Scholarly Project Final Report

Report*:*

Introduction *(≥250 words)*

Aortic dissection is a highly morbid pathology which typically requires urgent surgical intervention to achieve the best chance of survival. Studies have shown that between 2012 and 2019, there was an increase in mortality from aortic dissection[1]. While this increase is likely multifactorial, there was a concomitant rise in vascular comorbidities such as diabetes and hypertension which that was likely contributory[1]. Age is an independent risk factor for the development of cardiovascular disease[2] and thus there is likely to be increased incidence of aortic pathologies including dissection. Given the urgency of treatment and high morbidity and mortality risks, it is important to elucidate the simplest and most durable operative technique with the best postoperative outcomes to improve patient survival and quality of life.

Acute type A aortic dissection (TAAD) has 22% in-hospital mortality, with almost 66% of patients subsequently developing a related adverse event[1]. Despite improvements in surgical management, high rates of neurologic complications and mortality remain complicating factors. Prior studies have sought to characterize risk factors associated with negative outcomes and found that emergent surgery was associated with higher postoperative risk, recommending that ascending and hemiarch replacement be performed in emergent settings rather than total arch replacement[3]. Elective repair of ascending and aortic arch disease was shown to have significantly lower rates of morbidity and mortality compared to urgently indicated surgeries[4]. Nonetheless, total arch replacement is considered the gold standard for palliation of arch dissection and disease as it allows for elimination of downstream diseased aortic tissue[3].

The aortic arch encompasses the region from the innominate artery to the left subclavian artery, and total arch replacement requires interruption of the cerebral circulation leading to increased risk of neurologic morbidity such as stroke[5]. Prolonged time spent in hypoxic circulatory arrest without additional cerebral perfusion methods was shown to cause longer emergence from anesthesia and increased the risk of stroke or mortality[5,6]. Strategies such as selective anterior cerebral perfusion (SACP) have improved neuroprotection and decreased poor neurologic outcomes, however, neurologic injury is still a concern[5]. SACP improves recovery and decreases long term residual deficits from stroke compared to other cerebral cannulation methods or hypoxic circulatory arrest alone[6]. Additionally, prolonged cardiopulmonary bypass time was found to increase cerebral emboli in brain tissue specimens; for each hour increase in bypass time there was a 90.5% increase in number of emboli[7]. Thus, longer time on bypass increases the risk for ischemic damage to the brain. Optimizing these factors could result in improved neurologic outcomes and recovery postoperatively.

Prior studies have described the following sequence for aortic arch replacement: resection of the proximal arch then transection of the distal arch between the left common carotid and subclavian arteries prior to placement of the stent graft[8]. This method resulted in decreased circulatory arrest and bypass time but also was associated with spinal cord injury and difficulty with graft placement in patients with underlying connective tissue pathology[8]. More recent studies have suggested a tailored approach to repair sequencing with decision making guided by the presence of connective tissue disease or need for combined surgical procedures[9]. One such study compared a minimally invasive sternotomy to typical approach and found a decrease in combined mortality and stroke outcomes with comparable long-term results[9]. The sequence of revascularization was suggested to decrease bypass times and cardiac ischemia. Notably, however, this

technique was studied in individuals undergoing repair of degenerative aneurysm rather than acute dissection. A 2025 review of outcomes in patients undergoing redo arch replacement after a prior limited repair demonstrated high rates of reintervention with freedom from reintervention decreasing from 38% at 5 years to 27% by 10 years[10]. Overall survival in the cohort was reported as 64%[10]. Notably, total arch replacement at the time of acute dissection has been shown to increase early mortality, however, it also is associated with decreased distal aortic events and need for reintervention[10].

Here we present intra- and postoperative outcomes and potential benefits of an alternatively sequenced arch repair strategy in the setting of thoracic aortic arch dissection.

Methods *(≥250 words)*

IRB Approval

Study approval was obtained via the Oregon Health and Science University Institutional Review Board on 4/2/2019; the study identification number is STUDY00019703.

Inclusion criteria

We performed a retrospective cohort study of all patients with aortic dissection who underwent total aortic arch replacement between 2014-2025 at Oregon Health and Science University. The electronic health record (EHR) was reviewed, and an aortic surgery database was established, including all procedures performed between July 2014 and November 2025. 258 cases were identified as operations involving the aortic arch and subsequent review of operative notes identified 102 total arch cases. The cases were subdivided into alternative (AT) and standard (ST) technique based on operation type reported in operative notes. Demographic information, intraoperative data, and postoperative outcomes were obtained from the EHR and aortic arch database.

