. Increased use of antegrade cerebral perfusion (ACP) and deep hypotermic circulatory arrest in experienced hands made open surgery of the ascending aorta and aortic arch aneurysms more successful today. The increase in the variety of surgical equipment to provide unilateral and bilateral cerebral perfusion or monitorization, the effectiveness of the cerebral protection instantly decreased the risk of perioperative stroke or postoperative morbidity and mortality. Despite these improvements, there are many problems which affect patients' prognosis, like arterial cannulation strategies, cross clamp time, cardiopulmonary bypass time and patient related co-morbidity factors [1,2].

Although we know that the best choice for providing arterial perfusion to patients during cardiopulmonary bypass is the antegrade flow via aortic cannulation, we also need another arterial perfusion sites to perform aortic hemiarch and total arch surgery. But flow dynamics in these arterial cannulation sites (axillary and femoral arterial sites), and patient related co-morbidities (variations of the circle of Willis, intracerebral arterial pathologies, abdominal aortic thrombi and peripheral arterial diseases (PAD)), still have the complication risk for brain, kidneys and other organs. Today, stroke rates of the patients are related to prolonged total circulatory arrest (TCA) or incomplete cerebral protection [2]. Multiorgan deficiencies are related to prolonged cardiopulmonary bypass or arterial perfusion which does not provide antegrade flow to these organs and thus leading to deficient organ perfusion, especially on brain and kidneys [2-4]. So, despite increased experience in surgical technique and improved brain protection strategies, there are still problems to be solved.

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In this advanced era of the open aortic aneursym surgery, we wanted to present our single centre experience. So, we retrospectively analyzed our elective aortic root, ascending aorta and aortic hemiarch surgery experiences in concomitant with aortic valve diseases. We investigated them for postoperative outcomes such as neurologic dysfunction and kidney injury relating to arterial cannulation sites.

Materials and Methods

Between January 2012 and April 2018, 112 consecutive patients, who underwent elective aortic root, ascending aorta and aortic hemiarch operations, were retrospectively analyzed. All of the operations were the first cardiac surgery for the patients. The main indications for aortic operations were degenerative aortic aneurysm and aortic valve disease, but mitral valve surgery and coronary artery bypass surgery were added to the procedure in the presence of concomitant diseases. None of the patients had preexisting neurologic injury.

All patients were operated on using midsternal approach. We used aortic arch, axillary artery and femoral artery for arterial cannulation and a venous single two-stage cannula in the right atrium in the majority of the patients. 8-Fr Dacron graft was anastomosed to axillary artery in an end-to-side fashion for axillary cannulation. Appropriate femoral arterial cannula was inserted through retrograde way into common femoral artery using Seldinger technique for femoral cannulation. We did not use femoral artery when the presence of abdominal aortic thrombi or aneurysm on computed tomography. In the TCA cases, patients were profoundly cooled to a core temperature of less than 18 °C and external cooling was performed to the head with ice packing. In the ACP cases, patients were cooled to a core temperature between 22 °C and 25 °C, followed by systemic arrest and declamping of the aorta. ACP was performed through antegrade way. In patients with axillary cannulation, brachiocephalic artery was clamped before removing the aortic clamp and the cerebral perfusion was initiated at a rate of 10 mL/min/kg. In patients with femoral artery cannulations, ACP was performed with a cannula which was inserted through the ostium of the brachiocephalic artery. Bilateral carotid arterial perfusion was performed according to preference of surgeon, but cerebral saturation measurement and arterial pressure was the main indicator to determine the cerebral perfusion method in these patients. Intraoperative cerebral monitoring was achieved by oxygen saturation in the frontal lobes with near-infrared spectroscopy and right radial artery pressure lines. Aortic aneurysms which extend to proximal of the aortic arch, short curvature of the aortic arch was excised and the graft was anastomosed in a hemiarch configuration. Hemiarch reconstruction was achieved using ACP or TCA with a distal open aortic technique. In the majority of the patients, after completing hemiarch anastomosis, arterial cannula was transferred to the graft to provide antegrade perfusion for the rest of the procedure.

