Late outcomes of strategic arch resection in acute type A aortic dissection

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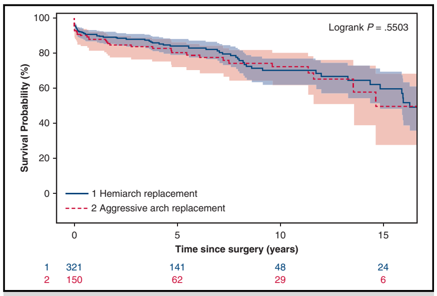
ABSTRACT

Objective: To compare perioperative and long-term outcomes in patients undergoing hemiarch and aggressive arch replacement for acute type A aortic dissection (ATAAD).

Methods: From 1996 to 2017, we compared outcomes of hemiarch (n = 322) versus aggressive arch replacements (zones 2 and 3 arch replacement with implantation of 2-4 arch branches, n = 150) in ATAAD. Indications for aggressive arch were arch aneurysm >4 cm or intimal tear in the aortic arch that was not resectable by hemiarch replacement, or dissection of arch branches with malperfusion.

Results: Patients in the aggressive arch group were significantly younger (mean age: 57 vs 61 years old) and had significantly longer hypothermic circulatory arrest, cardiopulmonary bypass, and aortic crossclamp times. There were no significant differences in perioperative outcomes between hemiarch and aggressive arch groups, including 30-day mortality (5.3% vs 7.3%, $P = .38$) and postoperative stroke rate (7% vs 7%, $P = .96$). Over 15 years, Kaplan–Meier survival was similar between hemiarch and aggressive arch groups (log-rank $P = .55$, 10-year survival 70% vs 72%). Given death as a competing factor, incidence rates of reoperation over 15 years (2.1% vs 2.0% per year, $P = 1$) and 10-year cumulative incidence of reoperation (14% vs 12%, $P = .89$) for arch and distal aorta pathology were similar between the 2 groups.

Conclusions: Both hemiarch and aggressive arch replacement are appropriate approaches for select patients with ATAAD. Aggressive arch replacement should be considered for an arch aneurysm >4 cm or an intimal tear at the arch unable to be resected by hemiarch replacement, or dissection of the arch branches with malperfusion. (J Thorac Cardiovasc Surg 2019;157:1313-21)



Long-term survival in hemiarch and aggressive arch replacement in patients with ATAAD.

Central Message

Both hemiarch and aggressive arch replacement are appropriate approaches for select patients with acute type A aortic dissection.

Perspective

Both hemiarch and aggressive arch replacement are appropriate approaches for select patients with acute type A aortic dissection with good short- and long-term outcomes if the procedure can achieve the goal of resecting the intimal tear at the aortic arch and/or arch aneurysm and resolve the malperfusion of arch branch vessels.

See Commentary on page 1322.

Acute type A aortic dissection (ATAAD) is a lethal event associated with an operative mortality between 20% and 25%.[1] Resection of the intimal tear and replacement of the ascending aorta are considered mainstays of operative therapy. Although the aortic arch is often involved in the aortic dissection, the optimal management of the aortic arch during surgical therapy for ATAAD remains uncertain.

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Abbreviations and Acronyms

ACP	= antegrade cerebral perfusion
ATAAD	= acute type A aortic dissection
CAD	= coronary artery disease
CI	= confidence interval
HCA	= hypothermic circulatory arrest
HR	= hazard ratio
MFS	= Marfan syndrome
RCP	= retrograde cerebral perfusion
TEVAR	= thoracic endovascular aortic repair

Some surgeons advocate for a conservative approach to the aortic arch, limiting the extent of repair to a hemiarch replacement. This approach minimizes the operative time during an already-complex surgical repair, potentially lowering morbidity and mortality and sufficient to preserve life in an emergent setting.[2-5] However, patients with ATAAD and hemiarch repair may be susceptible to a greater risk of aortic rupture, late stroke, and/or at an increased risk of future reoperation(s).[6-9] Others advocate for a more aggressive upfront approach by addressing the long-term deterioration of the aortic arch by replacing the total arch.[10-14] This approach may lead to longer circulatory arrest, crossclamp, cardiopulmonary bypass, and overall operative times, which may also increase the risk of operative mortality and/or worsened perioperative complication rates.[15,16]

In this context, we examined consecutive patients over the previous 20 years who underwent hemiarch versus aggressive arch replacement and compared perioperative outcomes, long-term survival, and reoperation rates. We hypothesized that with proper patient selection both hemiarch and aggressive arch replacement are appropriate operations with favorable short- and long-term outcomes.

METHODS

This study was approved (September 26, 2016; HUM00118824) by the University of Michigan Institutional Review Board (Michigan Medicine, Ann Arbor, Mich) and a waiver of consent was obtained.

Study Population

Between July 1996 and January 2017, there were a total of 545 open repairs for ATAAD; 73 were excluded from this study for (1) no arch replacement (n = 32) and (2) zone 1 arch replacement (aortic arch was divided between innominate artery and left common carotid artery with reimplantation of innominate artery) (n = 41). In total, 472 patients underwent an aortic arch procedure with conservative management (hemiarch replacement, n = 322) or aggressive management (zones 2/3 arch replacement, n = 150) during repair for an ATAAD (Figure E1). Hemiarch replacement involved replacement of the arch from the base of the innominate artery to the lesser curvature of the aortic arch with no reimplantation of arch branch vessels. Zone 2 or 3 arch replacement involved replacing the arch between the left common carotid artery and left subclavian artery or distal to the left subclavian artery with implantation of 2 to 4 arch branch vessels. Indications for aggressive arch replacement included an arch aneurysm >4 cm or intimal tear located in the arch that could not be resected by a hemiarch replacement, or dissection of arch branch vessels with malperfusion.

