Zone 2 Arch Repair for Acute Type A Dissection: Evolution From Arch-First to Proximal-First Repair

**Methods**  From Jan. 2015 to Mar. 2023, Zone 2 arch repair Type A dissection, N=45

**Results**  
**Proximal-first vs. Arch-first**  
- Bladder temp: 24.9 vs. 19.7 °C, P<0.001
- CPB time: 230 vs. 177.5 min, P<0.001
- Lower body ischemic time: 87 vs. 28 min, P<0.001

Mortality+Morbidity: 11.5% vs. 57.9%, P=0.001

**Summary**  
Zone 2 arch repair using proximal-first technique for ATAD repair yields shorter lower body ischemic time with warmer core temperature resulting in fewer morbidities when compared to the arch-first technique.
Zone 2 Arch Repair for Acute Type A Dissection: Evolution From Arch-First to Proximal-First Repair

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Abbreviations

ACP = antegrade cerebral perfusion
ATAD = acute type A aortic dissection
CCA = common carotid artery
CT = computed tomography
ET = elephant trunk
IA = innominate artery
RAX = right axillary artery
SCA = subclavian artery
TEVAR = thoracic endovascular aortic repair
Central Picture

Proximal first Zone 2 arch repair in acute type A aortic dissection

Central Message

Zone 2 arch using proximal-first technique in acute dissection yields shorter cardiopulmonary bypass and lower body ischemic time resulting in better outcomes compared to the arch-first technique.

Perspective Statement

Zone 2 arch repair using proximal-first technique for ATAD repair is reproducible which is associated with lower operative mortality and morbidity, and less blood product use when compared to the arch-first technique. Both proximal and distal intervention including endovascular repair can be safely performed after Zone 2 arch repair, if necessary.
Abstract

Objective: With growing experience of acute type A aortic dissection (ATAD) repair, Zone 2 arch repair has been advocated. The aim of this study is to compare the outcome between “proximal-first” and “arch-first” Zone 2 repair.

Methods: From January 2015 to March 2023, 45 patients underwent Zone 2 arch repair out of 208 ATAD repairs: arch-first, N=19, and proximal-first technique, N=26 since January 2021. Indications were: aortic arch or descending tear; complex dissection in neck vessels, cerebral malperfusion, or aneurysm of the aortic arch.

Results: The lowest bladder temperature was higher in the proximal-first technique (24.9 vs. 19.7 °C), P<0.001). Cardiopulmonary bypass (230 vs. 177.5 min, P<0.001), myocardial ischemic (124 vs. 91 min, P<0.001), and lower body circulatory arrest time (87 vs. 28 min, P<0.001) were shorter in proximal-first technique. The arch-first group required more packed red blood cells (Arch-first, 2 units vs. Proximal-first, 0 units, P=0.048), platelets (Arch-first, 4 units vs. Proximal-first, 2 units, P=0.003) and cryoprecipitates (Arch-first, 2 units vs. Proximal-first, 1 unit, P=0.024). Operative mortality or major morbidities were higher in the arch-first group (57.9% vs. 11.5%, P=0.001). One-year survival was comparable (Arch-first, 89.5+/−7.0% vs. 92.0+/−5.5%, P=0.739). Distal intervention was successfully performed in 5 patients (endovascular, N=3, and open repair, N=2).

Conclusions: Zone 2 arch repair using proximal-first technique for ATAD repair yields shorter lower body ischemic time with warmer core temperature resulting in shorter cardiopulmonary bypass time, less blood product use and fewer morbidities when compared to the arch-first technique.

Key words: Aortic Dissection; Arch; Zone 2 arch
Introduction

With growing experience of acute type A aortic dissection (ATAD) repair and the evolution of endovascular technique, extended arch repair has been proposed to resect or cover the primary entry and allow more options for distal intervention, if necessary.\textsuperscript{1-7} Although total arch repair is the most extensive procedure done to address problems in the aortic arch and proximal descending aorta, this procedure may add significant lower body circulatory arrest time due to the need to address the left subclavian artery (SCA) and deep surgical field in this acute setting. All these may result in higher mortality and morbidity outcomes.\textsuperscript{2,4,8,9} For improved safety and efficacy, the concept of Zone 2 arch repair has been advocated.\textsuperscript{1-12} This procedure provides more endovascular options for the downstream aorta including thoracic endovascular aortic repair (TEVAR) with left common carotid artery (CCA) to left subclavian artery bypass or TEVAR using one- branched graft. To date, favorable remodeling of the distal aorta after TEVAR or frozen elephant trunk (ET) technique has been reported although further evidence is necessary in terms of the safety of these approaches.\textsuperscript{2,4,6,7}