Postoperative confusion, agitation, obtundation and delirium were accepted as temporary neurologic dysfunction. Stroke, coma and presence of new brain lesions confirmed by imaging studies (Computed tomography, magnetic resonance imaging) were defined as permanent neurologic dysfunction [5]. AKI was defined using Acute Kidney Injury Network Criteria. These criteria stage kidney injury according to the ratio of postoperative serum creatinin to preoperative level; 1.5 to 2 times: Stage 1, 2 to 3 times: Stage 2, 3 times: Stage 3 [6].

Statistical Analysis

Continuous variables were expressed as mean ± standard deviation and categorical variables as numbers and percentages. Univariate and multivariable logistic regression analyses were performed to determine risk factors of neurologic dysfunction and AKI. Statistical analysis was performed using IBM SPSS Statistics, version 22 (IBM Corp, Armonk, NY).

Results

112 consecutive patients, who underwent elective aortic root, ascending aorta and aortic hemiarch operations, were retrospectively analyzed. There were 68 male patients (60.7%) and 44 female patients (39.3%), with a mean age of 58.3 ± 14 years. 36 patients underwent Bentall operation (composite graft replacement of the aortic valve, aortic root and ascending aorta, with re-implantation of the coronary arteries into the graft), 32 patients underwent ascending aorta replacement and 44 patients underwent ascending aorta and aortic valve replacement. Aortic resection was extended to aortic hemiarch in 38 patients. 8 patients had mitral valve replacement and 7 patients had coronary bypass surgery additionally to main aneurysm surgery. All preoperative data are depicted in Table 1.

Table 1: Demographic data of the patients.

Variable		**N (%)**	**Mean ± SD**
Age			58.3 ± 14
Sex		Male 68 (60.7%)	
		Female 44 (39.3%)	
Diabetes Mellitus		63 (56.3%)	
Hypertension		84 (75%)	
PAD		29 (25.9%)	
COPD		57 (50.9%)	
BMI			27.8 ± 6
BMI	< 25	35 (31.3%)	
	25-30	44 (39.3%)	
	< 30	33 (29.5%)	
EF			55.7 ± 7.6
Preoperative creatinin (mg/dl)			0.9 ± 0.4
Preoperative HGB (g/L)			12.5 ± 3.6

SD: Standard deviation; PAD: Peripheral arterial disease; COPD: Chronic obstructive pulmonary disease; BMI: Body mass index; EF: Echocardiographic ejection fraction; HGB: Hemoglobin.

Table 2: Operative data.

Variable		N (%)	Mean/SD
Cardiac operation	Bentall	36 (32.2%)	
	AVR + AAR	44 (39.3%)	
	AAR	32 (28.5%)	
Aortic distal anastomosis	Ascending aorta	74 (67%)	
	Hemiarch	38 (33%)	
Cannulation	Axillary	20 (17.8%)	
	Arcus	50 (44.6%)	
	Femoral	42 (37.6%)	
CCT (min)			89.2 ± 37.2
TBT (min)			127.2 ± 48.6
ACP/min		26 (23.2%)	20.2 ± 9.4
TCA/min		12 (10.7%)	16.1 ± 7.6

SD: Standard deviation; AVR: Aortic valve replacement; AAR: Ascending aorta replacement; CCT: Cross clamp time; TBT: Total bypass time; ACP: Antegrade cerebral perfusion; TCA: Total circulatory arrest.

Table 3: Postoperative complications.