Data-Collection Techniques

Investigators obtained Society of Thoracic Surgery data elements from the University of Michigan Department of Cardiac Surgery Data Warehouse to determine pre-, intra-, and postoperative characteristics as previously reported.[17] Medical records, including operative reports, were reviewed to supplement data collection. Reoperation events included open repair (sternotomy or thoracotomy) or thoracic endovascular aortic repair (TEVAR) primarily for arch aneurysm or descending thoracic aortic aneurysm only. Reoperations primarily for aortic root pathology were included in total events of reoperation for any reason. Survival was obtained through the National Death Index database through December 31, 2015,[18] supplemented with medical record review and phone call survey. Further survival data and reoperation data were collected from a thorough medical record review on patients' return visits as well as surveys (including letters and phone calls, January 2018). Loss of follow-up or end of the study period were treated as censors during the time to events analysis.

Operative Techniques

Aortic arch replacement was performed with hypothermic circulatory arrest (HCA) with or without cerebral perfusion. Retrograde cerebral perfusion (RCP) was achieved through a separate cannula in the superior vena cava. Antegrade cerebral perfusion (ACP) was achieved through direct cannulation into the innominate artery and left common carotid artery in the early years and a chimney graft sewn to the innominate artery, right axillary artery, right intrathoracic subclavian artery, or right common carotid artery in recent years. RCP, unilateral ACP, or bilateral ACP was chosen based on surgeons' preference. Conversion of unilateral ACP to bilateral ACP was initiated by inserting a separate cannula directly into the left common carotid artery when left cerebral saturation by near-infrared spectroscopy decreased independently. Arch branch vessels were resected and replaced if they were thrombosed and significantly occluded. Separate incisions were made at the neck to replace the whole common carotid arteries if the common carotid arteries were thrombosed and occluded. Arch branch vessels were replaced or reimplanted with separate branch grafts. Patients were cooled down to <20°C if RCP was used and 24°C to 28°C if ACP was used in the recent years. A frozen elephant trunk (cTAG 10 cm; Gore W. L. Gore & Associates, Flagstaff, Ariz) was placed into the true lumen of the descending thoracic aorta distal to the left subclavian artery if the intimal tear was found in the proximal descending aorta to cover the intimal tear or a very narrow true lumen was found in the distal thoracic or abdominal aorta on the computed tomography angiogram to prevent lower body malperfusion.

Statistical Analysis

Data are presented as median (interquartile range, 25%, 75%) for continuous data and n (%) for categorical data. Univariate comparisons between hemiarch replacement and aggressive arch replacement were performed using χ^2 tests for categorical data and Wilcoxon rank sum tests for continuous data. Multivariable logistic regression was used to calculate the odds ratio of aggressive arch versus hemiarch replacement for 30-day mortality and other postoperative major complications adjusting for age, sex, coronary artery disease (CAD), acute myocardial infarction, preoperative severe aortic insufficiency, and cardiac tamponade based on the significantly different preoperative conditions between hemiarch and aggressive arch replacement groups. Crude survival curves since operation were estimated using the nonparametric Kaplan–Meier method. Log-rank test was used to compare the survival of groups (hemiarch vs aggressive arch replacement). Cox proportional hazards regression was used to calculate the adjusted hazard ratios (HRs) with 95% confidence interval (CI) for death, also adjusting for age, sex, CAD, acute myocardial infarction, preoperative severe aortic insufficiency, and cardiac tamponade.

TABLE 1. Demographics and preoperative characteristics of patients

Variables	Hemiarch (n = 322)	Aggressive arch (n = 150)	*P* value
Patient age, y	61 (50, 70)	57 (48, 66)	.03
Sex (female) (%)	96 (30)	46 (31)	.85
BSA	2.1 (1.9, 2.2)	2.0 (1.9, 2.2)	.96
Pre-existing comorbidities			
Hypertension	230 (71)	107 (71)	.98
Diabetes mellitus	21 (6.5)	9 (6)	.83
History of smoking			.96
None	140 (44)	66 (44)	
Former	90 (28)	40 (27)	
Current	91 (28)	43 (29)	
CAD	71 (23)	15 (9)	.0004
COPD	25 (8)	16 (11)	.29
History of stroke	9 (3)	3 (2)	.76
History of renal failure	12 (4)	6 (5)	.885
On dialysis	7 (2)	2 (3)	.53
Marfan syndrome	16 (5)	5 (3)	.42
Other connective tissue disease	3 (1)	2 (1)	.65
PVOD	39 (12)	18 (12)	.97
Previous cardiac surgery	31 (10)	18 (12)	.62
Aortic valve morphology			.009
Unicuspid/bicuspid	34 (11)	4 (3)	
Tricuspid	237 (74)	124 (83)	
Quadricuspid	1 (0.3)	0 (0)	
Unknown	50 (15.5)	22 (15)	
Preoperative AI			.055
None	80 (26)	54 (39)	
Trace	39 (13)	17 (12)	
Mild	66 (21)	18 (13)	
Moderate	48 (16)	21 (15)	
Severe	75 (24)	30 (21)	
Ejection fraction	55 (50, 60)	55 (50, 60)	.99
NYHA function class			
III/IV	60 (19)	35 (23)	.24
Acute myocardial infarction	13 (4)	1 (1)	.045
Acute stroke	13 (4)	7 (5)	.75
Acute renal failure	40 (12)	26 (17)	.15
Acute paralysis	4 (1)	4 (3)	.27
Cardiogenic shock	31 (10)	10 (7)	.29
Tamponade	36 (11)	6 (4)	.01
Preoperative creatinine	1.0 (0.8, 1.3)	1.0 (0.9, 1.4)	.61
Malperfusion syndrome			
Coronary	11 (3)	2 (1)	.20
Cerebral	13 (4)	7 (5)	.75
Spinal cord	4 (1)	4 (3)	.26
Celiac	7 (2)	1 (1)	.24
Mesenteric	27 (8)	16 (11)	.42
Renal	25 (8)	14 (13)	.56
Extremity	28 (9)	19 (13)	.18
Delayed operation	48 (15)	32 (21)	.08

