ORIGINAL ARTICLE

Perioperative and Neurological Complications after Open Thoracic Aortic Surgery in a High-Volume Aortic Surgery Center

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Objective: Thoracic aortic surgery is associated with an increased risk of mortality and complications. The present study aimed to evaluate the incidence of 30-day mortality and perioperative major complications after open thoracic aortic surgery in a high-volume aortic center.

Materials and Methods: The present study was a retrospective analysis and included patients who underwent open thoracic aortic surgery with cardiopulmonary bypass (CPB) between December 2018 and November 2020. Demographics and perioperative data were analyzed. The incidence of 30-day mortality and risk factors of perioperative and neurological complications were determined.

Results: One hundred ninety-five patients were included in the present study. Most were male, at 67.2%, with a mean age of 59.3±14.5 years. The incidence of 30-day mortality was 4.6%, with a 95% confidence interval (CI) 2.5 to 8.5. The major complication characterized by the Clavien-Dindo classification was 40.5%. The multivariable analysis identified aortic arch surgery (adjusted odds ratio (aOR) 2.86, 95% CI 1.11 to 7.33, p=0.029), maximum vasoactive-inotropic (VIS_{max}) score greater than 10 (aOR 2.58, 95% CI 1.01 to 6.64, p=0.049), and VIS_{max} score greater than 20 (aOR 5.54, 95% CI 1.67 to 18.34, p=0.005) as significant risk factors for postoperative major complications. In addition, aortic arch surgery, preoperative neurological complications (aOR 4.01, 95% CI 1.47 to 10.95, p=0.007), cerebral desaturation of greater than 20% reduction of regional cerebral oxygen saturation $rScO_2$ during CPB (aOR 4.60, 95% CI 1.49 to 14.15, p=0.008), and red blood cell transfusions of more than one blood volume (aOR 4.19, 95% CI 1.01 to 17.36, p=0.048) were identified as risk factors for postoperative stroke.

Conclusion: The present study demonstrated a 30-day mortality rate of 4.6% after thoracic aortic surgery. Operations of the aortic arch and VIS_{max} score of greater than 10 are associated with an increased risk of major postoperative complications. Reduction of $rScO_2$ during CPB is strongly associated with postoperative stroke.

Keywords: Aortic aneurysm; Aortic dissection; Thoracic aorta; Surgery; Mortality; Morbidity

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Thoracic aortic surgery is associated with high morbidity and mortality[1-5]. The introduction of endovascular aortic repair has contributed to improving patient outcomes[6,7]. However, certain conditions still require open surgical repair with the use of cardiopulmonary bypass (CPB). The postoperative outcomes are influenced by various factors, including the nature of aortic pathologies, organ dysfunctions during the perioperative period, and the institution's annual surgical case volume[2-4,8]. Studies have demonstrated that centers with higher annual case volumes tend to have lower rates of mortality and complications[4,8]. The aim of the present study was to report the incidence of 30-day mortality following open thoracic aortic repair under CPB from a high-volume aortic center. The secondary aim was to utilize the standard definitions and classifications of postoperative complications for reporting the incidence and associated risk factors of perioperative and neurological complications after surgery.

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Materials and Methods

The present study was a retrospective descriptive study approved by The Institutional Review Board

at Siriraj Hospital (Si. 541/2020). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Patients aged 18 years and older who underwent open thoracic aortic surgery with CPB between December 2018 and November 2020 were included. Patients lost to follow-up were excluded. Demographic, surgical, and perioperative data were retrieved from the hospital's electronic medical records.

Study definitions

The postoperative events were defined according to the Society of Thoracic Surgeons (STS) General Thoracic Surgery Database Data (GTDB) Collection Form version 2.3[9] and the American College of Surgeons (ACS) NSQIP Surgical Risk Calculator[10]. Postoperative morbidity included acute myocardial infarction, atrial or ventricular arrhythmia, cardiac arrest with return of spontaneous circulation (ROSC), stroke, acute paralysis, delirium, pneumonia, reintubation, reoperation, tracheostomy, acute kidney injury, urinary tract infection, surgical site infection, sepsis, limb ischemia, and bowel ischemia. The postoperative complications were later classified using the Clavien-Dindo classification of surgical complications before analysis[11].

The lowest value of regional cerebral oxygen saturation ($rScO_2$) recorded during the preoperative baseline, pre-CPB, and post-CPB periods were identified and used in statistical analysis. Maximum vasoactive-inotropic (VIS_{max}) score[12] was computed [VIS = dopamine dose (μg/kg/minute) + dobutamine (μg/kg/minute) + 100×epinephrine dose (μg/kg/minute) + 50×levosimendan dose (μg/kg/minute) + 10×milrinone dose (μg/kg/minute) + 10,000× vasopressin (units/kg/minute) + 100×norepinephrine dose (μg/kg/minute)], using the maximum dosing rates of vasoactive and inotropic medications (μg/kg/minute or IU/kg/minute) during the first 24 hours of postoperative intensive care unit (ICU) admission[13]. Levosimendan and vasopressin were not available during the study period and were omitted from calculations. The estimated blood volume was calculated by the equation[14] [Average blood volume equal weight (kg) × average blood volume (mL/kg)], using 75 as adult male average blood volume and 65 as adult female.