Variable		N (%)	Mean/SD
Postoperative drainage (ml)			632.1 ± 382.5
RBC Transfusion (u)			1.8 ± 1.5
Inotropic support		66 (58.9%)	
Extubation time (hour)			20.3 ± 15.5
Postoperative creatinin (mg/dl)			1.2 ± 0.7
AKI	Stage I	25 (22.3%)	
	Stage II	12 (10.7%)	
	Stage III	1 (0.9%)	
Dialysis		1 (0.9%)	
TND		6 (5.4%)	
PND		6 (5.4%)	
In-hospital death		9 (8%)	
ICU stay (day)			4.7 ± 3.3
Total hospital stay (day)			11.3 ± 5.6

SD: Standard deviation; RBC: Red blood cell; AKI: Acute kidney injury; TND: Temporary neurologic dysfunction; PND: Permanent neurologic dysfunction; ICU: Intensive care unit.

Table 4: Univariate and multivariate analysis for neurologic dysfunction.

Variable	Univariate					Multivariate				
	OR	% 95 CI			p	OR	% 95 CI			p
Age	1.07	1.01	-	1.13	***0.028***					
Sex	1.33	0.38	-	4.72	0.656					
BMI	0.98	0.88	-	1.08	0.662					
EF	1.00	0.93	-	1.09	0.937					
HT	4.07	0.50	-	33.03	0.189					
DM	1.10	0.33	-	3.70	0.878					
COPD	5.64	1.18	-	27.05	***0.031***					
PAD	12.00	2.97	-	48.44	***0.000***	17.43	3.37	-	90.3	***0.001***
Revision	2.76	1.30	-	5.86	***0.008***					
CCT	1.01	1.00	-	1.03	0.185					
TBT	1.01	1.00	-	1.02	***0.031***					
ACP time	2.69	0.77	-	9.33	0.120					
TCA time	0.74	0.09	-	6.26	0.779					
Drainage	1.00	1.00	-	1.00	0.283					
Inotropic support	> 100	0.00	-	> 100	0.997					
RBC Transfusion	1.67	1.18	-	2.37	***0.004***					
AKI	29.74	3.66	-	241.46	***0.001***	41.41	4.40	-	389.8	***0.001***
Dialysis	4.45	0.37	-	53.20	0.238					
ICU stay	1.20	1.04	-	1.38	***0.014***					
In hospital stay	0.86	0.72	-	1.04	0.119					

Logistic Regression Test: BMI: Body mass index; EF: Ejection fraction; HT: Hypertension; DM: Diabetes mellitus; COPD: Chronic obstructive pulmonary disease; PAD: Peripheral arterial disease; CCT: Cross clamp time; TBT: Total bypass time; ACP: Antegrade cerebral perfusion; TCA: Total circulatory arrest; RBC: Red blood cell; ICU: Intensive care unit.

We used aortic arch cannulation site in 50 patients (44.6%), axillary artery cannulation site in 20 patients (17.8%) and femoral artery cannulation site in 42 patients (37.6%) for the institution of CPB. Cerebral protection was achieved by means of ACP in 26 patients (23.2%). TCA was used in 12 patients (10.7%). Aortic resection was limited to ascending aorta in 74 patients (67%) and it was extended to aortic hemiarch in 38 patients (33%). The mean aortic cross-clamp time and total bypass time were 89.2 ± 37.2 minutes and 127.2 ± 48.6 minutes, respectively. The mean duration of ACP and TCA were 20.2 ± 9.4 minutes and 16.1 ± 7.6 minutes, respectively (Table 2).

The mean postoperative first day drainage was 632.1 ± 385.5 ml. 14 patients needed to early postoperative reoperation (revision) due to bleeding problems. Mean transfused red blood cell was 1.8 ± 1.5 units. 66 (58.9%) patients needed to positive inotropic treatment (Dopamine, dobutamine or adrenaline) on postoperative period due to hypotension or low cardiac output. Mean intensive care unit stay was 4.7 ± 3.3 days and mean in hospital stay was 11.3 ± 5.6 days. Nine patients (8%) died during hospitalization (Table 3).