(Continued)

TABLE 1. Continued

Data presented as median (25%, 754%) for continuous data and n (%) for categorical data. *BSA*, Body surface area; *CAD*, coronary artery disease; *COPD*, chronic obstructive pulmonary disease; *PVOD*, peripheral vascular occlusive disease; *AI*, aortic insufficiency; *NYHA*, New York Heart Association.

As patients may experience death before reoperation, cumulative incidence curves adjusting for death as the competing risk were generated to assess reoperation rates over time. The Gray test was used to test the difference in the cumulative incidence curves between the 2 groups. Incidence rates were calculated for long-term events (such as stroke, transient ischemic attack, endocarditis, reoperation for aortic arch or descending thoracic aortic aneurysm), in which the numbers of events were divided by total patient years of follow-up. Rate ratio tests were used to compare the incidence rates between the 2 groups. Cox proportional hazards regression was used to calculate the cause-specific HRs for reoperation by treating death as a competing risk and adjusting for age, sex, hypertension, and connective tissue disease. *P* values of less than .05 (2-tailed) were considered statistically significant. All statistical calculations used SAS 9.4 (SAS Institute, Cary, NC).

RESULTS

Demographics and Preoperative Data

Patients in the aggressive arch group were significantly younger (mean age: 57 vs 61 years old, $P = .03$), had significantly lower incidences of CAD, acute myocardial infarction, cardiac tamponade, and fewer bicuspid aortic valve (all $P < .05$). Other pre-existing conditions, such as hypertension, diabetes, renal failure, chronic obstructive pulmonary disease, and New York Heart Association function class were similar between groups. There was no significant difference in malperfusion syndrome between the hemiarch and aggressive arch groups, including cerebral, spinal cord, celiac/hepatic, mesenteric, renal, and extremities malperfusion (Table 1).

Intraoperative Data

The aggressive arch group had significantly less aortic root replacements but more complex aortic arch operations with reimplantation of 2 to 4 arch branch vessels as well as significantly more frozen elephant trunk placements, use of ACP, and longer HCA, cardiopulmonary bypass, and aortic crossclamp times. The lowest temperature of the body during HCA was similar between the 2 groups. There were no significant differences between groups for concomitant surgeries (including coronary artery bypass, mitral valve, and tricuspid valve surgery) or intraoperative transfusion of packed red blood cells (Table 2).

Perioperative Outcomes

There were no significant differences in perioperative outcomes between hemiarch and aggressive arch groups,

TABLE 2. Intraoperative outcomes

Variables	Hemiarch (n = 322)	Aggressive arch (n = 150)	P value
Aortic root procedure			
AVR only	5 (2)	3 (2)	.71
Root replacement	117 (36)	28 (19)	<.0001
Bentall	37 (11.5)	15 (10)	
Inclusion	53 (16.5)	6 (4)	
VSARR	27 (8)	7 (5)	
Root repair	178 (55)	98 (65)	.04
Frozen elephant trunk	11 (3)	18 (12)	.0003
CPB time, min	217.5 (176, 269)	227 (190, 274)	.056
Crossclamp time, min	144 (108, 195)	160 (133, 205)	.002
HCA			
HCA time, min	32 (26, 39)	43.5 (34, 55)	<.0001
ACP or RCP			<.0001
ACP	91 (28)	54 (36)	
RCP	194 (60)	5 (3)	
Both ACP and RCP	32 (10)	91 (61)	
Neither	5 (2)	0 (0)	
Lowest temperature, °C	18 (16.7, 19.8)	18 (16.2, 22)	.46
Bladder	24.5 (19.5, 31.9)	26 (19.7, 29.6)	.90
Esophageal	22.6 (17.6, 31.2)	24.2 (18.6, 29.9)	.47
Concomitant procedures			
CABG	20 (6)	6 (4)	.33
Mitral valve	0 (0)	2 (1)	.1
Tricuspid valve	4 (1)	0 (0)	.31
Blood transfusions (PRBCs)			.39
0 units	63 (21)	25 (17)	
1 unit	25 (8)	7 (5)	
2 units	26 (9)	14 (10)	
≥3 units	189 (62)	100 (68.5)	

Data presented as median (25%, 75%) for continuous data and n (%) for categorical data. *AVR*, Aortic valve replacement; *VSARR*, valve-sparing aortic root replacement; *CPB*, cardiopulmonary bypass; *HCA*, hypothermic circulatory arrest; *ACP*, antegrade cerebral perfusion; *RCP*, retrograde cerebral perfusion; *CABG*, coronary artery bypass graft; *PRBCs*, packed red blood cells.

including postoperative myocardial infarction, stroke and paraplegia, new-onset renal failure, new hemodialysis, permanent dialysis, sepsis, prolonged ventilation, reoperation for bleeding, length of hospital stay, 30-day mortality (5.3% vs 7.3%, $P = .38$), in-hospital mortality (Table 3), and operative mortality, which included mortality occurring within 30 days postoperatively and/or in-hospital (7% vs 9%, $P = .41$). The multivariable logistic regression showed that only reoperation for bleeding was significantly greater in the aggressive arch replacement group with adjusted odds ratio of 1.97 ($P = .049$), and the 30-day mortality and other major complications were not significantly different (Table 4).