Statistical analysis

The sample size was calculated based on the previously reported 15% 30-day mortality rate[2,3,15]. With 5% error, a sample of 195 patients was needed. Data were analyzed using IBM SPSS Statistics, version 21.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean and standard deviation or median (minimal, maximum) where appropriated. Categorical variables were presented as numbers and percentages. Univariable analyses of factors related to major complications were performed using the chi-squared and unpaired t-test. Logistic regression analysis was performed to determine the association between major complications and factor variables. The p-value of less than 0.05 was considered statistically significant.

Results

Characteristics of the study cohort

Between December 2018 and November 2020, 202 patients underwent open thoracic surgery with the use of CPB. A total of 195 patients were included in the present study. Demographic data and comorbidities are listed in Table 1. Most of the cohort were male, at 67.2%, with a mean age of 59.3±14.5 years and had normal body mass index (BMI) for 83.6%. About 50% of the patients were diagnosed with thoracic aortic aneurysms (Table 2). Hypertension, in 75%, was the most prevalent coexisting comorbidity, followed by smoking in 32%. Two common surgical sites were the aortic root, ascending or descending aorta in 37.9%, and combined operations in 34.4%. The combined operations group consisted of one of the following, 1) aortic root and total arch replacement, 2) ascending aorta with hemi- or partial or total arch replacement, or 3) Bentall operation with hemi- or partial or total arch replacement. The mean CPB time was 232.0±117.5 minutes with a median deep hypothermic circulatory arrest (DHCA) time of 4 (1 to 57) minutes.

It is important to note that emergency surgical procedures consisted of about 54% of this cohort. Patients who underwent emergency surgeries had a higher incidence of preoperative organ dysfunction at 77% and 25% of them had preoperative neurological complications compared with 8% in the patients who underwent elective surgeries (p=0.04). Myocardial infarction, although present in about 17% of the cohort, did not differ between elective and emergency surgeries at 16% versus 18% (p=0.637). Furthermore, a considerable proportion of patients had life-threatening conditions before surgery as aortic rupture, hypotension, and cardiac tamponade were the leading conditions in this category.

Table 1. Preoperative demographic data

Variables	n=195
Sex; n (%)	
Male	131 (67.2)
Female	64 (32.8)
Age (years); mean±SD	59.3±14.5
Age; n (%)	
<65 years	112 (57.4)
≥65 years	83 (42.6)
Body mass index; n (%)	
18.5 to 24.99 kg/m^2	163 (83.6)
<18.5 or ≥25.0 kg/m^2	32 (16.4)
ASA-PS classification; n (%)	
3	108 (55.4)
4	87 (44.6)
Emergency surgery; n (%)	105 (53.8)
History of comorbidities; n (%)	
Hypertensive disease	148 (75.9)
Smoking	64 (32.8)
Coronary artery disease	54 (27.7)
Previous aortic surgery	33 (16.9)
Chronic kidney disease	32 (16.4)
Diabetes mellitus	29 (14.9)
Congestive heart failure	28 (14.4)
Cerebrovascular disease	17 (8.8)
Chronic obstructive pulmonary disease	12 (6.2)
Preoperative complications; n (%)	
Neurological complications	34 (17.4)
Myocardial infarction	33 (16.9)
Aortic rupture	28 (14.4)
Shock	21(10.8)
Cardiac tamponade	17 (8.7)
Limb ischemia	10 (5.1)
Cardiac arrest	3 (1.5)

ASA-PS=American Society of Anesthesiologists physical status; SD=standard deviation

Table 2. Perioperative data

Variables	n=195
Diagnosis; n (%)	
Aneurysm	102 (52.3)
Dissection	93 (47.7)
Site of operation; n (%)	
Aortic root or ascending or descending aorta	74 (37.9)
Combined operations	67 (34.4)
Aortic arch	38 (19.5)
Thoracoabdominal aorta	16 (8.2)
Anesthetic time (minutes); mean±SD	567.4±203.6
Operative time (minutes); mean±SD	479.7±196.0
Cardiopulmonary bypass time (minutes); mean±SD	232.0±117.5
Aortic cross clamping time (minutes); mean±SD	183.5±92.2
DHCA time (minutes); median (min-max)	4 (1 to 57)
$rScO_2$ monitoring; n (%)	164 (84.1)
$rScO_2$ decreased >20% from baseline; n (%)	
No	64 (39.0)
Yes	
• Prior to cardiopulmonary bypass	10 (6.1)
• During cardiopulmonary bypass	59 (36.0)
• Both	31 (18.9)
Spinal drainage; n (%)	14 (7.2)
Intraoperative PRC transfusion; n (%)	
<1 blood volume	182 (93.3)
≥1 blood volume	13 (6.7)
VIS_{max}; median (min-max)	3.3 (0 to 77.1)
VIS_{max}; n (%)	
0 to 10	148 (75.9)
>10 to 20	27 (13.8)
≥20	20 (10.3)
Re-operation; n (%)	26 (13.3)
ICU re-admission; n (%)	13 (6.67)
Length of ICU stay (hours); median (min-max)	71.2 (13.0 to 4,279.5)
Length of hospital stay (days); median (min-max)	14.0 (2.0 to 182.0)