Arch-first technique is another approach used to treat arch pathology.\textsuperscript{13-15} We previously reported about the safety and efficacy of arch-first technique in complex cases such as the redo total arch repair.\textsuperscript{14,15} Arch-first repair is often used with deep hypothermia, however, in the setting of ATAD repair, there is a longer cardiopulmonary bypass time and lower body ischemic time which may be associated with coagulopathy, respiratory failure, renal failure, among others.

Based on this background, we recently introduced the unique technique of proximal-first Zone 2 arch repair which yields short lower body and myocardial ischemic time similar to hemiarch repair, facilitates subsequent TEVAR, and enables concomitant Bentall procedure by using a single piece of ascending graft, if necessary.\textsuperscript{11} There is a paucity of data comparing different types of Zone 2 arch repair in the setting of ATAD. We hypothesized that our new technique of Zone 2 arch repair with warmer core temperature theoretically shortens lower body ischemic and
cardiopulmonary bypass time which could improve the outcome. The aim of this study is to compare the characteristics and outcome between “proximal-first” Zone 2 arch repair and “arch-first” Zone 2 repair as a historical control.

**Patients and Methods**

From January 2015 to March 2023, 45 patients (21.6%) out of 208 ATAD repairs underwent Zone 2 arch repair at our center (Supplemental Figure 1). Indications for Zone 2 arch repair were: aortic arch or descending tear, complex dissection in neck vessels, cerebral malperfusion, or aneurysm of the aortic arch. After January 2021, we started proximal-first technique for Zone 2 arch repair. This retrospective study was approved by the Institutional Review Board, with a waiver of informed consent (#14209, approval date 5/2/2020).

The details of each technique and ATAD repair at our institute was described elsewhere.\(^{11,15,16}\) The summary is shown in Figure 1. The right axillary artery (RAX) was used for arterial return.\(^ {16}\) Cerebral oximetry monitoring was routinely used.

**Proximal-First Technique**

After aortic cross-clamping, proximal repair was performed by using a one-branched Dacron graft.\(^ {11}\) Core cooling was initiated aiming for a bladder temperature of 25-26 °C. A 12x8x8 mm trifurcated graft (MAQUET, San Jose, CA) was trimmed to a bifurcated graft which is anastomosed to a proximal, right greater curvature of the ascending graft. Alternatively, a four-branched graft (Hemashield Platinum Woven Aortic Branch, MAQUET, San Jose, CA) could be used. Unilateral antegrade cerebral perfusion (ACP) was then initiated by reducing pump flow from the RAX (6-10 mL/kg/min) followed by clamping the innominate artery (IA) and left CCA (Figure 2A). Distal aortic anastomosis was then performed under hypothermic circulatory arrest.
of the lower body. After completion of the distal aortic anastomosis, total cardiopulmonary bypass flow resumed by perfusing both RAX and side branch of an ascending graft, rewarming then ensued, thus ending cardiac ischemia and lower body ischemia (Figure 2B). The left CCA was reconstructed, followed by the IA anastomosis (Figure 2C). At the time of completion of IA anastomosis, rewarming was usually completed.

Arch-First Technique

The ascending aorta was cross-clamped and proximal aorta dissected out. Core cooling was initiated aiming for a bladder temperature of 18-22 °C.\textsuperscript{15} After reaching the target temperature, unilateral ACP via the RAX was initiated. A 12x8x8 mm trifurcated graft was fashioned to a bifurcated graft which was anastomosed to the left CCA followed by IA anastomosis (Figure 3A). Next, distal aortic anastomosis with a conventional ET technique under bilateral ACP was performed (Figure 3B). This was followed by the proximal aortic anastomosis using the same ET graft (Figure 3C). Finally, the proximal portion of bifurcated graft was performed (Figure 3D) and then systemic circulation and rewarming process resumed. For patients who underwent aortic root replacement or ascending repair using a separate graft, an ascending/aortic root graft to ET graft anastomosis was required.