Long-Term Outcomes

From all 472 patients, we had 356 (75.4%) patients' responses to the surveys and information in the medical charts. Our total follow-up time for long-term events was 2524.5 patient years. The mean follow-up time was 5.3 years. Sixty percent (285/472) of all cases were performed in the second decade (2008-2017).

The long-term survival was similar between hemiarch and aggressive arch groups: 10-year Kaplan–Meier survival: 70% (95% CI, 62%-77%) versus 72% (95% CI, 62%-80%), Log-rank test P value = .55 (Figure 1). After adjustment for age, sex, CAD, acute myocardial infarction, preoperative severe aortic insufficiency, and cardiac tamponade in the Cox proportional hazard regression, there was no statistically significant difference in late mortality between aggressive arch and hemiarch groups ($HR_{adjusted}$, 1.4; 95% CI, 0.92-2.2, $P = .11$). The adjusted HR of all-cause death for age was 1.033 (95% CI, 1.02-1.05, $P = .0003$), for CAD was 1.7 (95% CI, 1.09-2.7, $P = .02$), and for acute myocardial infarction was 2.2 (95% CI, 0.9-5.8, $P = .1$).

The incidence rates of combined reoperations for the aortic arch and descending thoracic or thoracoabdominal aortic pathology were not significantly different in hemiarch versus aggressive arch groups, including open repair through sternotomy for aortic arch pathology and thoracotomy or TEVAR for descending thoracic or thoracoabdominal aortic aneurysm. Incidence rates of reoperation for separate aortic arch pathology and descending thoracic aortic aneurysm or thoracoabdominal aneurysm were not significantly different between groups, either (Table 5). Ten-year postoperative cumulative incidence of reoperation primarily for the pathology of the aortic arch, descending, or thoracoabdominal aorta was not significantly different between hemiarch and aggressive arch groups adjusted for death as a competing factor (13.9%; 95% CI, 9.2%-19.7% vs 11.7%; 95% CI, 6.7%-18.2%); Gray test P value = .89, Figure 2, *A*), nor the cumulative incidence of all reoperation for any aortic pathology, including aortic root, ascending aorta, arch, and distal aorta (Figure 2, *B*). Given death as the competing event, hemiarch replacement compared with aggressive arch replacement did not significantly increase the hazard of reoperation for aortic arch pathology or descending thoracic or thoracoabdominal aortic pathology (hemiarch replacement vs aggressive arch replacement, $HR_{adjusted}$, 1.08; 95% CI, 0.58-1.9; $P = .81$). The 30-day mortality was 0% for both subsequent open thoracic or thoracoabdominal aortic aneurysm repair and TEVAR (Table E1).

DISCUSSION

In this study, we report our 20-year experience of managing aortic arch replacement in 472 patients with ATAAD. We found with proper patient selection, the 30-day mortality and perioperative stroke rate were similarly low in both hemiarch and aggressive arch replacement groups. The 10-year survival was greater than 70% in both groups

TABLE 3. Postoperative outcomes

Variables	Hemiarch (n = 322)	Aggressive arch (n = 150)	P value
Myocardial infarction	4 (1)	1 (1)	1
Cerebrovascular accident	24 (7)	11 (7)	.96
Atrial fibrillation	126 (39)	45 (30)	.055
Pneumonia	65 (20)	23 (15)	.21
New-onset renal failure	31 (10)	15 (10)	.90
On dialysis	14 (4)	7 (5)	.88
Permanent	4 (1)	4 (3)	.27
Reoperation for bleeding	26 (8)	18 (12)	.17
Deep sternal wound infection	8 (2.5)	5 (3)	.56
Sepsis	11 (3)	2 (1)	.24
Paraplegia	3 (1)	1 (1)	.77
GI complications	29 (9)	11 (7)	.54
Need for tracheostomy	13 (4)	4 (3)	.46
Prolonged vent	179 (56)	84 (56)	.93
Hours intubated	44 (23.9, 106.5)	50 (24, 100.5)	.9
Reintubation	19 (6)	13 (9)	.27
Postop length of stay, d	10 (7, 17)	11 (7, 18)	.5
Total length of stay, d	12 (7, 19)	12 (8, 22)	.6
Intraoperative mortality	2 (1)	3 (2)	.33
In-hospital mortality	22 (7)	14 (9)	.34
30-d mortality	17 (5)	11 (7)	.38

Data presented as median (25%, 75%) for continuous data and n (%) for categorical data. *GI*, Gastrointestinal. GI complications include but are not limited to: GI bleeding, pancreatitis, cholecystitis, mesenteric ischemia, hepatic failure, prolonged ileus, and clostridium difficile.

with no significant difference in the reoperation rate for pathology of the aortic arch and distal aorta over the 15-year follow-up period (Video 1).

How much of the dissected aortic arch should be replaced in ATAAD? Our criteria for zone 2 or 3 aortic arch replacement includes an arch aneurysm >4 cm or intimal tear located in the arch, which cannot be resected by a hemiarch replacement, or dissection of the arch branch vessels with malperfusion. Our primary goal is not to leave any intimal tear or aneurysm in the aortic arch and resolve malperfusion of arch branch vessels. If hemiarch replacement cannot achieve this goal, we replace the arch as much as needed. Although zone 2/3 arch replacements are more complex than hemiarch replacements as shown in our study (Table 2), the perioperative outcomes and long-term survival were similar to the patients in the hemiarch group. This finding is consistent with reports from studies using data from the International Registry of Aortic Dissection,[19] German Registry for Acute Aortic Dissection type A,[20] and a meta-analysis,[11] although the in-hospital mortality or 30-mortality in those studies was higher (mortality for hemiarch: 13%-20%, mortality for total arch: 17%-26%).