Surgical technique

ST was defined as single vessel selective antegrade cerebral perfusion followed by arch vessel revascularization. Patients then underwent hypoxic circulatory arrest. After this point, the distal anastomosis was performed, the patient was rewarmed to normothermia, and the proximal repair was completed. AT was defined by the following sequence: single vessel selective antegrade cerebral perfusion was performed followed by hypoxic circulatory arrest. Patients then underwent distal repair and then were rewarmed to normothermia. At this point, proximal repair was completed, and finally arch vessels were revascularized. Operative details for AT are depicted in Figure 1.

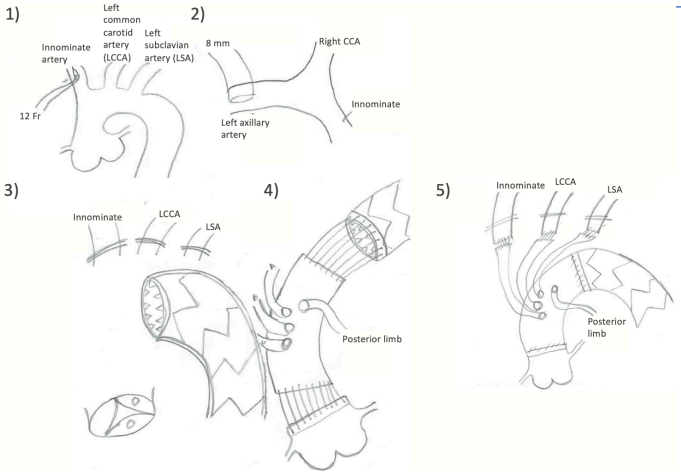

Figure 1. Diagram of alternative technique arch first sequencing, adapted from Castigliano Bhamidipati, DO, PhD, MSc.

Outcomes

Outcomes included baseline demographic information, intraoperative measures including cerebral perfusion time, cross clamp time, lowest intraoperative temperature, cerebral oximetry, intraoperative blood product use. Data were reviewed from the operative record and the perfusion report. Finally, postoperative outcomes including 30-day mortality, stroke rate, total length of stay, and survival at 1 year were assessed from the chart. subgroup of patients was evaluated for survival at 3 years; patients who had undergone surgery less than 3 years prior or who had been lost to follow up were excluded.

Statistical analysis

Demographic and categorical data are described by descriptive statistics including Fisher exact tests. Continuous data are reported as student's t-tests. All data are reported as mean +/- standard deviation or as percentages where appropriate. The p value was set at p=0.05. A subset of patients for whom 3 years had passed since the index of operation were assessed for survival up to 3 years via Kaplan Meier survival analysis.

Results *(≥500 words)*

Demographic data

Between July of 2014 and November 2025, 102 patients underwent total arch repair for thoracic aortic dissection at a single institution. 11 patients underwent ST repair, while 91 patients had AT repair. ST patients were 73% male, while AT were 69% male, there was no difference between groups (p>0.05, Table 1). 64% of the ST patients 75% of AT patients identified as White, there was no difference between groups with respect to race or ethnicity (p>0.05, Table 1). There was no difference in age between groups (ST 51±14 years vs AT 57±15 years, p>0.05; Table 1). BMI was not different between groups (ST 30.3±7.6 m/kg2 vs AT 29.8±6.4 kg/m2, p>0.05; Table 1). Incidence of hypertension and dyslipidemia were increased in the AT compared to ST (Hypertension: ST 46±52% vs AT 81±39%, p=0.02; Dyslipidemia ST 27±47% vs 63±49%, p=0.04; Table 1). Rates of other common comorbidities such were similar. The AT group had a higher rate of prior cardiac intervention compared to ST counterparts (ST 18±40% vs AT 59±49%, p=0.009;

Table 1).

Preoperative data

The AT group had increased rates of redo operations compared to ST (ST 9±30% vs AT 46±50%, p=0.04; Table 1). There were no differences in preoperative labs including hemoglobin, hematocrit, or creatinine between groups. The AT group had lower platelet counts compared to ST counterparts, however, neither group met standard criteria for thrombocytopenia (ST 304±207K vs 220±95K platelets, p=0.02; Table 1). Preoperative left ventricular ejection fraction was within normal limits and equivalent between groups (ST 62±8% vs 59±9%, p>0.05; Table 1).