End points and definitions

The primary outcomes were operative mortality and major morbidity (reoperations for any cardiac reason, renal failure, deep sternal wound infection, prolonged ventilation/intubation, and cerebrovascular accident/permanent stroke) defined in STS database. Secondary outcomes were blood product use and intraoperative measures (cardiopulmonary bypass time, myocardial ischemic time, lower body circulatory arrest time, and lowest bladder temperature).\textsuperscript{4,12} The end
of selective ACP time was defined when both systemic and brain perfusion were restored through a single arterial inflow; this corresponded to completion of the IA anastomosis in proximal-first group, and completion of proximal anastomosis of the bifurcated graft in arch-first technique. A follow-up was performed at the aortic clinic every one to two years after surgery; the follow-up included an office visit and computed tomography (CT). Two patients were lost to follow-up within one-year after ATAD repair.

Statistical Analysis
Continuous variables were presented as the median (first; third quartile) and were compared using the Mann-Whitney U test, respectively. Categorical variables were expressed in percentages and were compared using the Chi-Square or Fisher’s Exact test (N<5). The survival curve was analyzed by the Kaplan-Meier method with the log-rank test. The P-value <0.05 was considered significant. Statistical analyses were performed using the SPSS 24.0 (IBM Corp, Armonk, NY).

Results
The median age was 64 years old (Table 1). Forty-four patients (97.8%) had DeBakey type I dissection. Forty-three patients (95.6%) had primary tear in the ascending aorta and/or aortic arch. Baseline characteristics were comparable except arch tear or ascending + arch tear was more predominant in the arch-first group (P=0.022). Preoperative any organ malperfusion was observed in 42.2% (N=19) of cases; cerebral malperfusion rate was 26.7% (N=12). Dissection of neck vessels were common: Innominate artery, 61.4% (N=27), right CCA, 34.1% (N=15), left CCA, 46.5% (N=20), and left SCA 39.5% (N=17).
Operative outcomes

The median lowest bladder temperature was higher in proximal-first technique (24.9 °C) compared to arch-first technique (19.7 °C) (P<0.001) (Table 2). Cardiopulmonary bypass time (230 vs. 177.5 min, P<0.001), myocardial ischemic time (124 vs. 91 min, P<0.001), and lower body circulatory arrest time (87 vs. 27.5 min, P<0.001) were significantly shorter in the proximal first technique. Arch-first group required more packed red blood cells (arch-first, 2 units vs. proximal-first, 0 units, P=0.048), platelets (arch-first, 4 units vs. proximal-first, 2 units, P=0.003) and cryoprecipitates (arch-first, 2 units vs. proximal-first, 1 unit, P=0.024).

Although mortality was comparable between groups, composite outcome of operative mortality and major morbidities were higher in the arch-first group (57.9% vs. 11.5%, P=0.001) (Table 3) which was likely driven by a combination of the following complications: reoperation for bleeding (Arch-first, 15.8% vs. Proximal-first, 0%, P=0.136), respiratory failure including tracheostomy (Arch-first, 36.8% vs. Proximal-first, 7.7%, P=0.042), stroke (Arch-first, 26.3% vs. Proximal-first, 7.7%, P=0.198), and kidney failure (Arch first, 21.1% vs. Proximal-first, 3.8%, P=0.182). One patient developed paraparesis whose lower body ischemic time was 114 minutes with the lowest tympanic and bladder temperature of 18.6 °C, 22.3 °C, respectively.

Survival and Aortic intervention after Zone 2 arch repair

The mean follow-up duration was 2.0+/−1.6 years in arch-first group and 1.1+/−0.6 years, respectively. Kaplan-Meier survival analysis showed that both groups showed comparable one-year survival (Arch-first, 89.5+/−7.0% vs. 92.0+/−5.5%, P=0.739) after Zone 2 arch repair (Figure 4).

There are 5 distal interventions. TEVAR was performed in 3 patients; the most recent patient underwent one-branch TEVAR. Two patients received “provisional extension to induce complete
attachment” technique\textsuperscript{5,7} to complete repair of the downstream aorta (Supplemental Table 1).