The operative mortality was much lower than that reported in the Society of Thoracic Surgeons Database, International Registry of Aortic Dissection, and German Registry for Acute Aortic Dissection type A probably due to 2 factors: (1) Case selection: we manage the patients with malperfusion syndrome (end-organ necrosis and dysfunction) with endovascular fenestration and stenting first, then perform open aortic repair if patients recover from organ failure.[21] In the past decade, we treated 354 patients with ATAAD with (n = 49) or without (n = 305) endovascular amenable malperfusion syndrome with this strategy. After malperfusion was resolved by endovascular fenestration/stenting, 15 (4%) patients died in the hospital all due to organ failure resulted from malperfusion syndrome but not aortic rupture before open aortic repair.[21] With this strategy, our in-hospital mortality of all comers with or without open aortic repair was 11% in the past decade.[21] Most patients with malperfusion syndrome (necrotic bowel or limb) are treated medically as nonoperative candidates at many institutions and are often not included in the reported operative mortality. (2) All ATAAD cases were primarily performed by 3 aortic surgeons who perform 15 to 25 ATAAD cases/year. Our case volume of ATAAD has increased every year in the past 2 decades to 50 to 60 cases/year (Figure E2). All of the ATAAD cases are concentrated on by 3 aortic surgeons. Every aortic

TABLE 4. Logistic model for 30-day mortality and perioperative outcomes

Outcomes	Crude OR (95% CI) aggressive vs hemiarch	P value	Adjusted* OR (95% CI) aggressive vs hemiarch	P value
30-d mortality	1.37 (0.62, 2.99)	.44	1.94 (0.84, 4.51)	.12
Myocardial infarction	0.53 (0.06, 4.82)	.58	0.71 (0.07, 7.16)	.77
Stroke	0.94 (0.45, 1.97)	.87	1.06 (0.50, 2.29)	.87
New-onset renal failure	0.97 (0.50, 1.88)	.92	1.14 (0.58, 2.24)	.70
Prolonged ventilation	1.48 (0.88, 2.47)	.14	1.68 (0.96, 2.93)	.07
Reoperation for bleeding	1.55 (0.82, 2.93)	.17	1.97 (1.001, 3.87)	.049
Hospital length of stay	1.11 (0.74, 1.67)	.61	1.35 (0.88, 2.08)	.17

OR, Odds ratio; *CI*, confidence interval. *Adjusted for age, sex, severe aortic insufficiency, coronary artery disease, acute myocardial infarction, tamponade.

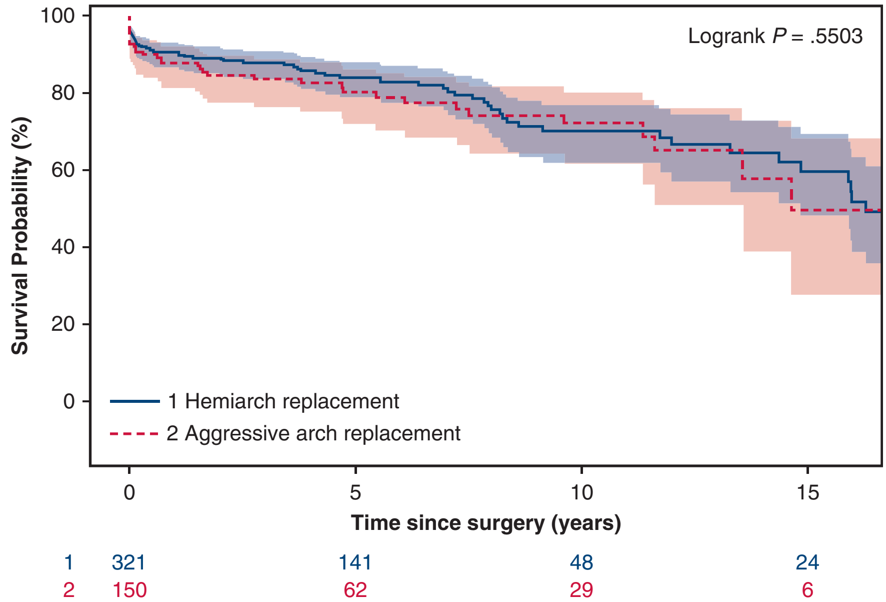


FIGURE 1. Kaplan–Meier long-term survival of patients with acute type A aortic dissection undergoing hemiarch or aggressive arch replacement.

surgeon is very familiar with procedures of the aortic root, arch, frozen elephant trunk, and malperfusion management in patients with ATAAD. This focused practice has helped us achieve better outcomes, as also seen in other institutions.[22] We think that the management of the aortic dissection patient should be restricted to surgeons with skill and interest in the management of aortic disease rather than leaving the aortic "disaster" in the hands of the junior-level surgeon on call unsupervised.

The second goal of arch replacement in ATAAD is to resolve the malperfusion of arch branch vessels. If there is dissection of arch branch vessels with significant occlusion, blood pressure gradient (>15 mm Hg) between aorta and radial arteries, or stroke, we replace the arch branches via aggressive arch replacement to resolve malperfusion and hopefully prevent future stroke from the embolization of the thrombus in the dissected common carotid arteries. We do not compromise the arch surgery because of a difficult aortic root replacement. We also perform endovascular fenestration and stenting before open aortic repair to resolve malperfusion in patients with ATAAD complicated by malperfusion syndrome.[21] Relieving the concern of malperfusion and end-organ death during the open aortic repair allows us to do a more aggressive operation if needed. The hemiarch group had more root procedures likely because they had more root pathology (such as root aneurysm) but less arch pathology (such as arch aneurysm).