Neurologic dysfunction

TND and PND was reported in 6 (5.4%) and 6 (5.4%)

patients respectively. At univariate analysis, age (p = 0.028), chronic obstructive pulmonary disease (COPD) (p = 0.031), PAD (p < 0.001), postoperative revision (p = 0.008), total bypass time (p = 0.031), red blood cell transfusion (p = 0.004) and AKI (p = 0.001) showed a statistically significant correlation with neurologic dysfunction. At multivariate analysis, PAD (p = 0.001) and AKI (p = 0.001) showed a significant correlation with neurologic dysfunction (Table 4). We saw that patients with neurologic dysfunction had more femoral cannulation (n = 8, 66%).

Kidney Injury

Acute kidney injury was reported in 38 (33.9%) patients (Stage I n = 25, Stage II n = 12 and Stage III n = 1). 1 patients (0.9%) needed dialysis on postoperative period. At univariate analysis, postoperative revision (p = 0.019), cross clamp time (p = 0.036), total bypass time (p = 0.026), TCA (p = 0.018), postoperative drainage (p = 0.036) and red blood cell transfusion (p = 0.002) showed a significant correlation with AKI. At multivariate analysis, there was no significant correlation with the variables (Table 5). We saw that femoral cannulation site was used more frequently in patients with AKI (n = 24, 63%). Patients who had stage II and III AKI (n = 10, 76%) had more femoral cannulation ratio compared to patients with stage I AKI (n = 14, 56%).

Discussion

Nowadays there is a wide experience in the treatments of ascending aortic aneurysms and aortic valve diseases in many heart surgery centers. Although, highly experienced aortic surgeons are still facing controversies in surgical approaches extending to the aortic arch. One of the most important intraoperative factors affecting the surgical morbidity of these patients is how the cannulation is performed and how the arterial flow is provided and how the cerebral protection is maintained. The strategy of cannulation and the strategy of cerebral protection, which are created as a result of patient-specific approaches in experienced centers, are the leading determinants of postoperative neurological damage, AKI and death [7,8]. In this study, we investigated the postoperative neurological dysfunction, AKI and perioperative factors affecting patients with chronic ascending and aortic arch aneurysms after elective surgery. We also discussed in detail the techniques of cannulation sites used in patients with neurological dysfunction and AKI.

The most important factors that determine the risk of neurological dysfunction in aneurysm surgery are how cerebral protection is achieved and where the cannulation is. Despite the fact that ACP and TCA applied under deep hypothermic circulatory arrest, they are the two most frequently used cerebral protection techniques, the use of TCA in elective aneurysm surgery has decreased over time. TCA largely left its place in unilateral and bilateral ACP applied in deep hypothermia [9]. In this study, we performed aortic hemiarch replacement in 38 patients (33%) and performed cerebral protection (ACP n = 26, 23.3%, TCA n = 12, 10.7%). The use of unilateral and bilateral ASCP technique under deep hypothermic arrest is increasing while our TCA practice to decline over the years. Postoperative TND rate was 5.4% (n = 6) and PND rate was 5.4% (n = 6). In a

Table 5: Univariate and multivariate analysis for AKI.

Variables	Univariate					Multivariate				
	OR	% 95 CI			p	OR	% 95 CI			p
Age	1.03	1.00	-	1.06	0.098					
Sex	1.65	0.72	-	3.76	0.233					
BMI	0.96	0.90	-	1.03	0.237					
EF	0.98	0.93	-	1.03	0.422					
BMI	0.96	0.90	-	1.03	0.237					
HT	2.26	0.83	-	6.16	0.112					
DM	0.94	0.43	-	2.07	0.880					
COPD	1.80	0.81	-	3.99	0.146					
PAD	1.55	0.65	-	3.70	0.327					
Revision	2.04	1.12	-	3.72	***0.019***					
CCT	1.01	1.00	-	1.02	***0.036***					
TBT	1.01	1.00	-	1.02	***0.026***					
ACP time	0.65	0.25	-	1.73	0.391					
TCA time	4.67	1.31	-	16.69	***0.018***					
Drainage	1.00	1.00	-	1.00	***0.036***					
Inotropic support	2.20	0.95	-	5.08	0.064					
RBC Transfusion	1.59	1.19	-	2.13	***0.002***					
Dialysis	> 100	0.00	-	> 100	0.999					
ICU stay	1.15	1.01	-	1.30	***0.034***					
In hospital stay	1.02	0.95	-	1.09	0.540					