DHCA=deep hypothermic circulatory arrest; $rScO_2$=regional cerebral oxygenation; PRC=packed red blood cell; VIS_{max}=maximum vasopressor inotrope score; ICU=intensive care unit; SD=standard deviation

Incidence of mortality and predictors of postoperative complications

The incidence of 30-day mortality was 4.6% (95% CI 2.5 to 8.5) in nine patients. The causes of death were neurological complications (3), malperfusion syndrome (2), reperfusion syndrome (1), multiple organ failure (2), and an undefined cause after hospital discharge (1). Out of nine mortality, eight patients underwent ascending aorta and/or aortic arch surgery, and one patient had thoracoabdominal aneurysm repair. Most deaths occurred after emergent surgical procedures in 89% versus 11% (p=0.040). Another two in-hospital deaths on postoperative day 45 and 182 were included, which contributed to the 5.6% (95% CI 3.2 to 9.8) mortality rate of the entire cohort.

The incidence of postoperative complications was 74.9% (95% CI 68.4 to 88.4) with 679 total events. Most patients had between two and four complications, while, interestingly, almost 5% had 10 complications or more (Figure 1). About 62% (421 events) were in Grade I and II (minor), and 38% (258 events) were in Grade III to V (major) (Table 3). Overall, 79 patients (40.5%) experienced major complications as Grade III to V (Figure 2), which resulted in significantly longer median ICU and hospital length-of-stay at 19.0 (2.0 to 182.0) versus 11 (4.0 to 47.0) days (p<0.01) and 172.7

Table 3. Postoperative complications

Complications	n=195; n (%)
Grade I	
Atrial Arrhythmia no treatment	9 (4.6)
Ventricular arrhythmia no treatment	6 (3.1)
Atelectasis	6 (3.1)
Surgical site infection	3 (1.5)
Vocal cord paralysis	3 (1.5)
Pleural effusion	3 (1.5)
Grade II require pharmacological treatment	
Anemia/coagulopathy need transfusion	173 (88.7)
Atrial arrhythmia on antiarrhythmic	89 (45.6)
Pneumonia on antibiotics	38 (19.5)
Acute kidney injury	36 (18.5)
Delirium	32 (16.4)
Urinary tract infection	14 (7.2)
Sepsis	9 (4.6)
Grade III requiring surgical, endoscopic or radiological intervention	
Grade IIIa not under general anesthesia	
• Ventricular fibrillation	33 (16.9)
• Acute paralysis requires spinal drainage	5 (2.6)
• Pleural effusion on (intercostal drainage)	5 (2.6)
• Pneumothorax (intercostal drainage)	1 (0.5)
• Chylothorax	1 (0.5)
• Massive hemothorax	1 (0.5)
• Bradycardia on pacemaker	1 (0.5)
Grade IIIb under general anesthesia	
• Reoperation (not including any bedside operations)	27 (13.8)
Grade IIIb under general anesthesia (continued)	
• Tracheostomy	12 (6.2)
Grade IV: life-threatening complication (including CNS complications)	
Grade IVa: single-organ dysfunction	
• Ischemic stroke	29 (14.9)
• Acute renal failure requires hemodialysis	23 (11.8)
• Seizure	18 (9.2)
• Sepsis with single organ affected	11 (5.6)
• Acute myocardial infarction	10 (5.1)
• Limb ischemia	9 (4.6)
• Congestive heart failure/cardiogenic shock	8 (4.0)
• Respiratory distress requires reintubation	8 (4.1)
• Ischemic bowel	6 (3.1)
• Post-cardiotomy syndrome	4 (2.0)
• Pulmonary embolism	2 (1.0)
• Subdural hematoma	2 (1.0)
• Abdominal compartment syndrome	1 (0.5)
• Liver failure	1 (0.5)
Grade IVb: multiorgan dysfunction	
• Septic shock or sepsis with multiorgan dysfunction	18 (9.2)
• Cardiac arrest with ROSC	6 (3.1)
• Low cardiac output syndrome	3 (1.5)
• Malperfusion syndrome	1 (0.5)
• Reperfusion syndrome	1 (0.5)
Grade V	
Death	11 (5.6)