Variable	ST (n=11)	AT (n=91)	p value
BMI, mean (SD), kg/m2	30.3 (7.6)	29.8 (6.4)	p>0.05
Male sex, n (%)	8 (73%)	63 (69%)	p>0.05
Age at operation, mean (SD), y	57 (15)	51 (14)	p>0.05
White race, n (%)	7 (64%)	68 (75%)	p>0.05
Hispanic ethnicity, n (%)		10 (11%)	p>0.05
Comorbidities, n (%)			
Hypertension	5 (46%)	74 (81%)	p=0.02*
Diabetes	2 (18%)	6 (7%)	p>0.05
Dyslipidemia	3 (27%)	57 (63%)	p=0.04*
Active smoking	3 (27%)	26 (29%)	p>0.05
Chronic lung disease	1 (9%)	13 (14%)	p>0.05
Obstructive sleep apnea	0 (0%)	24 (26%)	p>0.05
Peripheral vascular disease	0 (0%)	10 (11%)	p>0.05
Heart failure	2 (18%)	9 (10%)	p>0.05
Prior myocardial infarction	1 (9%)	5 (6%)	p>0.05
Arrhythmia	2 (18%)	13 (14%)	p>0.05
Cerebrovascular Disease	2 (18%)	16 (18%)	p>0.05
Prior Stroke or TIA	1 (50%)	15 (94%)	-
Pre-operative labs, mean (SD)			
Hemoglobin	12.0 (2.6)	12.4 (2.0)	p>0.05
Hematocrit	36.2 (6.9)	37.5 (5.5)	p>0.05
Platelet count (100,000)	304 (207)	220 (95)	p=0.02*
Creatinine	1.02 (0.1)	1.22 (0.4)	p>0.05
Left ventricular ejection fraction, mean (SD), %	62 (8)	59 (9)	p>0.05
Prior cardiac intervention, n (%)	54 (59%)	2 (18%)	p=0.009*

Table 1. AT and ST groups were demographically similar. BMI, age, sex, and race were similar between groups. Hypertension and dyslipidemia were more frequent in the AT group compared to ST counterparts; other common comorbidities including stroke and heart failure were similarly distributed. Baseline labs were similar; platelet count was decreased in AT compared to ST but was not clinically relevant. AT had a higher rate of prior cardiac interventions compared to ST. Left ventricular ejection fraction was equivalent between groups.

Intraoperative outcomes

AT and ST groups had similar distributions of operative subtypes and concomitant surgical interventions such as CABG or TEVAR (Table 2). The most common concomitant procedures were aortic valve repair or replacement. The AT group was more likely to undergo axillary artery cannulation compared to ST counterparts (27±53% vs 67±35%, p=0.004; Table 2). Rates of other arterial and venous cannulation site choices were similar (Table 2).

There was no difference in lowest intraoperative temperature between AT and ST groups (ST 21.1±6.5°C vs 20.5±4.3°C, p > 0.05; Table 2). Total operative time was shorter in the ST compared to AT (10.5±2.1 hours vs 11.8±2.1 hours, p=0.05; Table 2) and cardiopulmonary bypass time was equivalent between groups (ST 284±99 min vs 286±76 min, p>0.05; Table 2). Cerebral perfusion time was shorter in the AT group compared to ST (ST 67±49 min vs AT 44±14 min, p=0.006; Table 2) while cross clamp time trended shorter in the AT group (ST 185±95 min vs AT 142±69 min, p=0.06; Table 2).

There was no significant difference in intraoperative use of packed red blood cells (PRBCs; ST 2±2 packs vs AT 4±4 packs, p>0.05; Table 2), fresh frozen plasma (FFP; ST 4±2 packs vs AT 4±3 packs, p>0.05; Table 2), platelets (ST 2±1 pack vs AT 3±1 pack, p>0.05; Table 2), or cryoprecipitate (ST 1±1 pack vs AT 1±1 pack, p>0.05; Table 2) between groups. Lowest hemoglobin and hematocrit and highest glucose were similar intraoperatively (Table 2). Vasopressor requirements at the end of the operation were not different (Table 2). Postoperative cerebral oximetry was equal bilaterally (left region oxygen saturation ST 60±12% vs AT 60±10%, p>0.05; right region oxygen saturation ST 64±14% vs AT 61±9%, p>0.05; Table 2).