Logistic Regression Test: BMI: Body mass index; EF: Ejection fraction; HT: Hypertension; DM: Diabetes mellitus; COPD: Chronic obstructive pulmonary disease; PAD: Peripheral arterial disease; CCT: Cross clamp time; TBT: Total bypass time; ACP: Antegrade cerebral perfusion; TCA: Total circulatory arrest; RBC: Red blood cell; ICU: Intensive care unit.

study conducted by Dhuranlar, et al. [10] involving 837 patients with elective, urgent and emergent ascending and aortic arch aneurysm, the PND was 2.3%. In 501 patient undergoing aortic arch surgery performed by Khaladj, et al. [11], TND was 13.4% and PND was 9.6%. In a study conducted by Cefarelli, et al. [4], in which 563 aortic hemiarch replacements and 44 total arch replacements were performed, the TND and PND ratios were reported as 5.3% and 6.2%, respectively. Compared with these studies with high patient populations, we observed similar neurological dysfunction rates in our elective patients.

In univariate analysis, age, COPD, PAD, postoperative revision, TBT, RBC transfusion and AKI are the most important factors in development neurological dysfunction. In multivariate analysis, PAD presence and postoperative AKI development were found to be an independent risk factor for neurological damage. When the patients with neurological damage were examined in detail regarding the location of the cannulation, it was observed that femoral cannulation was used in 66% of these patients (n = 8). Femoral artery cannulation and retrograde arterial perfusion increase the risk of cerebral emboli and increase the likelihood of having a neurological event. In our study, aortic arch cannulation was performed in 44.6%, axillary artery cannulation in 17.8% and femoral artery cannulation in 37.6% of the patients. Our tendency to perform aortic arch cannulation or axillary artery cannulation as much as possible for the reasons mentioned has increased over the years. We strongly believe that, if possible, arterial perfusion with a cannula positioned at the distal end of the aneurysm or arterial perfusion with axillary arterial side graft anastomosis in aortic hemiarch and aortic arch surgery is the perfusion technique that minimizes the risk of cerebral damage and provides antegrade flow.

One of the other important factors affecting postoperative morbidity and mortality is AKI. In many studies investigating AKI associated with coronary bypass and heart valve surgery, the amount of blood transfusion and duration of cardiopulmonary bypass has been described as the most important factors influencing AKI [12,13]. In a study conducted by Lio, et al. [14] in 96 patients with aortic hemiarch and total aortic arch replacement, the rate of AKI was 22% and postoperative dialysis requirement was 1%. The rate of AKI in the Japanese population who underwent total arch replacement performed by Okita, et al. [15] was 15.4% and the dialysis requirement was 7.7%. In another study evaluating 890 patients who underwent only aortic root replacement, the dialysis requirement was reported as 0.5% [16]. The rate of patients requiring dialysis in our study is 0.9% (n = 1) although the AKI ratio is higher than other studies (Stage I: 22.3%, Stage II: 10.7% and Stage III: 1 0.9%) depending on the method used to describe AKI. Our results seem compatible with other studies. In our study, univariate analysis revealed that as the cross clamp time, total bypass time, TCA, postoperative drainage, revisions, and RBC transfusion increased, AKI development also increased. A direct risk factor for multivariate analysis was not identified (Table 5). These results indicate that AKI is closely related to cardiopulmonary bypass and transfusion same as in other cardiac surgical procedures.