CNS=central nervous system; ROSC=return of spontaneous circulation

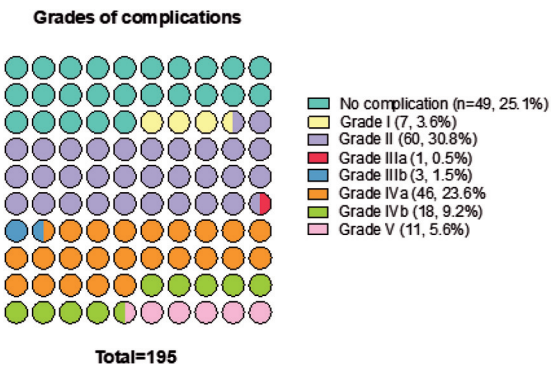

Figure 1. Grade of complications.

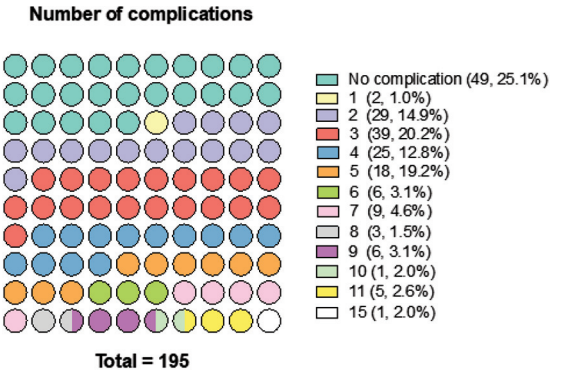

Figure 2. Number of complications.

(19.8 to 4,279.5) versus 43.2 (13.0 to 505.6) days, respectively.

Predictors of major complications from univariable analysis were American Society of Anesthesiologists physical status (ASA-PS) 4, emergency surgery, preoperative neurological complications, ruptured aorta, preoperative hypotension, limb ischemia, surgery at the aortic arch, combined operations, anesthetic time, operative time, CPB time of more than four hours, intraoperative packed red cell transfusions of one blood volume or more, and VIS_{max} score greater than 10 (Table 4, 5). However, only operations of the aortic arch (adjusted OR 2.86, 95% CI 1.11 to 7.33), VIS_{max} score greater

Table 4. Univariate analysis and multivariable logistic regression analysis of demographic factors for major complication

Factors	Major complications; n (%)		Crude OR (95% CI)	p-value[1]	Adjusted OR (95% CI)	p-value[2]
	No (n=116)	Yes (n=79)				
Sex						
Male	78 (67.2)	53 (67.1)	1			
Female	38 (32.8)	26 (32.9)	1.01 (0.59 to 1.85)	0.982		
Age (years)						
<65	65 (56.0)	47 (59.5)	1			
≥65	51 (4.0)	32 (40.5)	0.87 (0.49 to 1.55)	0.632		
Body mass index (kg/m^2)						
18.5 to 24.99	61 (52.6)	40 (50.6)	1			
<18.5 or ≥25	55 (47.4)	39 (49.4)	1.081 (0.61 to 1.92)	0.789		
ASA-PS classification						
3	73 (62.9)	35 (44.3)	1			
4	43 (37.1)	44 (55.7)	2.13 (1.19 to 3.82)	0.011*	1.48 (0.62 to 3.50)	0.374
Emergency	55 (47.4)	50 (63.3)	1.91 (1.07 to 3.43)	0.030*	0.85 (0.36 to 1.98)	0.702
Hypertension	88 (75.9)	60 (75.9)	1.01 (0.52 to 1.96)	0.989		
Smoking	35 (30.2)	29 (36.7)	1.34 (0.73 to 2.46)	0.341		
Coronary artery disease	29 (25.0)	25 (31.6)	1.39 (0.74 to 2.62)	0.309		
Previous aortic surgery	16 (13.8)	17 (21.5)	1.71(0.81 to 3.64)	0.158		
Chronic kidney disease	15 (12.9)	17 (21.5)	1.85(0.86 to 3.96)	0.112		
Diabetes mellitus	21 (18.1)	8 (10.1)	0.51 (0.21 to 1.22)	0.124		
Congestive heart failure	15 (12.9)	13 (16.5)	1.33 (0.59 to 2.96)	0.491		
Cerebrovascular disease	10 (8.6)	7 (8.9)	1.03 (0.37 to 2.83)	0.953		
Chronic obstructive disease	8 (6.9)	4 (5.1)	0.72 (0.21 to 2.48)	0.601		
Preoperative complications						
Neurological complications	15 (12.9)	19 (24.1)	2.13 (1.00 to 4.51)	0.045*	1.10 (0.44 to 2.79)	0.835
Acute myocardial infraction	17 (14.7)	16 (20.3)	1.48 (0.70 to 3.14)	0.306		
Aortic rupture	10 (8.6)	18 (22.8)	3.13 (1.36 to 7.21)	0.006*	1.42 (0.52 to 3.91)	0.492
Shock	6 (5.2)	15 (19.0)	4.30 (1.59 to 11.63)	0.004*	3.38 (1.03 to 11.06)	0.044*
Cardiac tamponade	9 (7.8)	8 (10.1)	1.34 (0.49 to 3.64)	0.565		
Limb ischemia	2 (1.7)	8 (10.1)	6.42 (1.33 to 31.10)	0.009*	4.48 (0.80 to 25.22)	0.089
Cardiac arrest	2 (1.7)	1 (1.3)	0.73 (0.06 to 8.20)	0.799		