Two patients underwent open repair of the descending thoracic aorta; one patient developed dilatation of the descending aorta without enlargement of the distal aortic arch, and the other patient required two-stage repair using classical elephant trunk.

For proximal reoperation, two patients received aortic root replacement after Zone 2 arch repair. Since a bifurcated graft is anastomosed to the ascending graft just above the sino-tubular junction, bilateral axillary artery cannulation was used to perfuse (i) the brain through the right axillary artery to bifurcated graft and (ii) systemic body through the left axillary cannulation through the left SCA (Supplemental Figure 2).

Discussion

In the present study, we compared our proximal-first Zone 2 arch repair and our historical control (arch-first technique). Ascending or hemiarch replacement is our standard approach as a life-saving procedure in the setting of ATAD which provides excellent survival.\textsuperscript{16-20} On the other hand, a subset of patients may develop positive remodeling of the downstream aorta\textsuperscript{1,17-19} where the debate is ongoing as to which patients might benefit from extensive arch repair with or without endovascular repair and if the benefits outweigh risks in this acute setting.\textsuperscript{3,4} In this regard, possible indications of extensive ATAD repair are as follows: complex tear in the aortic arch or descending thoracic aorta, complex dissection in neck vessels, arch aneurysm, cerebral malperfusion, an expected residual compression of the true lumen in a distal aorta with potential requirement of distal intervention later on.\textsuperscript{1,11,18} Although aortic reoperation after limited ATAD repair is safely performed in experienced centers,\textsuperscript{18} it would be better to reduce the rate of distal re-intervention (e.g. open thoracoabdominal repair) by performing Zone 2 arch repair and subsequent endovascular repair to complete the distal repair.\textsuperscript{11}
We previously reported the safety of arch-first technique in elective, complex arch repair including redo cases. However, the potential drawback of this approach, especially in the setting of ATAD, would be long lower body ischemic time and deep hypothermia which results in longer cardiopulmonary bypass time and can be associated with coagulopathy and end-organ dysfunction in critically ill patients. Our present data showed that proximal-first Zone 2 arch repair significantly shortened the lower body ischemic time and myocardial ischemic time by early perfusion of the lower body and heart where cardiopulmonary bypass time was approximately 50 minute shorter in proximal-first technique. By the time of completion of left CCA and IA anastomosis, rewarming process is usually completed. In the early outcomes, several potential benefits were observed such as less blood product use or lower mortality and morbidity rate. We introduced this technique due to several reasons: the sequence is the same as our hemiarch repair where we consider proximal repair is crucial in ATAD surgery. Second, our technique does not require additional cannulation to neck vessels for selective ACP which simplifies the procedure. Finally, when Bentall operation is performed, there is no need for the arch-graft to Bentall graft anastomosis (single-piece of Bentall graft and bifurcated graft). Matalanis and colleagues reported a “branch-first” technique, in which there are no periods of cerebral circulatory arrest or deep hypothermia. Although continuous brain perfusion using moderate hypothermia seems favorable, we have not used this technique due to a concern of clamping the neck vessels during beating status, and retrograde flow to the brain via the femoral artery without any right sided brain perfusion during IA anastomosis. Similar outcome could have been observed by utilizing distal first technique as other studies reported favorable outcomes in Zone 2 or total arch repair. This includes direct cannulation of supra-aortic vessels for selective ACP and restoration of lower body and rewarming after distal anastomosis.
using a side-arm of the arch/ascending graft or separate cannulation utilizing femoral artery or left axillary artery.\textsuperscript{8,9,12}