Variable	ST (n=11)	AT (n=91)	p value
Redo operation, n (%)	1 (9%)	42 (46%)	p=0.04*
Intervention, n (%)			
Ascending aorta + total arch	8 (73%)	62 (68%)	p>0.05
FET	6 (75%)	54 (87%)	p>0.05
Root + ascending aorta + total arch	3 (27%)	29 (32%)	p>0.05
FET	2 (66%)	27 (93%)	p>0.05
Concomitant surgery, n (%)			
TEVAR	0 (0%)	3 (3%)	p>0.05
Aortic valve repair	1 (9%)	10 (11%)	p>0.05
Aortic valve replacement	2 (18%)	15 (16%)	p>0.05
CABG	1 (9%)	5 (5%)	p>0.05
Cardiopulmonary bypass time, mean (SD), min	284 (99)	286 (76)	p>0.05
Cerebral perfusion time, mean (SD), min	67 (49)	44 (14)	p=0.006*
Cross clamp time, mean (SD), min	185 (95)	42 (69)	p=0.06
Arterial cannulation site, n (%)			
Aortic	5 (45%)	37 (41%)	p>0.05
Axillary	3 (27%)	61 (67%)	p=0.004*
Femoral	2 (18%)	12 (13%)	p>0.05
Venous cannulation site, n (%)			
Femoral	3 (27%)	25 (27%)	p>0.05
Right atrial	8 (73%)	60 (66%)	p>0.05
Other	2 (18%)	7 (8%)	p>0.05
Total OR time, mean (SD), hours	10.5 (2.1)	11.8 (2.1)	p=0.05*
Lowest temperature, mean (SD), C	21.1 (6.5)	20.5 (4.3)	p>0.05
Lowest hemoglobin, mean (SD)	7.5 (1.6)	7.8 (1.0)	p>0.05
Lowest hematocrit, mean (SD)	23.2 (4.8)	23.8 (3.3)	p>0.05
Highest glucose, mean (SD)	205 (46)	192 (34)	p>0.05
Intraop blood products, units (SD)			
Packed red blood cells	2 (2)	4 (4)	p>0.05
Platelet dose packs	2 (1)	3 (1)	p>0.05
Fresh frozen plasma	4 (2)	4 (3)	p>0.05
Cryoprecipitate	1 (1)	1 (1)	p>0.05
Vasopressor support to ICU, mean dose (SD)			
Epinephrine, mean (SD), mg	0.04 (0.06)	0.04 (0.03)	p>0.05
Norepinephrine, mean (SD), mcg	0.04 (0.04)	0.03 (0.04)	p>0.05
Milrinone, mean (SD), mcg	0.125 (0.15)	0.11 (0.14)	p>0.05
Vasopressin, mean (SD), U	0.45 (1.5)	1 (2.3)	p>0.05
Postoperative cerebral oximetry			
Left region oxygen saturation, % (SD)	60 (12)	60 (10)	p>0.05
Right region oxygen saturation, % (SD)	64 (14)	61 (9)	p>0.05

Table 2. AT patients had decreased cerebral perfusion times but longer overall surgeries compared to ST counterparts. Distribution of case types was similar between groups as were rates of concomitant surgical procedures. Cardiopulmonary bypass times were equivalent; however, AT had significantly shorter cerebral perfusion times and a trend toward decreased aortic cross clamp times. Overall case length was increased in AT compared to ST. AT was more likely to have axillary arterial cannulation. Intraoperative labs were similar, as was blood product transfusion requirement. Postoperative vasopressor needs were not different. Cerebral oximetry at the end of the case was equal bilaterally between groups.

Immediate postoperative outcomes and complications

Postoperative transfusion requirements were not different between groups for PRBCs, platelets, FFP, or

cryoprecipitate (Table 3). Postoperative labs were also equivalent (Table 3).

Average length of intubation was not different (ST 43.5±65.5 hours vs AT 61.0±97.5 hours, p>0.05) and reintubation rates were similar between groups (Table 3). Length of intensive care unit (ICU) stay (201.2±201.8 hours vs 174±185.6 hours, p>0.05) and hospital readmission rates did not differ. Total length of hospital stay was also similar (ST 20±14 days vs AT 17±14 days, p>0.05).

Major complication rates were overall similar. Stroke rate in the postoperative period was not different between groups (ST 18±89% vs AT 16±37%, p>0.05). Rates of renal failure were equal between groups (ST 27±47% vs AT 15±36%, p>0.05). Mortality at 30 days was not different (ST 9±30% vs AT 13±34%, p>0.05). There were no intraoperative mortalities. Rates of other complications including sepsis, bleeding requiring reintervention, and return to OR for a noncardiac cause were similar (Table 3).