ASA-PS=American Society of Anesthesiologists physical status; OR=odds ratio; CI=confidence interval

[1] Univariate analysis, [2] Multiple logistic regression analysis, * $p<0.05$, statistical significance

than 10 (adjusted OR 2.58, 95% CI 1.01 to 6.64), and VIS_{max} score greater than 20 (adjusted OR 5.54, 95% CI 1.67 to 18.34) were significantly associated with increased probability of major complications after multivariable analysis. At the VIS_{max} cut-off value of 10, the area under the receiver operating characteristic (ROC) curve was 0.63, sensitivity of 40%, and specificity of 85%.

Predictors of neurological complications

Postoperative ischemic stroke was the most common Grade IV complication and occurred in about 15% of the present study patient cohort. From univariable analysis, significant risk factors associated with postoperative stroke were diagnosis of aortic dissection, surgery of the aortic arch, preoperative neurological complications, VIS_{max} scores greater than 20, intraoperative packed red blood cell (PRC) transfusions of one or more blood volume, and cerebral desaturation defined as greater than 20% reduction of $rScO_2$ during CPB. However, after adjusting for the effects of other variables, only surgery of preoperative neurological complications (adjusted OR 4.01, 95% CI 1.47 to 10.95, p=0.007), cerebral desaturation with a greater than 20% reduction of $rScO_2$ during CPB (adjusted OR 4.60, 95% CI 1.49 to 14.15, p=0.008), and red blood cell transfusions of one or more blood volume (adjusted OR 4.19, 95% CI 1.01 to 17.36, p=0.048) remained significant risk factors (Table 6).

Table 5. Univariate analysis and multivariable logistic regression analysis of perioperative factors for major complications

Factors	Major complications		Crude OR (95% CI)	p-value[1]	Adjusted OR (95% CI)	p-value[2]
	No (n=116)	Yes (n=79)				
Diagnosis; n (%)						
Aneurysm	66 (56.9)	36 (45.6)	1			
Dissection	50 (43.1)	43 (54.4)	1.58 (0.89 to 2.80)	0.121		
Surgical site; n (%)						
Aortic root/ascending/descending	54 (46.6)	20 (25.3)	1			
Combined#	34 (29.3)	33 (41.8)	2.62 (1.3 to 5.29)	0.007*	2.18 (0.97 to 4.90)	0.059
Aortic arch	20 (17.2)	18 (22.8)	2.43 (1.07 to 5.51)	0.033*	2.86 (1.11 to 7.33)	0.029*
Thoracoabdominal	8 (6.9)	8 (10.1)	2.70 (0.90 to 8.16)	0.078	3.17 (0.88 to 11.47)	0.079
Anesthetic time (minutes); mean±SD	509.7±169.1	652.2±220.7	1.004 (1.002 to 1.006)	<0.01*		
Surgical time (minutes); mean±SD	422.3±157.5	564.0±216.4	1.004 (1.002 to 1.006)	<0.01*		
CPB time (minutes); mean±SD	209.1±96.3	265.7±137.0	1.005 (1.002 to 1.007)	0.002*		
CPB time; n (%)						
≤180 minutes	49 (42.2)	21 (26.6)	1		1	
181 to 240 minutes	34 (29.3)	20 (25.3)	1.373 (0.65 to 2.91)	0.410	1.37 (0.57 to 3.25)	0.072
>240 minutes	33 (28.4)	38 (48.1)	2.69 (1.35 to 5.37)	0.005*	2.14 (0.93 to 4.88)	0.122
Aortic cross clamping time (minutes); mean±SD	172.9±85.1	199.0±100.2	1.003 (1.000 to 1.006)	0.058		
DHCA (minutes); median (min-max)	3.5 (1 to 38)	4.5 (1 to 57)	1.02 (0.98 to 1.07)	0.298		
DHCA technique; n (%)						
Yes	39 (33.6)	37 (46.8)	1.74 (0.97 to 3.13)	0.603		
$rScO_2$ decreased >20%; n (%)						
No	49 (51.0)	22 (32.4)	1			
Yes						
• Before CPB	5 (5.2)	8 (11.8)	4.78 (1.12 to 20.36)	0.042*		
• During CPB	26 (27.1)	28 (41.2)	1.85 (0.89 to 3.84)	0.019*		
• Both	16 (16.7)	10 (14.7)	1.29 (0.53 to 3.15)	0.489		
Intraoperative PRC transfusion; n (%)						
<1 blood volume	114 (98.3)	68 (86.1)	1			
≥1 blood volume	2 (1.7)	11 (13.9)	9.22 (0.98 to 42.85)	0.005*		
Intraoperative PRC transfusion (L); mean±SD	1.7±0.9	2.5±1.5	1.85 (1.40 to 2.43)	<0.01*		
VIS_{max}; n (%)						
0 to 10	99 (85.3)	49 (62.0)	1		1	
>10 to 20	12 (10.3)	15 (19.0)	2.6 (1.10 to 5.81)	0.029*	2.58 (1.01 to 6.64)	0.049*
>20	5 (4.3)	15 (19.0)	6.06 (2.08 to 17.63)	0.001*	5.4 (1.67 to 18.34)	0.005*
Re-operation; n (%)	0 (0.0)	27 (34.2)		<0.01*		
ICU readmission; n (%)	3 (2.6)	10 (12.7)	5.46 (1.45 to 20.53)	0.012*		
Length of ICU stay (hours); median (min-max)	43.2 (13.0 to 505.6)	172.7 (19.8 to 4,279.5)		<0.01*		
Length of hospital stay (days); median (min-max)	11.0 (4.0 to 47.0)	19.0 (2.0 to 182.0)		<0.01*		