When utilizing warmer temperature during distal aortic anastomosis as opposed to deep hypothermia, spinal cord ischemia is an important issue even in ATAD.\textsuperscript{2,4} This devastating complication is not negligible after total arch repair with frozen or classical ET procedures with an incidence of 2.6\% for ATAD.\textsuperscript{4} In proximal-first technique, the risk of spinal cord ischemia would be minimum because of no need of ET with the lower body circulatory arrest time of 28 minutes at 25-26 °C which corresponds to true unilateral ACP time. This falls into the safe limit of unilateral ACP under moderate or deep hypothermia (<50 minutes) described in the study by Angleitner and colleagues.\textsuperscript{23} The overall stroke rate (15.6\%) in this study was higher than our previous series of all ATAD repairs (4.6-8.4\% including submitting data)\textsuperscript{16,24} which is likely due to a high prevalence of neck vessels dissection and cerebral malperfusion in patients who underwent Zone 2 arch repair.\textsuperscript{10-12} Another interesting result is that arch or ascending arch tear were higher in the arch-first group. This result suggests that we might have a lower threshold to perform proximal-first Zone 2 arch repair with growing experience. A decision of cannulation site must be made in order to perform the proximal-first technique. As we previously reported, the RAX can be safely cannulated in patients with IA dissection where our most recent experiences showed that RAX is usable in approximately 95\% of ATAD patients.\textsuperscript{16} An alternative approach if the RAX or IA is not available would be to perform the proximal-first Zone 2 arch repair using the left CCA cannulation, or using the other cannulation site using selective ACP from the orifice of the neck vessels.\textsuperscript{8,9,10,13}

With regards to proximal reoperation after Zone 2 arch repair, two patients successfully underwent Bentall procedure. In this setting, some patients need clamping the ascending graft and bifurcated graft, respectively, as proximal anastomosis of bifurcated graft is located just
above the sino-tubular junction. Bilateral axillary cannulation is an effective option (Supplemental Figure 2), and left CCA to left subclavian bypass is also useful. Alternatively, Di Eusanio et al. reported that a separate graft can be anastomosed to an 8-mm limb of a bifurcated graft after re-entry to the sternum which provides bilateral brain perfusion. We do not recannulate the old ascending graft in redo scenario due to a concern of embolism. For distal intervention, one of the potentials of Zone 2 arch repair would be an endovascular option which includes preemptive TEVAR to complete total arch repair as described before. We noted several limitations of this study. The main limitation of this single-center study is the small number of patients with a short follow-up period. The better outcomes with the proximal-first technique could have been due to the cumulative surgical experience as we switched to the surgical strategy of Zone 2 arch repair only in January 2021. One could argue that the rewarming process could be initiated after distal aortic anastomosis via the ascending ET graft or other cannulation site such as the femoral artery or left axillary artery.

In conclusion, Zone 2 arch repair using proximal-first technique for ATAD repair yields shorter lower body ischemic time with warmer core temperature resulting in shorter cardiopulmonary bypass time, less blood product use and better operative mortality and morbidity outcomes when compared to the arch-first technique (Figure 5). Both proximal and distal intervention can be safely performed, if necessary.
References