TABLE 5. Complications and reoperations for pathology of aortic arch and distal aorta during long-term follow-up

	Hemiarch		Aggressive arch		
	n = 322	Incidence rate (%/year)	n = 150	Incidence rate (%/year)	*P* value
TIA	3	0.17	1	0.12	1
Stroke	6	0.35	2	0.25	1
Bleeding	1	0.06	3	0.38	.19
Reoperation primarily for					
Aortic arch aneurysm	7	0.43	0	0	.15
TAA/A	27	1.7	15	2.0	.62
Surgery type					
TEVAR	4	0.25	2	0.27	1
Open TAA/A repair	23	1.4	13	1.8	.41
Open arch repair (median sternotomy)	7	0.43	0	0	.15
Total procedures	34	2.1	15	2.0	1

P value indicates the difference of the incidence rate between the hemiarch and aggressive arch groups. *TIA*, Transient ischemic attack; *TAA/A*, thoracic aortic aneurysm (TAA) or thoracoabdominal aortic aneurysm (TAAA); *TEVAR*, thoracic endovascular aortic repair.

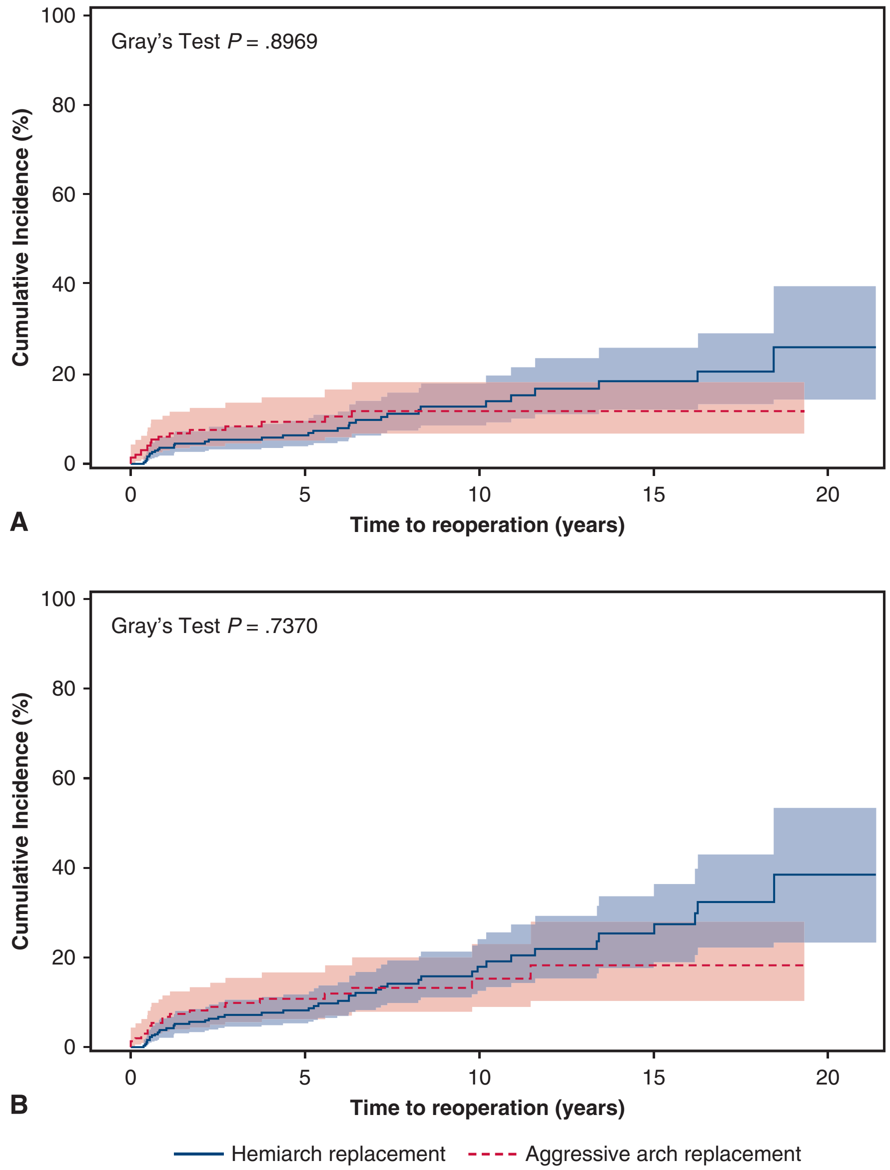
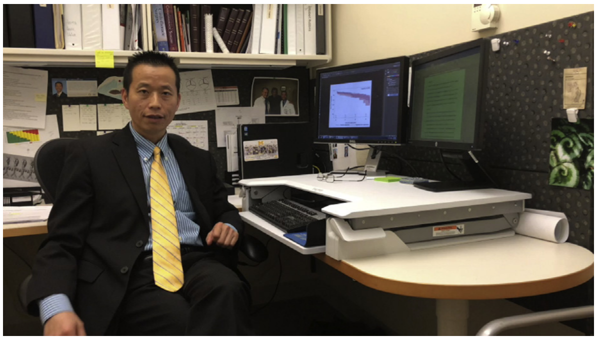


FIGURE 2. A, The cumulative incidence of only reoperation for aortic arch and distal aorta, including sternotomy for arch pathology, open repair of descending thoracic or thoracoabdominal aortic aneurysm, and thoracic endovascular aortic repair, adjusting for death as the competing event. B, The cumulative incidence of all reoperation for any aortic pathology, including aortic root, ascending aorta, arch, and distal aorta, adjusting for death as the competing event.