CPB=cardiopulmonary bypass; DHCA=deep hypothermic circulatory arrest; VIS_{max}=maximum vasopressor inotrope score; PRC=packed red blood cell; $rScO_2$=regional cerebral oxygenation; ICU=intensive care unit; SD=standard deviation; OR=odds ratio; CI=confidence interval

Combined: aortic root and total arch replacement, ascending aorta with hemi- or partial or total arch replacement, Bentall operation with hemi- or partial or total arch replacement

[1] Univariate analysis, [2] Multiple logistic regression analysis, * $p<0.05$, statistical significance

Continuous intraoperative monitoring of bilateral $rScO_2$ with a near-infrared spectroscopy monitor (NIRS) was utilized in about 85% of patients. Cerebral desaturation occurred in 60% of the patients, 36% were during the CPB period, and 19% occurred both before and during the CPB period. The preoperative baseline and pre-CPB $rScO_2$ values were not different between those with postoperative stroke and those without. However, patients who later had postoperative stroke demonstrated significantly lower $rScO_2$ values bilaterally during the CPB period (Figure 3A). In univariable analysis, an increase in $rScO_2$ during CPB, on either the left or the right frontal areas, decreased the probability of developing postoperative stroke (crude OR 0.97, 95% CI 0.94 to 0.99, p=0.042 and 0.96,

Table 6. Multivariable logistic regression analysis of demographic factors for postoperative stroke

Factors	Postoperative stroke; n (%)		Crude OR (95% CI)	p-value[1]	Adjusted OR (95% CI)	p-value[2]
	No (n=166)	Yes (n=29)				
Diagnosis						
Aneurysm	92 (55.4)	10 (34.5)	1			
Dissection	74 (44.6)	19 (65.5)	2.36 (1.04 to 5.29)	0.041*		
Preoperative neurological complications						
No	143 (88.8)	18 (62.1)	1		1	
Yes	23 (13.9)	11 (37.9)	3.80 (1.59 to 9.07)	0.002*	4.01 (1.47 to 10.95)	0.0071*
Surgical site						
Aortic root/ascending/descending aorta	67 (40.4)	7 (24.1)	1			
Combined#	55 (33.1)	12 (41.4)	2.09 (0.77 to 5.67)	0.149		
Aortic arch	28(16.9)	10 (34.5)	3.42 (1.18 to 9.89)	0.023*		
Thoracoabdominal	16 (6.9)	0 (0.00)	0 (0)	0.998		
VIS_{max}						
0 to 10	130 (78.3)	18 (62.1)	1			
>10 to 20	22 (13.3)	5 (17.2)	1.64 (0.55 to 4.88)	0.372		
>20	14 (8.4)	6 (20.7)	3.10 (1.06 to 9.08)	0.040*		
$rScO_2$ monitoring	138 (83.1)	26 (89.7)	1.75 (0.49 to 6.21)	0.582		
$rScO_2$ decreased >20%						
No	65 (47.1)	6 (23.1)	1		1	
Yes						
• Before CPB	11 (8.0)	2 (7.7)	2.95 (0.49 to 17.81)	0.238	2.38 (0.36 to 15.86)	0.372
• During CPB	39 (28.3)	15 (57.7)	4.39 (1.49 to 12.91)	0.007*	4.60 (1.49 to 14.15)	0.008*
• Both	23 (16.7)	3 (11.5)	1.26 (0.28 to 5.67)	0.759	1.02 (0.21 to 4.96)	0.984
Intraoperative PRC transfusion						
<1 blood volume	158 (95.2)	24 (82.8)	1		1	
≥1 blood volume	8 (4.8)	5 (17.5)	4.12 (1.24 to 13.62)	0.028*	4.19 (1.01 to 17.36)	0.048*