### Table 1. Preoperative characteristics

<table>
<thead>
<tr>
<th></th>
<th>All N=45</th>
<th>Arch-First N=19</th>
<th>Proximal-First N=26</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>64 [55, 73.5]</td>
<td>66 [60, 74]</td>
<td>63 [55, 73]</td>
<td>0.190</td>
</tr>
<tr>
<td><strong>Male</strong></td>
<td>32 (71.1%)</td>
<td>13 (68.4%)</td>
<td>19 (73.1%)</td>
<td>0.734</td>
</tr>
<tr>
<td><strong>Body surface area, m²</strong></td>
<td>2.04 [1.88, 2.23]</td>
<td>2.08 [1.87, 2.22]</td>
<td>2.00 [1.88, 2.25]</td>
<td>0.558</td>
</tr>
<tr>
<td><strong>Hypertension</strong></td>
<td>40 (93.0%)</td>
<td>17 (89.5%)</td>
<td>23 (95.8%)</td>
<td>0.833</td>
</tr>
<tr>
<td><strong>Diabetes mellitus</strong></td>
<td>7 (15.6%)</td>
<td>2 (10.5%)</td>
<td>5 (19.2%)</td>
<td>0.706</td>
</tr>
<tr>
<td><strong>Creatinine ≥1.5 mg/dL</strong></td>
<td>4 (9.3%)</td>
<td>3 (15.8%)</td>
<td>1 (4.2%)</td>
<td>0.439</td>
</tr>
<tr>
<td><strong>Coronary artery disease</strong></td>
<td>5 (11.1%)</td>
<td>2 (10.5%)</td>
<td>3 (11.5%)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Atrial fibrillation</strong></td>
<td>2 (4.7%)</td>
<td>0</td>
<td>2 (8.3%)</td>
<td>0.736</td>
</tr>
<tr>
<td><strong>Cerebrovascular disease</strong></td>
<td>3 (6.7%)</td>
<td>1 (5.3%)</td>
<td>2 (7.7%)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Connective tissue disease</strong></td>
<td>2 (4.4%)</td>
<td>0</td>
<td>2 (8.3%)</td>
<td>0.614</td>
</tr>
<tr>
<td><strong>Prior TEVAR</strong></td>
<td>3 (6.7%)</td>
<td>2 (10.5%)</td>
<td>1 (3.8%)</td>
<td>0.778</td>
</tr>
<tr>
<td><strong>Prior sternotomy</strong></td>
<td>3 (6.7%)</td>
<td>1 (5.3%)</td>
<td>2 (7.7%)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Aortic insufficiency ≥2+</strong></td>
<td>26 (57.8%)</td>
<td>12 (63.2%)</td>
<td>14 (53.8%)</td>
<td>0.532</td>
</tr>
<tr>
<td><strong>Ejection fraction, %</strong></td>
<td>60 [60, 60]</td>
<td>60 [50, 60]</td>
<td>60 [60, 60]</td>
<td>0.656</td>
</tr>
<tr>
<td><strong>Intubation</strong></td>
<td>4 (8.9%)</td>
<td>2 (10.5%)</td>
<td>2 (7.7%)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Cardiogenic shock</strong></td>
<td>12 (26.7%)</td>
<td>6 (31.6%)</td>
<td>6 (23.1%)</td>
<td>0.524</td>
</tr>
<tr>
<td><strong>DeBakey I dissection</strong></td>
<td>44 (97.8%)</td>
<td>19 (100%)</td>
<td>25 (96.2%)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Tear location</strong></td>
<td></td>
<td></td>
<td></td>
<td>0.022</td>
</tr>
<tr>
<td><strong>Ascending</strong></td>
<td>23 (51.1%)</td>
<td>5 (26.3%)</td>
<td>18 (69.2%)</td>
<td></td>
</tr>
<tr>
<td><strong>Ascending+Arch</strong></td>
<td>6 (13.3%)</td>
<td>5 (26.3%)</td>
<td>1 (4.2%)</td>
<td></td>
</tr>
<tr>
<td><strong>Arch</strong></td>
<td>14 (31.1%)</td>
<td>8 (42.1%)</td>
<td>6 (23.1%)</td>
<td></td>
</tr>
<tr>
<td><strong>Descending</strong></td>
<td>1 (2.2%)</td>
<td>0</td>
<td>1 (4.2%)</td>
<td></td>
</tr>
<tr>
<td><strong>Others/unknown</strong></td>
<td>1 (2.2%)</td>
<td>1 (5.3%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Any malperfusion</strong></td>
<td>19 (42.2%)</td>
<td>10 (52.6%)</td>
<td>9 (34.6%)</td>
<td>0.187</td>
</tr>
<tr>
<td><strong>Cerebral</strong></td>
<td>12 (26.7%)</td>
<td>7 (36.8%)</td>
<td>5 (19.2%)</td>
<td>0.245</td>
</tr>
<tr>
<td><strong>Coronary</strong></td>
<td>1 (2.2%)</td>
<td>0</td>
<td>1 (3.8%)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Mesenteric</strong></td>
<td>3 (6.7%)</td>
<td>1 (5.3%)</td>
<td>2 (7.7%)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Arm</strong></td>
<td>7 (15.6%)</td>
<td>3 (15.8%)</td>
<td>4 (15.4%)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Leg</strong></td>
<td>4 (8.9%)</td>
<td>2 (10.5%)</td>
<td>2 (7.7%)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Innominate artery dissection</strong></td>
<td>27 (61.4%)</td>
<td>11 (61.1%)</td>
<td>16 (61.5%)</td>
<td>0.977</td>
</tr>
<tr>
<td><strong>Right CCA dissection</strong></td>
<td>15 (34.1%)</td>
<td>7 (38.9%)</td>
<td>8 (30.8%)</td>
<td>0.576</td>
</tr>
<tr>
<td><strong>Left CCA dissection</strong></td>
<td>20 (46.5%)</td>
<td>9 (50.0%)</td>
<td>11 (44.0%)</td>
<td>0.697</td>
</tr>
<tr>
<td><strong>Left subclavian artery dissection</strong></td>
<td>17 (39.5%)</td>
<td>8 (44.4%)</td>
<td>9 (39.6%)</td>
<td>0.576</td>
</tr>
</tbody>
</table>
Values are expressed in n (%), or median (First;Third quantile). CCA=common carotid artery
### Table 2. Operative details.