Variable	ST (n=11)	AT (n=91)	p value
Post-operative blood products, units (SD)			
Packed red blood cells	4 (7)	3 (7)	p>0.05
Platelet dose packs	1 (2)	1 (2)	p>0.05
Fresh frozen plasma	1 (2)	1 (1)	p>0.05
Cryoprecipitate	0 (1)	0 (1)	p>0.05
Post-operative labs			
Hemoglobin	8.0 (2)	8.8 (1.4)	p>0.05
Hematocrit	27.7 (4.0)	27.0 (4.0)	p>0.05
Peak creatinine	2.45 (2.48)	1.87 (1.17)	p>0.05
Ventilation time, mean (SD), hr	43.5 (65.5)	61.0 (97.5)	p>0.05
Reintubation, n (%)	1 (9%)	14 (15%)	p>0.05
ICU time, mean (SD), hr	201.2 (201.8)	174.0 (185.6)	p>0.05
ICU readmission, n (%)	1 (9%)	7 (8%)	p>0.05
Total hospital days, mean (SD), day	20 (14)	17 (14)	p>0.05
Major Complications, n (%)	6 (55%)	60 (66%)	p>0.05
30d mortality	1 (9%)	12 (13%)	p>0.05
Bleeding requiring takeback	0	3 (3%)	p>0.05
Stroke	2 (18%)	15 (16%)	p>0.05
Renal failure	3 (27%)	14 (15%)	p>0.05
Return to OR for noncardiac reason, n (%)	3 (27%)	9 (10%)	p>0.05
Sepsis	1 (9%)	4 (4%)	p>0.05
Deep sternal infection	0	0	p>0.05

Table 3. Postoperative complication rates, ICU stay, and total hospital stay lengths were similar. There were no differences in postoperative blood products or lab results. Ventilation time, reintubation frequency, ICU readmission frequency, and length of ICU stay were equal between AT and ST groups. Major complications including 30-day mortality, stroke, and renal failure were similar.

Midterm postoperative outcomes

Survival at 1 year was not different between groups (ST 91% vs AT 76%, p>0.05; Table 4). patients were followed out to 3 years postoperatively and overall survival rates were similar (Figure 2). Endoleak was a rare complication in either group (Table 4).

Variable	ST (n=11)	AT (n=91)	p value
1-year survival, n (%)	10 (91%)	55 (76%)	p>0.05
2-year survival, n (%)	9 (90%)	43 (73%)	p>0.05
3-year survival, n (%)	6 (86%)	31 (69%)	p>0.05
Readmission, n (%)	1 (9%)	16 (18%)	p>0.05
Endoleak, n (%)	2 (18%)	5 (5%)	p>0.05

Table 4. There was no difference in readmission or survival at one, two, and three years postoperatively. Readmission frequency was similar between groups; survival was not different up to 3 years postoperatively. Endoleak was a rare complication and frequency of leak was equivalent between groups.

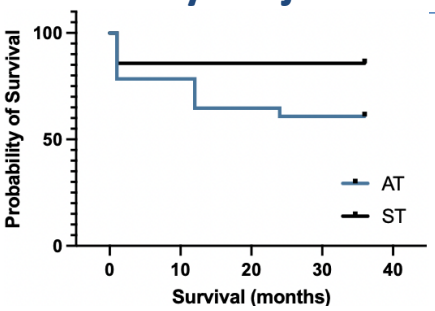

Figure 2. Probability of survival was similar up to 3 years postoperatively between AT and ST in a subgroup of patients. There was no significant difference in probability of survival at one, two, or three years postoperatively.

Discussion *(≥500 words)*

Here we demonstrate that an alternatively sequenced strategy for total arch replacement has equivalent outcomes to a standard approach in the immediate postoperative period and out to follow up to 3 years postoperatively. Our data demonstrated shorter cerebral perfusion times in the alternatively sequenced group compared to standard sequencing and a trend towards decreased aortic cross clamp time. Prior studies suggest that prolonged cross-clamp time is associated with increased postoperative transfusion requirements, while extended length of circulatory arrest increases the risk of stroke or death[11,12]. Interestingly, we also found that patients in the AT group had overall longer operative times, a finding that may be explained by the increased incidence of prior cardiac intervention. While the overall case time was longer, the time spent on bypass was similar and prior cardiac operations can result in increased adhesion burden and dissection time. Nonetheless, operative data and outcomes were otherwise similar between groups. AT and ST groups had equivalent length of ICU and hospital stay, 30-day mortality, and complication rates. Rates of neurologic morbidity, renal failure, sternal infection, re-operative bleeding, and sepsis were not different. Furthermore, AT and ST demonstrated equivalent survival at 1, 2, and 3 years postoperatively. Aortic arch intervention requires longer bypass and cross-clamp times compared to non-arch or hemiarch operations[13], so optimizing this the surgical workflow to decrease cross-clamp time may help to improve outcomes. Our goal in this study was to elucidate whether an alternatively sequenced operative technique would prove noninferior standard technique in both intraoperative and postoperative outcomes.