VIS_{max}=maximum vasopressor inotrope score; $rScO_2$=regional cerebral oxygenation; CPB=cardiopulmonary bypass; PRC=packed red blood cell; OR=odds ratio; CI=confidence interval

Combined: aortic root and total arch replacement, ascending aorta with hemi- or partial or total arch replacement, Bentall operation with hemi- or partial or total arch replacement

[1] Univariate analysis; [2] Multiple logistic regression analysis, * p<0.05, statistical significance

95% CI 0.92 to 0.99, p=0.028). Interestingly, patients with cerebral desaturation during CPB presented with significantly higher baseline $rScO_2$ values compared to those without. However, the values later became significantly lower during the CPB period (Figure 3B). Although the reduction of $rScO_2$ was shown to increase the risk of postoperative stroke, the risk factors for cerebral desaturation were not found in the present study cohort. In addition, the proportion of patients who received NIRS monitoring was not different between those who developed postoperative stroke and those who did not at 89.7% versus 83.1% (p=0.38).

Discussion

In this single-center retrospective cohort study involving patients who underwent open thoracic aortic surgery with CPB, the main findings are (i) the incidence of 30-day mortality was 4.6%, (ii) perioperative factors associated with major complications were preoperative hypotension, aortic arch surgery, and VIS_{max} score greater than 10, (iii) more than 20% reduction of $rScO_2$ during CPB is common and strongly associated with postoperative stroke.

Incidence of mortality rate

Thoracic aortic surgeries are considered high risk and associated with considerable organ dysfunctions, prolonged hospital length-of-stay, and high mortality rates[1-5]. The incidence of postoperative mortality is a widely accepted postoperative outcome measurement after thoracic aortic surgery. It has been reported in the range of 3.2% to 20% from different patient cohorts[3-5,8,16,17]. In a large cohort of 83 Korean aortic surgery centers, where each center was categorized

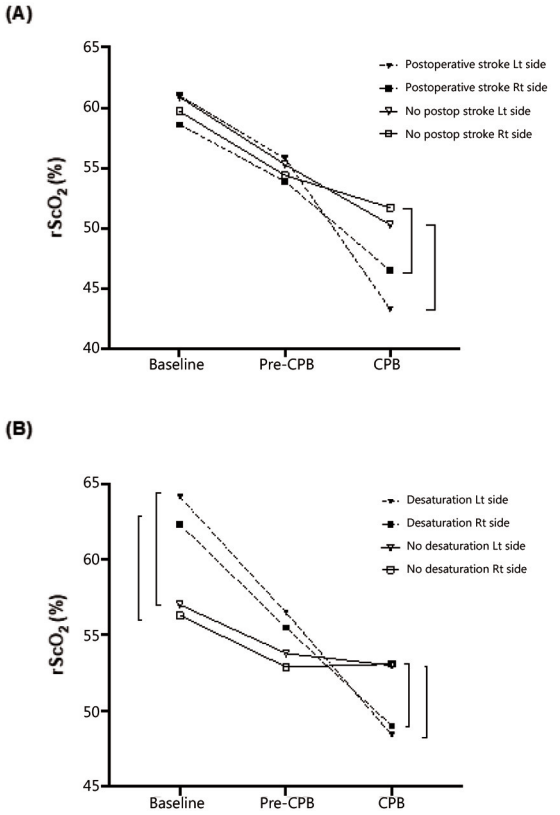

Figure 3. Postoperative stroke and cerebral desaturation.

into either low with less than 30 cases per year, medium with 30 to 60 cases per year, and high volume with more than 60 cases per year, they reported the incidence of in-hospital mortality of 8.6% in the high-volume centers, while the medium and low volume centers reported higher 30-day mortality of 10.7% and 21.9%, respectively[8]. In another larger cohort study in the United States involving 1,045 centers, overall operative mortality was 3.2%. However, the risk of mortality in the low-volume center, defined as less than 50 annual cases, increased significantly[17].

The present study center, by the same definitions, would be categorized as a high-volume center, and reported a comparable in-hospital mortality rate, at 5.6%, to the previous studies[2,18]. However, it should be noted that more than 50% of the patients in the present study, compared to less than 5% in the Korean cohort and less than 3% in the U.S. cohort, presented for emergency surgical procedures, which was known to be associated with higher mortality risk[4,18].