|                                      | All  
|--------------------------------------|------|
|                                      | N=45 | Arch-First  
|                                      | N=19 | Proximal-First  
|                                      | N=26 | P-value  
| Cardiopulmonary bypass, min         | 204 [172, 239] | 230 [207, 290] | 177.5 [157, 215] | 0.002 |
| Lower body circulatory arrest time, min | 37 [27, 80] | 87 [59, 134] | 28 [24, 33.3] | <0.001 |
| Lowest bladder temperature, °C       | 23.0 [20.0, 25.0] | 19.7 [18, 22.0] | 24.9 [24.0, 25.0] | <0.001 |
| Myocardial ischemic time, min        | 106 [84, 146] | 124 [113, 166] | 91 [81.3, 116.5] | 0.001 |
| Selective antegrade cerebral perfusion time, min | 55 [49, 72] | 74 [56, 114] | 52 [47, 52] | 0.001 |
| Bentall operation                     | 9 (20.0%) | 5 (26.3%) | 4 (15.4%) | 0.597 |
| Coronary artery bypass grafting      | 1 (2.3%) | 1 (5.3%) | 0 | 0.906 |
| Mitral or tricuspid valve procedure   | 2 (4.4%) | 1 (5.3%) | 1 (3.8%) | 1.00 |
| pRBC use                             | 20 (44.4%) | 12 (63.2%) | 8 (30.8%) | 0.031 |
| pRBC, units                          | 0 (0, 3) | 2 (0, 4) | 0 (0, 2) | 0.048 |
| Platelets, units                     | 3 (2, 4) | 4 (3, 5) | 2 (2, 3) | 0.002 |
| Fresh frozen plasma, units           | 0 (0, 2) | 0 (0, 2) | 0 (0, 2) | 0.709 |
| Cryoprecipitates, units              | 2 (0, 4) | 2 (2, 4) | 1 (0, 2.75) | 0.024 |

Values are expressed in n (%), or median (First;Third quantile). pRBC=packed red blood cell
Table 3. Hospital Outcomes

<table>
<thead>
<tr>
<th></th>
<th>All N=45</th>
<th>Arch-First N=19</th>
<th>Proximal-First N=26</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative mortality</td>
<td>4 (8.9%)</td>
<td>2 (10.5%)</td>
<td>2 (7.7%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Operative mortality + Major morbidity</td>
<td>14 (31.1%)</td>
<td>11 (57.9%)</td>
<td>3 (11.5%)</td>
<td>0.001</td>
</tr>
<tr>
<td>Permanent stroke</td>
<td>7 (15.6%)</td>
<td>5 (26.3%)</td>
<td>2 (7.7%)</td>
<td>0.198</td>
</tr>
<tr>
<td>Re-exploration for bleeding</td>
<td>3 (6.7%)</td>
<td>3 (15.8%)</td>
<td>0</td>
<td>0.136</td>
</tr>
<tr>
<td>Tracheostomy</td>
<td>9 (20.0%)</td>
<td>7 (36.8%)</td>
<td>2 (7.7%)</td>
<td>0.042</td>
</tr>
<tr>
<td>Renal failure</td>
<td>5 (11.1%)</td>
<td>4 (21.1%)</td>
<td>1 (3.8%)</td>
<td>0.182</td>
</tr>
<tr>
<td>Deep sternal wound infection</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>Spinal cord ischemia</td>
<td>1 (2.3%)</td>
<td>1 (5.3%)</td>
<td>0</td>
<td>0.906</td>
</tr>
<tr>
<td>Leg ischemia</td>
<td>4 (8.9%)</td>
<td>2 (10.5%)</td>
<td>2 (7.7%)</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Figure Legends

**Figure 1.** Surgical steps of arch-first and proximal-first Zone 2 arch repair.

Yellow bars show the duration of circulatory arrest time of the lower body for each technique.