While there are several strategies for management of aortic dissection, the goal of the index operation is to eliminate all areas of aortic pathology to prevent morbidity at the index event or subsequent development of distal disease[14]. As such, total arch replacement may be indicated. Recent data suggest that total arch replacement can be safely performed with equivalent rates of early mortality compared to non-arch or hemiarch replacements, providing support for early total arch replacement[13,15]. A 2025 review of redo arch repairs also demonstrated acceptable mortality outcomes in the total arch replacement cohort providing further support for this strategy to help reduce the development of distal aortic pathology[10]. However, there is limited data examining comparative outcomes of operative sequencing in total arch replacement. An observational study of the arch first sequencing was recently published showing acceptable morbidity and mortality rates compared to the literature up to five years postoperatively[16]. Our data show similar outcomes in an alternatively sequenced cohort, suggesting it is an equally feasible alternative.

Stroke and persistent neurologic morbidity are feared outcomes of aortic arch surgery. Neurologic insults

are thought to be predominantly mediated by postoperative embolic events[7,17]. Neurologic injury is reported at rates ranging from 5.2-18%[13,15,17]. Neuroprotective strategies such as SACP are the strongest preventive factors against postoperative neurologic morbidity, and routine monitoring of cerebral oxygenation can predict poor neurologic outcomes. Bilateral and unilateral SACP are associated with similar neurologic outcomes for TAAD, although in patients undergoing prolonged ACP, bilateral SACP had improved survival[18]. Prior studies show that patients undergoing aortic arch surgery who spent more than 30 minutes below the absolute oxygenation threshold of 60% had increased complications and longer hospital stays[19]. Interestingly, left-sided desaturations have been associated with lower scores on postoperative cognitive testing[20]. Patients in both AT and ST groups were above this threshold bilaterally on average. We also found that alternative sequencing had no difference in rate of post-operative stroke and stroke rates were comparable to published data.

Aortic dissection can also be highly mortal. In-hospital mortality rates range anywhere from 5.3-25%, with higher rates seen emergent operations[15,21,22]. Notably, many studies pool operative techniques (e.g. hemiarch and total arch replacement) when reporting outcomes, limiting direct comparison[21,22]. Cardiopulmonary bypass times greater than 200 minutes have also been associated with increased risk of mortality[21], however, despite long bypass times patients in both groups had acceptable mortality rates. A recent study of the arch first strategy reported operative mortality rate of 16.3%[16]. We found an immediate postoperative mortality of 13% in the alternatively sequenced group. Here we have shown that immediate postoperative mortality was equivalent in patients undergoing arch first repair, and this survival trend was maintained out to 3 years postoperatively. Our findings suggest that this is a safe, feasible strategy for total arch replacement in the setting of aortic dissection.

Limitations

This is a retrospective single institution study and is therefore limited by study design. We only included patients with aortic dissection undergoing total arch replacement and some were lost to follow up; therefore, the number of participants is limited. This limits the statistical power to detect significant differences between the two surgical techniques presented herein. Additionally, given that this is a single center study with a highly experienced operator performing the AT operation, other institutions may not have the equivalent outcomes. Expert operators have been shown to have shorter cross-clamp and bypass times and improved long-term mortality[23] suggesting that individual surgeon expertise contributes to improved outcomes. This is a technically complex operation that requires highly specialized operative, ICU, and nursing teams, all of whom are critical for operative success and postoperative recovery.

Conclusions *(2-3 summary sentences)*

Aortic arch dissection is a complex disease process often requiring surgical intervention to prevent adverse outcomes; however, surgical management also has high rates of postoperative morbidity and mortality. We performed a retrospective cohort study of standard versus alternative revascularization sequences in total arch replacement and demonstrate here that AT had shorter cerebral perfusion times and equivalent neurologic morbidity and mortality up to 3 years postoperatively. We demonstrate that an alternative sequence of revascularization presents a noninferior alternative that may be easier to manage technically.

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