Postoperative morbidity and mortality

Postoperative complications are common after thoracic aortic surgeries. The present study utilized standard definitions for characterizing postoperative events(9,10), and each event was later classified into minor and major complication categories according to Clavien-Dindo classification[11]. With this approach, the authors were able to capture almost 700 events occurring in the postoperative period with detailed classifications. The most common minor complication encountered in the cohort was postoperative transfusions for either anemia or coagulopathy, at 88%. Although postoperative transfusions are common after thoracic aortic surgery, the present study reported rate is higher than other previous studies[4,19]. The present study also reported a high incidence of postoperative pulmonary infection, at 19.5%, as well as acute kidney injury, at 18.5%, however, these are comparable to previously reported incidences[15,20].

About 40% of the patients developed postoperative major complications in Grade III or IV. The VIS_{max} score at the first 24 hours after ICU admission was a risk factor for major complications in the multivariable analysis. The utility of VIS_{max} has been shown in previous studies[12,13] where VIS_{max} is associated with various adverse outcomes after cardiac surgery with good diagnostic sensitivity and specificity. However, the diagnostic cutoff values are varied and range from 5 to exceeding 30. In addition, the variations among institutional practices may limit the applicability of VIS_{max}. In the present study cohort, with the VIS_{max} cutoff value at 10, from the multivariable analysis, it had only a fair area under the ROC curve and had low diagnostic sensitivity, although high specificity for major complications.

Postoperative stroke

Postoperative ischemic stroke was the most common major complication in the present study. With an incidence of about 15%, it was higher than previously reported. Previous studies found around 10% incidence of stroke after thoracic aortic surgery[18,21,22], consistent with a large cohort of more than 1,000 patients that reported an incidence of 7%[23]. The use of $rScO_2$ monitoring is common during thoracic aortic surgery, where inadequate cerebral perfusion can occur throughout the perioperative period, which should be promptly treated when it occurred[24,25]. The threshold for interventions of more than 20% $rScO_2$ reduction from baseline is widely adopted among institutions[26], including the present study. Although intraoperative $rScO_2$ monitoring is essentially routine in cardiac and thoracic aortic surgery, the evidence supporting its benefits in

reducing perioperative stroke is still limited[27]. As shown in the present study cohort, even though having more than 85% utilization rate of continuous $rScO_2$ monitoring, and measures to maintain its value within 80% of baseline were constantly used, the authors still observed a high incidence of cerebral desaturation, at 60%, associated with an increased risk of postoperative stroke. It is worth mentioning that, although the incidence of stroke after aortic surgery was widely reported, effective risk-reducing strategies are still limited.

In the present study institute, the methods of cerebral protection used, such as moderate to deep hypothermia or DHCA in 39.5%, and selective antegrade cerebral perfusion (SACP) in 60% were selected based on operation, patient factors, and clinical conditions. In aortic arch surgery, cannulation is typically performed at the central aorta or axillary artery to ensure adequate cerebral and systemic perfusion. In complex thoracoabdominal aortic surgery, combined cannulation strategies ensure antegrade cerebral perfusion such as via the axillary artery or central aorta, and systemic perfusion such as through femoral or central aortic cannulation. The choice of cannulation sites varies depending on the patient's anatomy and the extent of the aortic pathology.

Interventions aimed at improving oxygen delivery 1) ensure cannula are positioned correctly and functioning optimally 2) increase oxygen supply by optimizing ventilation, increasing FiO_2, 3) improve cardiac output or CPB flow, and ensure mean arterial pressure (MAP) is adequate to maintain cerebral perfusion, 4) optimize hemoglobin levels to enhance oxygen-carrying capacity, and 5) maintain normocarbia[28].

The present study has limitations. First, it was a single-center study with a small sample size. Most patients presented with emergent surgical conditions with a high incidence of preexisting organ dysfunctions. Second, the authors did not analyze surgical and perfusion techniques such as cannulation sites, surgical repairs, and other CPB variables. These factors could potentially influence outcomes. Third, risk scores were not used to assess patients' severity in the preoperative period, which will limit comparisons to other institutions. And fourth, although the authors adhered to standard definitions when characterizing complications, due to the retrospective design, there might still be variations in how these definitions were applied.

Conclusion

In the present study, the authors reported a 30-day mortality rate of 4.6% after open thoracic aortic surgery with CPB. Operations of the aortic arch and VIS_{max} score greater than 10 are associated with an increased risk of major postoperative complications. Reduction of $rScO_2$ during CPB is strongly associated with postoperative stroke, necessitating prompt intervention to correct inadequate cerebral perfusion during the perioperative period.

What is already known on this topic?

Thoracic aortic surgery is known to be associated with a high risk of mortality, morbidity, and stroke, as widely reported.

What does this study add?

A high incidence of cerebral desaturation during CPB is associated with an increased risk of postoperative stroke.

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Conflicts of interest

The authors declare no conflict of interest.

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