Our perioperative stroke rate in the aggressive arch replacement group was similar to those in other large studies.[12,19,20] In recent years, the stroke rate was 4%,[17] which is similar to the results reported by the Pittsburgh group (stroke rate 3.4%) in the same time frame, who replace all the dissected carotid arteries with or without malperfusion.[23] In our study, the incidence of transient ischemic attack and stroke in patients with ATAAD with total arch replacement during follow-up was 0.12% and 0.25% separately (Table 4). Therefore, we recommend replacing the arch branches if they are dissected with subsequent malperfusion to achieve low perioperative and long-term stroke rates. Taken together, our results suggest that aggressive arch replacement can be performed in patients with ATAAD with good outcomes despite the complexity of the operation.

Should we perform aggressive arch for all patients with ATAAD? The answer is no. If the patient does not have an arch aneurysm, intimal tear at the arch, or malperfusion of the brain or upper extremity, we recommend performing a hemiarch replacement. Currently in our practice, we have also found that the proximal arch aneurysm or intimal tear can frequently be resected with an aggressive hemiarch replacement by a peninsular technique,[17] replacing 60%



VIDEO 1. Discussion of aortic arch management in acute type A aortic dissection repair. Video available at: https://www.jtcvs.org/article/S0022-5223(18)32936-2/fulltext.

to 70% of the dissected aortic arch to achieve our primary goal. In this study, 68% of dissected arches were repaired with a hemiarch replacement. In the past decade, we have performed more hemiarch replacements than zone 2/3 arch replacements every year (Figure E2). The criteria of aggressive arch replacement have not changed over the past couple decades. Compared with the aggressive arch group, the patients with a hemiarch replacement had similar perioperative outcomes (Table 3), long-term survival rate (Figure 1), as well as reoperation rate for pathology of the aortic arch, descending thoracic aorta, or thoracoabdominal aorta in the 15-year follow-up (Figure 2). This result highlights that hemiarch replacement was adequate for the dissected aortic arch in patients with ATAAD if there was no aortic arch aneurysm or intimal tear left at the aortic arch. Shi and colleagues[3] reported similar results to those reported herein such as no difference in short- and long-term outcomes by comparing the hemiarch and total arch replacement with frozen elephant trunk in patients with ATAAD with no intimal tear at the arch. Zhang and colleagues[24] did a similar study and found that the hemiarch with frozen elephant trunk had a greater reintervention rate due to multiple intimal tears at the arch after the repair of the ATAAD, including intimal tears at the distal anastomotic site at the arch. Their results support the concept and importance of not leaving or creating any intimal tear at the dissected aortic arch after arch repair, which is our primary goal.

The management of the aortic arch in patients with connective tissue disease in the setting of ATAAD is still controversial. Bachet and colleagues[25] recommend an aggressive approach to the arch in patients with Marfan syndrome (MFS) with ATAAD to prevent potential reoperation of the arch; however, they only had 19 patients with MFS with ATAAD in their study. Schoenhoff and colleagues[26] emphasized, in their study, the need for reinterventions is precipitated by the dissection itself and not by limiting the procedure to the hemi-arch replacement in patients with acute aortic dissection. We did not use known connective tissue disease as an indication for total arch replacement. After ATAAD, patients with MFS frequently develop an aneurysm of the distal aorta, including descending thoracic or thoracoabdominal aortic aneurysm, which warrants an operation. Total arch replacement does not eliminate the need for reoperation of a distal aortic aneurysm. The distal arch aneurysm in patients with MFS that can develop after ATAAD repair can be repaired during descending thoracic or thoracoabdominal aortic aneurysm repair. The Cox proportional hazard analysis of cumulative incidence of reoperation showed the HR of MFS versus non-MFS was 1.15 (95% CI, 0.53, 2.50), $P = .72$. Our data did not support connective tissue disease as an indication for an aggressive approach of arch replacement.

In the real world, total arch replacement in patients with ATAAD still remains a challenge as operative mortality of total arch replacement in patients with ATAAD ranges from 17% to 33%.[12,16,19,20,27-29] Some studies[16,29] recommend conservative arch management for all patients with ATAAD because it is reasonable to conservatively manage the aortic arch in ATAAD to save the patient's life first, especially if the surgeon is inexperienced with ATAAD and/or total arch replacement. At our center, patients with ATAAD are operated on by aortic surgeons familiar with aortic pathology and arch replacement. We also manage the malperfusion of abdominal viscera and extremities upfront with endovascular fenestration and stenting and then perform the open aortic repair following resolution of malperfusion. Resolving the malperfusion preoperatively allows us to be more aggressive during the aortic arch repair in patients with ATAAD if indicated, as we described previously.

Our study is limited by a single-center and retrospective experience. The incomplete follow-up of patients could underestimate the incidence of reoperations in both groups. Most patients who had ATAAD repair at the University of Michigan came back for additional operations if they needed one. We suspect those who were lost to follow-up are more likely not to have had a reoperation or died without notice. However, we cannot exclude the possibility that some reoperations could have been performed at other places and patients were lost to follow-up. The number of patients with follow-up at 15 years postoperative was relatively small, but there is a reasonably good sample size at 10-year follow-up. Primarily only aortic surgeons operate on ATAAD, and we manage malperfusion syndrome endovascularly before the open aortic repair. Therefore, our experience may not apply to all centers operating on patients with ATAAD.