We think that the surgical transfusion volume is influenced by the surgical variables such as the patient's preoperative condition, cardiopulmonary bypass time and postoperative revision need, but we do not think that the only risk factor is perfusion time related to cardiopulmonary bypass [17,18]. We evaluated the effects of axillary artery, ascending aorta, and femoral artery cannulations on the renal and carotid artery flows in a study that we had previously performed to investigate the relationship between organ perfusions and the cannulation sites. We conclude that the renal artery flows in the setting of axillary artery and ascending aorta cannulation is significantly higher than that obtained with femoral cannulation. In the results of this experimental study, there was no significant difference between renal artery flows with axillary and ascending aorta cannulation sites [17]. These results indicate that the failure of antegrade perfusion in addition to the atheroembolic risk associated with retrograde perfusion of femoral cannulation site has also a negative effect on organ perfusion. In our study, we observed that femoral cannulation rate among the AKI patients was 63% (n = 24). In addition, femoral cannulation is associated with development of higher rate of advanced kidney injury in patients with AKI (Stage II and III AKI, n = 10, 76%).

In an experimental study conducted by Gaier, et al. [18], carotid artery perfusions were examined during ECMO perfusion. In the absence of cardiac output, carotid artery flows in the setting of ascending aortic cannulation and femoral artery cannulation were found to be higher than those with axillary artery cannulation. Experimental work by Demertzis, et al. [19] also showed a decrease in carotid flow with axillary artery perfusion, and this decrease was attributed to Venturi effect. We have also found in our experimental study, the flow through the femoral cannulation cannot be transmitted to aortic arch with the increase of cardiac output. We also found that central cannulation and axillary cannulation had positive effects on intraabdominal organ perfusion and femoral cannulation was inadequate for intraabdominal circulation [17]. Gaier, et al. [18] found cerebral perfusion pressure to be at least as effective as the flow rate for cerebral circulation and indicated that the cerebral perfusion pressure was highest with ascending aorta and axillary artery cannulation. In another study, unilateral and bilateral cerebral perfusion were found to have no effect on mortality, but unilateral perfusion was reported to have high risk for neurological dysfunction due to variations of the circle of Willis, thus the bilateral perfusion may be more effective than the unilateral one [20]. These results show that for all organs, antegrade perfusion is necessary both during cardiopulmonary bypass and during cerebral perfusion. The most suitable pathway for cerebral and renal circulation in the light of these data is the ascending aortic cannulation and aortic arch cannulation. For cerebral perfusion, we also believe that unilateral cerebral perfusion with axillary cannulation may be less favorable due to Venturi effect, frequent variations of the circle of Willis and lower perfusion pressures. The insufficiency of this perfusion pressure can be avoided by bilateral perfusion of carotid arteries as far as possible, and our surgical tendency is changing that way over the years. In addition, for aneurysm surgery, regardless of the perfusion problems, we believe that atheroembolism, caused by femoral cannulation, is a very real risk factor and femoral cannulation site should be preferred only with certain exceptions. We conclude that systemic perfusion provided by aortic arch or axillary artery cannulation is the most appropriate route for cerebral and peripheral circulation [4,21,22].

Given the retrospective nature of our study, the possibility of single-centered work and the number of patients has a lower level of evidence than multicenter prospective randomized trials with larger databases. Detection of preoperative cerebral circulation, detection of signs such as intraoperative ACP time and temperature, and inclusion of these results in an evaluable study may give more reliable results on ACP. It also would be better to compare patients who had circulatory arrest and those who didn't. But we could not do it due to low patient population. There is a need for more standardization.

In conclusion, ascending aorta, aortic root, and aortic arch surgery with appropriate surgical technique carry acceptable risk for neurological damage and kidney damage. There is a close relationship between the technique of cannulation and neurological dysfunction and development of AKI. Femoral cannulation adversely affects cerebral perfusion and intraabdominal perfusion, disrupting brain and kidney circulation and increasing mortality and morbidity rates. We conclude that the use of bilateral antegrade cerebral perfusion with axillary artery or aortic arch cannulation for ascending aortic and aortic arch surgery is the surgical technique that minimizes postoperative morbidity and mortality.

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Conflict of Interest

There is no conflict of interest between authors.

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