*This step can be skipped when sawing a bifurcated graft before cross-clamp or using a four-branched graft. CPB=cardiopulmonary bypass, IA=innominate artery, LCCA=left common carotid artery, RAX=right axillary artery

**Figure 2.** Proximal-first technique. (A) After proximal anastomosis, distal anastomosis is performed with moderate hypothermic circulatory arrest. The brain is perfused by unilateral ACP from the right axillary artery. (B) After completion of distal anastomosis, systemic perfusion is resumed including the lower body and left SCA. Rewarming is initiated during left CCA anastomosis. (C) The IA is anastomosed and the end of selective ACP.

ACP=antegrade cerebral perfusion, CCA=common carotid artery, SCA=subclavian artery

**Figure 3.** Arch-first technique. (A). After circulatory arrest of the lower body, bifurcated graft is anastomosed to the left CCA followed by innominate artery anastomosis. (B) Bilateral ACP is established and distal anastomosis is performed with an inverted graft into the distal aorta. (C) Ascending graft is pulled out and anastomosed above the sino-tubular junction. (D) proximal part of a bifurcated graft is anastomosed to the ascending graft. Systemic perfusion is resumed and rewarming is initiated. ACP=antegrade cerebral perfusion, CCA=common carotid artery

**Figure 4.** Kaplan Meier survival curve.

**Figure 5.** Graphical Abstract

**Supplemental Figure 1.** A flow chart of study population

**Supplemental Figure 2.** Proximal reoperation after Zone 2 arch repair. Bilateral axillary cannulation was used during Bentall operation while the ascending graft and bifurcated graft were separately clamped.
Survival

Patient at risk

Arch-first
19 10 8 6 4

Proximal-first
26 14 2 0

P = 0.739
Zone 2 Arch Repair for Acute Type A Dissection: Evolution From Arch-First to Proximal-First Repair

Methods  From Jan. 2015 to Mar. 2023, Zone 2 arch repair Type A dissection, N=45

Results  Proximal-first vs. Arch-first
Bladder temp: 24.9 vs. 19.7 °C, P<0.001
CPB time: 230 vs. 177.5 min, P<0.001
Lower body ischemic time: 87 vs. 28 min, P<0.001
Mortality+Morbidity: 11.5% vs. 57.9%, P=0.001

Summary  Zone 2 arch repair using proximal-first technique for ATAD repair yields shorter lower body ischemic time with warmer core temperature resulting in fewer morbidities when compared to the arch-first technique.
Acute type A Dissection Repair  
N = 208  
Jan. 2015 – Mar. 2023  

Exclusion  
Hemi-arch repair: N = 154  
Total arch repair: N = 9  

Zone 2 arch repair  
N = 45  

Arch-first  
N = 19  

Proximal-first  
N = 26
### Supplemental Table 1. Distal intervention after Zone 2 arch repair

<table>
<thead>
<tr>
<th>Arch-first technique</th>
<th>Indication</th>
<th>Procedure</th>
<th>Interval from Zone 2 repair</th>
<th>Outcome</th>
</tr>
</thead>
</table>
| 66 yo, female         | Aneurysm of aortic arch and descending aorta | 1. Reoperative total arch repair+elephant trunk  
                      |            | 2. Repair of descending aorta, left thoracotomy | 15 months | Alive |
|                      |            |           | 18 months | Alive |
| 65 yo, male           | Enlarged false lumen | TEVAR (PETTICOAT)+left SCA-CAA bypass | 2 months | Alive |
| Proximal-first technique |            |           |            |        |
| 59 yo, male           | Enlarged false lumen | TEVAR (PETTICOAT) + left SCA-CCA bypass | 3 months | Alive |
| 27 yo, female         | Aneurysm of descending aorta | Repair of descending aorta, left thoracotomy | 8 months | Alive |
| 28 yo, male           | Enlarged false lumen | TEVAR (one-branch+PETTICOAT) | 2 months | Alive |

PETTICOAT=provisional extension to induce complete attachment, TEVAR=thoracic endovascular repair