CONCLUSIONS

Both hemiarch and aggressive arch replacements are appropriate operations for select patients with ATAAD with good short- and long-term outcomes. Patients with

ATAAD should have aggressive arch replacement to resect the aortic arch aneurysm or intimal tear in the arch that cannot be resected by hemiarch replacement, or replace the arch branch vessels to resolve malperfusion of dissected aortic arch branch vessels.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: aortic dissection, aortic arch surgery, total arch replacement, long-term outcome, acute type A aortic dissection

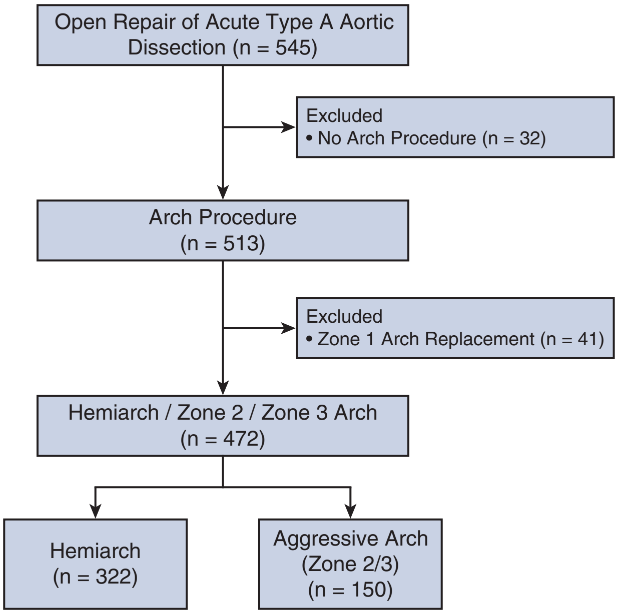

FIGURE E1. Study selection among the total of 545 patients undergoing central aortic repair for an acute type A aortic dissection at the University of Michigan from July 1996 to January 2017.

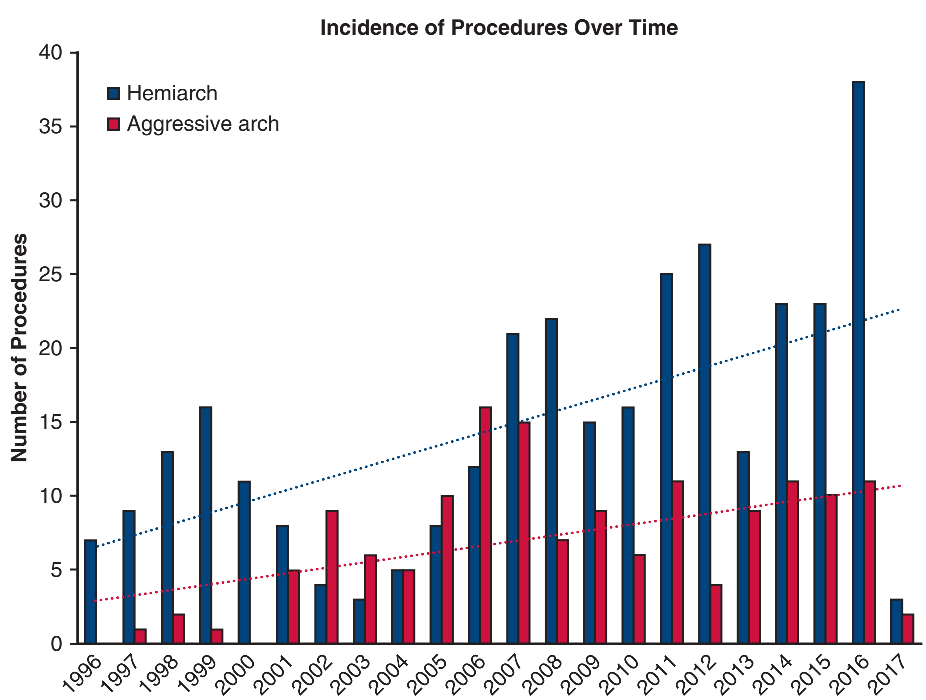

FIGURE E2. Annual number of the hemiarch and aggressive arch replacements in acute type A aortic dissection over time. 1996 only includes July to December. 2017 only includes January.

TABLE E1. Open TAA/A and TEVAR first redo surgery outcomes

Variables	TEVAR (n = 6)	Open TAA/A (n = 36)	*P* value
Patient age, y	66 (62, 78)	59 (52, 64)	.015
Sex (female) (%)	3 (50)	7 (19.4)	.134
Myocardial infarction	0 (0)	0 (0)	
Cerebrovascular accident	0 (0)	3 (8.3)	1.0
Atrial fibrillation	0 (0)	5 (13.9)	1.0
Pneumonia	0 (0)	1 (2.8)	1.0
New-onset renal failure	0 (0)	0 (0)	
Reoperation for bleeding	0 (0)	0 (0)	
Deep sternal wound infection	0 (0)	0 (0)	
Sepsis	0 (0)	0 (0)	
Paraplegia	0 (0)	1 (2.8)	1.0
GI complications	0 (0)	2 (5.6)	1.0
Need for tracheostomy	0 (0)	0 (0)	
Prolonged vent	0 (0)	0 (0)	
Reintubation	0 (0)	0 (0)	
Intraoperative mortality	0 (0)	0 (0)	
In-hospital mortality	0 (0)	1 (2.8)	1.0
30-d mortality	0 (0)	0 (0)	

Data presented as median (25%, 75%) for continuous data and n (%) for categorical data. *TEVAR*, Thoracic endovascular aortic repair; *TAA/A*, thoracic aortic aneurysm (TAA) or thoracoabdominal aortic aneurysm (TAAA); *GI*, gastrointestinal.